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This Issue in Brief

Some Ideas Regarding Economics of Telecommunications Engineering—The telecommunications industry and other utilities like gas, electricity, and railroads are characterized by inexorable growth in plant investments that are retrieved only by the slow process of writing them off as depreciation. The development of such systems should be based on a critical ratio of the excess of revenue over expense divided by the investment.

To minimize investment, long plant life and flexibility to meet even totally unanticipated requirements are indispensible. Revenue comes from providing service that will benefit the subscriber, and plant investment must be predicated on this. Expenses for operation and maintenance are of primary concern in maintaining a satisfactory critical ratio. Many examples are given of these factors that determine the critical ratio.

In telecommunications, well-maintained plant is not depreciated because it has worn out. Obsolescence through advances in technology is effective only when the replacement plant will greatly reduce costs. The major reasons for depreciation of plant are that new functions must be performed and new requirements met that are beyond the capacity of the older plant.

Crosspoint Elements and Relays with Miniaturized Reed Contacts—By reducing the length of a reed contact from 80 to 50 millimeters (3 to 2 inches) while retaining its ability to make and break current, its use both in the speech path as a crosspoint connector and in the control circuits significantly reduces the space required for telephone switching installations.

Several basic methods of operation of reed contacts as crosspoint elements are presented in a single table for easy comparison. A crosspoint system has been selected in which 2 or 4 reed contacts are mounted within a single actuating coil for the 2- or 4-wire speech path, and a single additional contact is included for a local latching circuit to hold the connection. Simple interruption of the holding circuit restores the contacts to the normal open condition. Operate current is limited only by thermal considerations. By operating at 24 volts, wire sizes presently used for electromagnetic relays may be used with reliable performance for many millions of operations. A basic assembly of 5 crosspoints permits great flexibility in constructing matrixes.

Semielectronic Reed Crosspoint Telephone Switching System *10-CX*—The *10-CX* is a semielectronic telephone switching system comprising a multilink switching network with miniature *H 50* reed contact assemblies as crosspoints and centralized fully electronic control circuits of the programed data processor type.

Through electronic scanners, all data relating to lines, junctors, trunks, signaling units, and the switching network are collected by the peripheral circuits and transferred to the central processor for further treatment. Coded instructions are communicated via a common bus to the peripheral circuits, which in their turn carry out the marking and driving actions in the network and its associated circuits.

The network is arranged in modules of 1024 lines. Path selection is performed according to a link alignment procedure, while the marking and the electrical holding is of the series type via the third wire.

Crosspoints, inlets, and outlets are identified by binary codes to simplify transfer of information between the network and the control part of the exchange.

By concentrating all logic functions of the exchange in the central processor and using binary presentation of the network parameters, the peripheral circuits are kept very simple. They are conceived as modular units serving 2 network modules of 1024 lines each.

All functions relating to call treatment as well as to maintenance and observation are concentrated in the central processor, which operates under control of stored programs. The processor consists of a single ferrite-core memory and electronic logic circuits such as arithmetic unit and control unit. Use of high-speed components minimizes the number of control circuits, which in turn improves reliability and reduces space requirements. Reliability and maintenance facilities are greatly improved by the full duplication of all centralized units, by the use of redundant codes, and by the introduction of automatic means for fault localization and supervision.

History of Inertial Navigators and Some Thoughts on Research Management—Although the law of inertia was recorded by Galileo over three centuries ago and formalized by Newton only a few decades later, its practical application to navigation occurred in the present century.

A 1931 memorandum described the use of three masses, each with a single degree of freedom perpendicular to the others and all held fixed in space, to measure the acceleration of a vehicle carrying them. Included were various means of obtaining double integration of acceleration to provide three vectors the sum of which gives the path traversed by the vehicle.

It was thought that the field was too far from the interests of the corporation and that depressed business conditions made even the expenditure of patent fees unwise. Thus, Henri Busignies, now General Technical Director of the International System, left this field which later became of great engineering and economic importance.

The principles of the inertial navigator, Schuler tuning to compensate for gravitation effects, and the patent issued to Boykow in 1934 are discussed.

Pentaconta 32 Telephone Switching System for Rural Networks—This crossbar switching system permits expansion of a rural exchange in 32-line units. For 128 lines a single stage of switching is adequate. Two-stage switching provides for a unit block of 768 lines, and four such blocks with interblock junctors will accommodate about 3000 lines.

Plug-in units, a modular system for plug-in frames to utilize bay space fully, and factory-made cables for interconnection between terminal strips on top of each bay facilitate manufacture, test, transportation, installation, and maintenance, as well as providing the much-desired flexibility of capacity.

Mobile Radio Equipment *SEM 25*—The *SEM 25* transmitter-receiver is for general use in vehicles. The transmitter power is 15 watts with automatic tuning. The frequency range of 26 to 70 megahertz is divided into 880 discrete crystal-controlled frequencies with 50-kilohertz spacing. Frequency modulation is used.

The control unit is either mounted to the front panel of the transmitter-receiver or can be up to 8 meters (26 feet) away from it. It provides for frequency selection and all necessary switching functions.

The selected frequency is indicated directly on a mechanical scale and is set in 1-megahertz and 50-kilohertz steps. A 10-position switch can select that many preset frequencies out of the 880 available.

The 2.5-meter (8.2-foot) rod antenna is adjusted automatically by an antenna tuning unit mounted at its base.

Man-Made Quartz Crystal—Although synthetic quartz crystals have been produced for about a century, the early work of mineralogists was of only scientific curiosity. The demands of the second world war for quartz electric resonators stimulated interest in production quantities of synthetic quartz.

Commercial production of synthetic quartz is done in a cylindrical autoclave at pressures of about 2000 kilograms per square centimeter (30 000 pounds per square inch). Small chips of natural quartz, which may be entirely unsuitable for resonator use because of twinning or other defects, are placed in a perforated steel container in the lower half of the autoclave. Thin rectangular seed-plates cut to desired orientation from twin-free quartz crystals are mounted on steel frames in the upper half of the autoclave.

Demineralized water and sodium hydroxide pellets are added, and the sealed autoclave is heated electrically to about 350 degrees Celsius at the top and 390 degrees Celsius at the bottom. This temperature difference produces a denser solution above which promotes interchange of solutions through holes in a baffle plate that separates the two zones.

The warmer solution below dissolves the quartz bits and when cooled on passing to the upper zone deposits quartz on the seeds. After 11 to 28 days the newly grown crystals are removed. They are of convenient shape for resonator manufacture and weigh between 0.55 and 1.33 kilograms (1.2 and 2.9 pounds) each.

The Q factor of synthetic quartz is lower than for natural quartz and decreases as the rate of growth is increased. However, fast-grown crystals are suitable for resonators in channel filters, and quartz can be grown for most resonator applications.

Transmission-Loss Measurements Made on Two Knife-Edge Diffraction Paths Over the Andes—Telephone service between Argentina and Chile is presently provided by cable circuits passing over the Andes. A study of other methods of communicating across this mountain barrier concluded that it would be possible to establish a direct wide-band radio circuit between communication centers each side of the Andes.

Results are given of transmission-loss measurements made on two knife-edge diffraction paths crossing the Andes. The loss on both paths was found to be considerably less than would be estimated for a normal beyond-the-horizon path of the same angular distance, but greater than would be the case for an ideal knife-edge.

It was found that for a large percentage of the time the loss and fading on both paths were characteristic of a knife-edge diffraction path, but that for the remainder of the time the fading recorded was typical of a beyond-the-horizon or scatter path.

Number Analyzer, an All-Electronic Route Translator—An all-electronic universal route translator has been developed for the nodal exchanges of the National Telephone Network of The Netherlands, with the aim of improving the adaptability of these exchanges to modifications within the telephone network and of reducing the updating effort involved.

The translator has been designed around a newly developed semipermanent capacitor store which contains all relevant network data. The equipment is fully electronic and its high operating speed makes it capable of handling the traffic of any size of exchange.

The article specifies the route data to be delivered, describes how they are arranged within the capacitor store, and how they are accessed. Modifications of the stored data are made by changing code strips.

When used in an electromechanical switching system, special interface circuits are provided for speed adaptation. These circuits, called buffers, can handle a rather limited amount of traffic and hence their number depends on the calling rate of the exchange.

To ensure service continuity in case of a failure, duplication has been used for the centralized parts. The buffers operate on a load-sharing basis, two buffers being provided per group of telephone registers.

The number analyzer has been incorporated in the *7E-N* rotary system as a route translator for nodal exchanges and as a class-of-line store for local offices.

Portable 7-Gigahertz Radio System for Multichannel Telephony—The *BFM24-7000* radio equipment provides 24 telephone channels in the 7-gigahertz band and is suitable for 6 hops, each of about 150-decibel loss, over a total path of 180 miles (300 kilometers). The receiver-transmitter requires only 30 watts and a supplementary order wire consumes 5 watts. Multiplied phase modulation is used and the signal is demodulated to baseband at each repeater.

In the transmitter, solid-state amplifiers produce a carrier of 2 watts at about 225 megahertz and passive varactor multipliers provide at least 50 milliwatts at 7 gigahertz. Similar multiplication but at lower power gives 5 milliwatts for the local oscillator of the receiver.

Alarms are provided for low signal levels in both the transmitter and receiver. Both bay mounting and portable versions are available.

Railway Cable with High Screening Properties—On the highest section of the Oslo-Bergen railway, booster transformers could not be installed because of a bypass feeding line. On this and on adjoining sections, the terrain was such that to install the railway cables at a sufficient distance from the track to reduce the interference to an acceptable level would have been very costly. The development of a cable with sufficiently good screening properties to permit it to be laid in the ballast of the railway track therefore meant considerable savings in the installation cost.

An aluminum-sheathed cable armored with one soft steel tape and one ARMCO *M-6W* tape was found to have a better screening factor than required to meet the limit of 0.3 at an induced voltage of 2 volts per kilometer at $16\frac{2}{3}$ hertz. Installation of different sizes of this type of cable in the ballast gave an induced voltage of approximately 0.35 volt per 100 ampere-kilometers on the section with booster transformers, and of approximately 0.5 volt per 100 ampere-kilometers on the section without booster transformers. This was satisfactory for the cables belonging to the railway, but long-distance cables operated by the Norwegian Telecommunication Administration must still be placed at least 12 meters from the center of the track. In this location and with booster transformers installed, the induced voltage varies between 0.1 and 0.2 volt per 100 ampere-kilometers, depending on the type of cable used.

Magnetic Thin-Film Memory Having Low Access Currents—The access time for magnetic thin-film memories is limited by the associated circuits. Monolithic integrated circuits offer improved speed and cost but require reduction in the power used to control the magnetic film.

A continuous Permalloy film 380 angstrom units thick is evaporated on a copper substrate serving as a common ground return with both an underlayer and a protective outer coating of silicon oxide. Access is by two printed-circuit networks of narrow conductors running at right angles to each other and placed very close to the magnetic film to provide tight coupling. Each memory cell in the continuous film is bounded by the crossing surfaces of its two controlling conductors.

A memory of this type with a capacity of 1024 words of 36 digits each has an access time for readout of 85 nanoseconds and a read-write cycle of twice this time. Operating power is well within the limits of standard microelectronic units. The use of two crosspoints per bit eliminates stray signals of readout via capacitance coupling with the word conductor. By dividing the memory into two subassemblies driven in parallel, the stray signals from the information current are attenuated.

Some Ideas Regarding Economics of Telecommunications Engineering

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Editorial Note: Presented here are some principles underlying the economics of the design, construction, and operation of public telecommunications networks based largely on experience in a privately owned operating company. It is recognized that government-owned systems may face quite different economic conditions so that the application of these principles may be different in such cases. Nevertheless, both types of systems have many of the same types of problems. Mr. Huntley, who has had extensive experience with telecommunications operating and manufacturing organizations, presents in the following paper a summary of his knowledge of the subject.

1. Introduction

The importance of applying economic principles to the engineering of telecommunications plant is self-evident. Not only has telecommunications become an essential in business, political, and social life, but the service itself from the standpoints of employment, investment, revenue, profit, et cetera, is an important and growing component of the economy. It can play its proper role only if it is, and remains, economically healthy. Being one of the—if not *the*—most-complex and highly technical industries, it is unusually dependent on engineering.

Neither nonengineering management nor science alone, nor both together, can do the job; the engineer is the only one who can mate science and the wants of people to produce the right offspring in the form of desirable service and economic health.

Day-to-day telecommunications engineering activities are composed of three inextricably interwoven things in more-or-less equal proportions.

(A) Service: how much, what types, and when.

(B) Money: investment, revenue, and expenses.

(C) Technology: how to use it to produce the desired results with respect to **(A)** and **(B)**.

These things form the theme and thesis of what follows.

2. General Considerations

The telecommunications industry (along with a few others like gas, electricity, and railroads) is characterized by very-large plant investments that grow rapidly and inexorably, turn over very slowly, and cannot be retrieved except by the slow process of "writing them off" via the depreciation route. That is, the plant in which the money is invested is unique to the industry and hence (with the exception of certain things such as land and some buildings) has very-low resale or salvage or residual value; usually not much more than the junk value of the raw materials.

Quantitative information is available for many countries and typically shows that gross annual revenue is much less than gross book investment in plant—in some cases only a third of the gross book investment, or even less. This is the reverse of the situation in many industries in which gross revenue often exceeds gross book investment, sometimes by 3 or more to 1.

The annual investments in new plant are also very large; often they are as much as a quarter to a third or more of gross revenue and, in some countries, they are large enough to represent an important factor in the overall economy of the country. As one example, in the United States in 1966, the telecommunications industry invested about $4.8 thousand million which was around 8 percent of the total invested in plant and equipment by all United States industry.

On the other hand, the amount written off annually is usually relatively small; often not over a few percent of the gross book value.

This kind of an investment pattern results in a physical plant with a very wide age distribution. A little of it is brand new, but much more of it is anywhere from 5 to 25 years old and some of it is so old that it is of types which have not even been produced for 35 years or more.

What this says is that plant once bought stays around a long, long time and that, as a result, the economic health of the enterprise is critically dependent on the wisdom with which money is invested in plant and the effectiveness with which the plant is used. Since it is the engineer who designs the plant with the objective of producing certain results by being used in some particular manners, it is he who is primarily responsible for the economic health of the enterprise—whether he is conscious of the fact or not.

Specifically, he must plan every job he does so that, not only for that job but considering its effect on the enterprise as a whole, the following critical ratio will forever* be a maximum.

$$\text{Critical Ratio} = \frac{\text{Revenue} - \text{Expense}}{\text{Investment}}.$$

While this ratio is of the same form as that which is frequently called "profit ratio," it is used here as an indication of how the quality of the engineering affects the ease (or lack thereof) with which the enterprise as a whole can obtain a desirable profit level, rather than as an indication of what profit level is desirable. Maximizing it in connection with specific engineering jobs does not, therefore, connote that the enterprise will want to maximize its overall profits regardless of other considerations; it merely gives the enterprise maximum freedom of action in selecting charges to customers to obtain a desired profit level, or, in situations where amounts which can be charged are limited by government or other restrictions, to be as profitable as possible.

In considering how to keep this critical ratio maximized, the engineer must take these facts into account.

*The word "forever" is used here and in the following in a not-quite-literal sense; it should be translated to mean "as long as electrical means are used for interchange of information" or "far beyond what anyone now in this profession can foresee or even care about."

(A) Telecommunications technology is advancing and changing rapidly, but it is impossible to predict precisely what it will look like in the future.

(B) The public always wants better quality, more convenience, and more attractive service; their wants grow and change as the enterprise grows in ability to satisfy them and it is impossible to predict precisely what form they will take and how they will change as time goes on.

(C) The magnitudes of the existing plant and of the investment in it are so great that it is impossible to make radical changes overnight. No technological miracle and no scientific breakthrough can solve problems in one fell swoop; they must be solved by evolution.

The engineer must so plan that the plant he buys will—in addition to doing today's job—have maximum capability to incorporate and use effectively whatever advances occur in technology and be able to cope with whatever service requirements may arise. This requires superlative engineering, but it turns out to be not too difficult as will be evident from the following discussions.

3. Practical Application of the Critical Ratio

In considering how to maximize the critical ratio, the engineer must avoid falling into either of the following two traps.

(A) Assume that increasing the numerator by raising the charges for basic service is a satisfactory alternative to increasing the ratio by superlative engineering.

It is true that increases in charges for basic services sometimes become necessary despite the best the engineer can do. The temporary relief that this affords should not cause him to relax; rather, it should cause him to search his soul whether the increase might have been avoided if he had done a better job.

(B) Assume that, because one part of the operation may be so profitable as to provide a reasonably large magnitude of the ratio for the entire operation, he need not worry too much about the parts that are less profitable—or actually produce losses.

In some types of industries, it is possible (or at least it is thought so to be) to let the less-profitable phases of the operations wither on the vine or even be abandoned. The reverse is true in telecommunications; the parts of the operations where increasing the critical ratio is hardest are the largest and must be given the most attention.

As an example, the long-distance business is, in most organizations, by far the most profitable and there is great temptation increasingly to rely on it; a process that in the United States at least has come to be known as "riding the gravy train." The problem is that this part of the business can exist and grow only as telephones exist and grow. As lots of telephones mean lots of local calls, unless these other parts of the business are profitable in their own right, sooner or later there will not be enough "gravy" to go around.

It is no exaggeration to say that the economic importances of phases of telecommunication operations are inversely proportional to the *n*th power of their glamor.

With this background, we can now appraise how practically the engineer can go about maximizing the critical ratio in connection with the jobs for which he is responsible.

3.1 Minimizing Investment

Obviously, in the usual situation where there is more than one way to do a job, the most-straightforward way to increase the magnitude of the ratio is to select the way that results in the lowest investment. This has three effects:

(A) It increases the magnitude directly by reducing the denominator.

(B) It reduces that part of the numerator relating to the cost of financing the investment.

(C) It may or may not affect the other costs (for example, maintenance and depreciation) or the revenue, depending on the nature of the job, the types of plant involved, et cetera.

In addition, minimizing the investment in each job increases the number of jobs that can be done within the limits of an overall construction budget, and this has a beneficial effect on the amount and quality of service that can be given and the revenue from it. It is surprising in how many cases this simple approach turns out to be the best one, provided: It is done with an eye to the future, maintenance and other costs are controlled, and its direct or indirect effect on revenue is taken into account.

Keeping an eye on the future means simply that one must consider not only the effect of the investment he is making this year, but how the pattern it sets will affect the ratio forever.

Three different investment patterns may be recognized; one ideal, and two less-desirable alternatives. The ideal pattern is to minimize the investment both initially and in the future and simultaneously to keep expenses under control. This should always be the primary objective of the engineer. In many cases, it can be done if the engineer strives hard enough, uses sufficient imagination, and forces technology to develop and manufacturers to produce the types of equipment and plant he needs.

It is particularly important to note that science and technology do not necessarily produce the most-useful kinds of hardware automatically; the engineer must see to it that the facts and promises of science are turned into things he needs to do the best possible job.

Sometimes despite his efforts, the engineer cannot reach this objective and he is forced, at least temporarily, to adopt one or the other less-desirable alternative.

The first of these alternatives is to minimize the initial investment (by, for example, limiting the amount of plant put in or selecting a type of plant purely because it is cheaper than some other type) even though it is quite certain that this will increase future investment needs or cause service or other problems. This alternative is tempting because it makes the available construction money go farther and because it accords with the mathematics of money, which says that postponement of expenditures is, per se, advantageous. However, as proved by experience, when the time comes that investment must be increased or service problems arise, the people who have to pay or solve the problems are likely to think that the original planning was too short-sighted.

It is a method that obviously should be used with discretion.

The second alternative is to do the reverse; increase the initial investment to minimize the chances of future higher-than-normal investments and service problems. This is not particularly tempting because it uses up more than its share of available construction money and flies in the face of the indications of the mathematics of money. But if done with discretion and not on the fallacy that just because one way costs more than another it is per se better, it may be good business.

It is, of course, possible to get a mathematical balance between the two undesirable alternatives by some sort of cost study and in some cases this may be desirable provided:

(A) The result is not looked on as providing an answer but merely as a set of figures that along with other information and ideas may be useful in arriving at the best answer based on judgment.

(B) It does not detract from efforts to come as close as possible to the ideal of minimizing the investment initially and forever.

3.2 Maximizing the Numerator

While the engineer must devote much of his attention to the types, magnitude, and timing of investment, his responsibility must include consideration of how to increase the revenue and keep expenses under control.

For most types of jobs, the engineer's responsibility in connection with revenue is indirect (rather than direct) but is nonetheless of importance. Primarily he must select types and locations of plant in such a way that the overall network can grow logically and smoothly not only in size but in ability to provide whatever kinds of service customers may want. To put it another way, revenue comes from providing service, and the engineer must be sure that he does not build anything into his design that would block growth in size, quality, or scope of service.

When it comes to expenses, his responsibility is frequently much more direct and goes beyond the effects of his investments on the total cost of money. In particular, he must play an important part in determining how, where, and how much operating and maintenance work should be done and how to minimize its cost. Obviously, these costs are a function of the overall design of the network and of the types of facilities used. Beyond these things, the engineer must take an active part in establishing the right methods, providing the right tools, et cetera, to get the best results with the least cost.

For example, in connection with maintenance, the engineer knows the plant best; he must assist and guide the people who actually do the work and provide them with the right test equipment, so that the effort expended produces maximum results and neither too much nor too little effort is expended. Maintenance is too big a subject to discuss exhaustively here, but it is a very-important factor in controlling expenses and an important function of engineering.

In short, while the engineer is primarily concerned with investment, he must consider the interplay of all three components of the critical ratio and how his actions affect it now and forever. In the following sections a number of examples are discussed that illustrate this interplay. For convenience, and not because they represent how jobs are classified in any particular organization, the examples are divided into these categories: growth, modernization, standing still, and new instrumentalities and services.

4. Growth Jobs

The problem of caring for growth is one of the pleasantest parts of the engineering job from the economic standpoint, because it supports and is tied directly to growth in revenue. In a relatively small but rapidly growing telecommunications operation, it is the most important of the four categories. Perhaps these are the reasons why, in many discussions of engineering economics, it is given the greatest—if not the sole—attention. Unless it is done with both the future and the present in mind, it can adversely affect the critical ratio sooner or later (or both), not only in connection with growth itself but also in connection with modernization and standing-still costs. In fact, proper engineering of growth jobs is the most-effective way to control modernization and standing-still costs. Three examples of growth jobs will be discussed: trunks and junctions, subscriber loops, and switching.

4.1 Trunks and Junctions

Trunks and junctions present an area that comes closest to being the engineer's paradise, because technology has handed him tools on a silver platter and all he must do is be smart enough to use them properly and to force further progress along the same lines. The principal tool is, of course, carrier in several forms, and the secondary tool is new forms of base plant, such as coaxial cable and radio.

These tools have many advantages. They usually permit lower investment initially, while history shows clearly that caring for future growth becomes less and less expensive as time passes. Also, these tools can provide much better transmission than audio circuits and are much better adapted to meet whatever new types of service may be wanted in the future; thus they minimize the future costs for modernization to meet new service requirements.

The potency of these tools is best known in what may be called the long-haul field—that is, trunks over, say, 25 or 50 miles (40 or 80 kilometers) long—where the economic and service advantages are overwhelming. It is almost literally true that it is difficult to keep the critical ratio from growing in this field; witness, for example, the "profits" from the long-distance business registered by almost all organizations.

As indicated earlier, this is the "gravy" area; the economic problems lie in two other areas.

(A) To extend the benefits of carrier to shorter and shorter distances.

(B) To exploit the huge amount of, and investment in, copper that exists in the trunk and junction plants and that by and large produces only one channel or half a channel per pair. Much of this copper is of types and is in locations suitable to serve as base plant for carrier. Since it has already been bought and paid for, it is by all odds the cheapest form of base plant; it is merely good sense to make as much use of it as is practicable before buying more base plant of any type.

There is no reason why these problems cannot be solved by applying the same principles that have been so successful in the longer-haul field. It merely requires the engineer to force technology to develop, and manufacturers to produce, the right gear and then use it properly. This is not an easy job, but with persistence it can be done; it is being done reasonably successfully at least in the United States and Canada. Their experience shows very clearly that thus minimizing the investment does not necessarily increase total expenses. Thus the numerator of the critical ratio may be about the same; at worst it will not be reduced enough to offset the beneficial effect of the lower investment. In short, carrier and good engineering can increasingly move the trunk and junction situation closer to the ideal of maximizing the critical ratio now and forever.

4.2 Subscriber Loops

Subscriber loops constitute one large and important area in which reducing the investment also reduces the expenses (by reducing the cost of money and depreciation expense without significant increase in any other component) and hence theoretically should be ideal for minimizing investment now and forever.

In fact, however, in many organizations it is difficult to control loop costs; they are already high and they show a distressing tendency to go higher. They form a major component of the annual construction expenditures; in some organizations they are the largest single component. The reason for this is that loop plant has a very-high raw-material-and-labor content; contrary to the situation in the trunk and junction, technology has not handed out tools on a silver platter; the engineer must dig out savings by hard and imaginative work. Some of the tools available and some of the engineering problems in applying them are discussed in the following.

A rather-evident and very-effective method of limiting investment is to minimize wire sizes, particularly for the longer loops. Average loop costs are usually made up of a large number of loops that cost less than the average and a smaller number that cost more—some a great deal more—than the average. The main reason for the above-average costs is that for loops longer than some arbitrary limit, wire sizes must be increased. Thus the longer the length, the bigger the wires, so that costs rise much faster than length. Obviously, if fine wires can be used to longer lengths, it will help greatly to bring the problem under control. To do this, two problems must be solved.

The first and easier one to solve, at least for moderate extensions of fine wire, is transmission; it involves two things:

(A) Reduction of trunk and junction losses to as near zero as practicable from the echo, crosstalk, and noise standpoints. This presents very little of an economic problem if carrier is used extensively in the trunk and junction plant. If carrier is not so used, the problem is tougher, but it is one that will have to be faced at some time anyway, as discussed in Section 5.

(B) Use of modern efficient telephones on the longer loops. The only problem here is to ensure that these new types of telephones do, in fact, get put on these loops. This takes a bit of doing, but it is not out of the question.

The second problem is signaling. This may be easy or difficult depending on the types of switching equipment. Even if some equipment must be added, the costs are likely to be much less than for large wires in long loops. For more-radical extensions, such as doubling the loop limits, more-radical measures (for example amplification and special signaling devices) may become necessary. Even the costs of these methods are likely to be small compared with the savings brought about by the ability to use fine wires.

In addition to reducing the cost of the cables themselves, using the finest wires practicable reduces the cost of supporting and containing structures as well as transportation and handling. For example, in densely developed areas, it is very expensive to reinforce duct lines; putting the maximum number of pairs in a duct by the use of the finest practicable wires will, in may cases, postpone the need for reinforcement for a long time, if not indefinitely. Even where cables are plowed or trenched, the smaller size and weight of fine-wire cables reduces the cost of the operation. The same thing is true where cables are supported on poles.

A second broad method that may be used in conjunction with, or separate from, extension of fine wires is switching in at least two forms. The first is use of concentrators; this does not reduce wire sizes but it does reduce the number of long circuits needed. The second is use of more full-fledged central offices so spaced and located that long loops are avoided or at least greatly reduced in number. To make this method of limiting investment economical requires striking the right balance between switching and cable costs so that the *total* is a minimum. This, in turn, depends on how effectively switching costs can be controlled vis-a-vis loop cable costs.

A third general method consists of using the loop plant more effectively and cutting down the costs of the numerous changes and rearrangements that accompany growth and movement. Many things are involved; for example, use of flexible cross-connection features, or, in some cases, the "dedicated-outside-plant" principle where applicable, labor-saving devices and methods for handling jointing and other types of connections and disconnections, proper organization, proper transportation and tools, et cetera. No one of these is likely to produce huge savings, but in total they are very significant.

Some day, of course, carrier will come to play an important role in loop design. It seems logical to assume that it will come as the evolutionary extension of the application of carrier to shorter and shorter lengths and hence that it will follow, rather than lead, the effective exploitation of copper in the junction plant. Thus its early use will continue to be in unusually long loops (such as rural lines) or in loops where adding wires would be unusually expensive because of conduit congestion or other reasons and only gradually will its use become more general. This puts extensive use far enough off in time so that it should not militate against using the tools now available with maximum effectiveness.

4.3 Costs of Switching Equipment

Switching equipment constitutes an area where wise use of the previously stated alternative of investing a little more initially to save a lot more later is likely to be good business. Buying a type of equipment just because it is slightly cheaper or because of tradition may result in severe economic problems later if changes become necessary to meet service requirements.

This does not imply that the engineer should not strive to keep the initial investment as low as practicable and still get the service features and flexibility he wants; he must use great ingenuity, imagination, and persistence to accomplish this result. There are so many factors involved that it would be witless to try to discuss them in detail. However, it can be said that they involve such things as coordinating and streamlining all phases of engineering, avoiding unnecessary variations in sizes and features provided in different installations, limiting frills that add nothing to serviceability, properly organizing installation work (including unnecessary duplication of testing), et cetera.

In selecting the type of equipment, the engineer must start his thinking from what he wants it to do and its availability, rather than from some particular type of hardware. Some of the things the engineer wants are great flexibility in routing of calls, ability to handle a wide variety of classes and types of service (including a wide range of bandwidths), and ability to set up connections as fast as instructions to the switches can be generated and transmitted. It makes little difference whether the hardware is electromechanical or full- or semi- or quasi-electronic, or what particular types of switches are used (provided they are fast), so long as there are no inherent limitations that would prevent giving the kinds and quality of service that will be called for in the future.

5. Modernization

By modernization is meant throwing existing plant away and building new plant to replace it or adding features to, and investment in, existing plant to cope with current or foreseeable service requirements or to control operating costs.

From the purely economic standpoint, it is a distasteful and difficult problem because it involves making investments without causing any corresponding increase in revenue. While it may open the door to increased revenue in the future by permitting better quality or broadened scope of service, its immediate reason is more of a defensive measure against degradation of service, stifling of growth because of inability to give service that customers want, or against rising operating expenses. Thus, in the competition for the (usually) limited amount of construction money available at any time, it is at a disadvantage compared with growth jobs.

The magnitude of the modernization job and its timing are largely functions of how forward-looking the engineering has been in the past in connection with growth. If the types and locations of plant that have been provided for growth are sufficiently flexible to cope with problems arising from increasing size and complexity of the overall network and from changing ideas of customers regarding service, the modernization problem is reduced; if this is not so, the reverse is true.

It does not help very much if the plant to be thrown away is old. The situation is that, before the old plant was thrown away, a certain total amount of plant existed; after it is thrown away, the amount of plant is less and new plant must be put in merely to restore the status quo. This is true regardless of the age of the plant, so long as it is still capable of performing the functions for which it was bought originally and regardless of how its age compares with the life span for which depreciation rates have been set up. These facts are given quantitative monetary meaning through depreciation accounting—a subject that, along with some of its effects on engineering and vice versa, is discussed briefly in Section 9.

Thus, there is no merit in postponing modernization while continuing to put in plant having limited service capability; postponement adds to the weight of the plant and investment that will have to be thrown away and hence simply compounds the problem. Rather, the types of new plant put in either for growth or for modernization should always make the maximum practicable use of the best technology available to minimize future modernization problems. A few examples of modernization problems in the switching and transmission areas are discussed in the following.

5.1 Switching

One of the major phases of the modernization of switching—replacement of manual operation by dial operation for local and long-distance service—is almost complete in many countries. While it has involved large investments, the large reduction in traffic operating expenses has resulted in significant increases in the critical ratio, particularly if maintenance costs have also been adequately controlled. However, unless the types of equipment used in this process have adequate flexibility and other features necessary to cope with growth in size and complexity of networks and with service wants of customers, a whole new generation of modernization problems will arise; in fact, it has arisen in some places.

Not infrequently, these problems arise almost as a confrontation. Some networks have already grown to the point where it is painfully evident that new concepts and new mechanisms are needed to cope with further growth in size and complexity or just to keep them from "falling apart." Some networks cannot provide high enough switching speed to be compatible with new methods of generating signals available to users (such as push-button pulsing or fast repertory dialers) or to cope with numerous very-short data messages, et cetera. Similarly, some types of switching mechanisms have difficulty in providing desired service features, for example, direct in and out dialing with billing to individual telephones at private automatic branch exchanges, or handling bands wider or narrower than voice.

When such a confrontation arises or can be foreseen, the only course open is to take the bull by the horns and shape an orderly growth and modernization program to overcome it. Experience clearly shows that postponement—for example, waiting for some scientific breakthrough—is particularly dangerous economically in this area, because of the large investment involved and the rapidity with which it grows as well as the rapidity with which new service requirements develop.

5.2 Transmission Improvement

The need to improve transmission is already being faced in some countries—and will undoubtedly be faced in others in the not-too-distant future—for at least two reasons.

(A) Users, being people, always want something better and the only way to keep them happy is by constant improvement.

(B) Many of the newer forms of service—particularly data—are more susceptive to transmission irregularities than is ordinary speech.

While data transmission will probably not be large quantitatively for some time, it has the virtue that it pinpoints transmission problems that should be looked at and taken care of but that might otherwise be let slide. As an example, almost all forms of data transmission are more affected by noise than is speech between people; people will tolerate magnitudes and types of noise that would practically ruin data transmission. Similarly, many forms of data transmission are much-more sensitive to phase and amplitude distortion than is speech between people.

The primary answer to these problems is to keep the signal-to-noise ratio up by keeping the trunk and junction losses low, and to use types of circuits that have low distortion—primarily carrier. Repeatered 2-wire circuits may be necessary in some cases as an expedient until carrier can be applied, but they tend to increase distortion and hence do not provide the same results as carrier. Admittedly, 4-wire audio circuits are also pretty good, but they cost a lot of money.

Since, as discussed earlier, carrier is the most economical way to provide for growth in a large proportion of the circuits, its extensive use for modernization should pose no difficult economic problems.

A problem, in some countries at least, is that there is already so much audio cable in the trunk and junction plant that it could not be used up as base plant for carrier for many years. This means that it will be difficult in such countries to get rid of even fairly long audio circuits for a long time. Still more important, it means that the longer the delay in getting started on extensive use of carrier, the larger will be the amount of, and investment in, audio cable and hence the tougher the modernization problem.

6. Standing Still

By "standing-still" costs is meant money that must be invested merely to maintain the existing amount and type of service; it is truly what economists might call "frictional loss." Since it does not even open the door to increased revenue or reduction in operating costs, it is an even-more-distasteful economic problem than modernization.

One example of standing still is the cost of having to abandon existing plant and put new plant in because of such things as new roads or other public or private works. The causes of this cost are at least evident to the naked eye and are therefore not likely to be overlooked.

More important in a large operation is the cost in the subscriber equipment field associated with the fact that people, businesses, and industries move about so much and change their minds so often about where they want telephones and other gear to be put. For example, in the United States, each telephone gained is the result of connecting 6 and disconnecting 5; the standing-still part thus constitutes 10/11 of the total station movement. The cost of this standing-still part is typically around 20 percent of the total annual construction program—around $938 million for subscriber equipment out of a total standing-still cost of about $1.25 thousand million (26 percent of total construction budget) in 1966. While other countries may be in a more-favorable position in this regard, there is considerable evidence that, in some of them at least, standing-still costs are not negligible and are growing.

This cost is all the more disturbing because it is insidious; there are no confrontations as in the modernization case; it starts small and just keeps growing faster than the business until it is discovered because someone looks for it or it gets so big that it cannot be ignored. The more customers the organization has, the more freely service becomes available, and the more varieties of service that are offered, the greater will be the total of physical movement by, and changes of mind on the part of, the customers. At the same time, since much of the cost of connecting a telephone (and practically all of the cost of disconnecting it) is labor, costs tend to rise as the product of increases in movement and of increases in labor rates.

Thus the trend is clear; the bigger the business and the more adequate and versatile the service, the greater and more important the frictional losses will become unless something is done about them.

The second disturbing feature is that this cost is not greatly reduced if telephone gain drops to zero or even becomes negative. Since it is more nearly proportional to the sum of "ins" and "outs" than to the difference, it is not inconceivable that it might stay the same, or actually go up, if hard times came and people discontinued service in droves. That is, the outs would exceed the ins but the total station movement might actually go up.

A third problem is that even after they have been recognized, standing-still costs are hard to control. The figure quoted above for the United States is after a number of years of intensive efforts to control these costs. At least it can be said that the control measures have reduced the rate of rise and that otherwise the figures would be much bigger.

Control of standing-still costs involves many things. Organization and proper methods will do some of it. An even larger part consists of using a host of factory-produced gadgets and devices with which to reduce field labor, for example, cables and other things for prewiring, plugs and jacks, modular construction of key and other equipment, use of single switching installations for several customers requiring private automatic branch exchanges, eliminating screw terminals and "skinning" of wires, et cetera.

The main point is that if the engineer wants to keep the critical ratio at a maximum, he must not neglect this unglamorous job. More specifically, he should examine the situation carefully to be sure that standing-still costs are exposed to the light of day. Even if they are now relatively small, he should be sure that controlling them becomes an important consideration so that, to the extent practicable, they don't become big. Saving even relatively small amounts of money is no disadvantage, particularly if it results in the development of methods and equipment that can lead to much-greater savings later.

7. New Services and Instrumentalities

It is with some relief that we can now turn to a more-pleasant subject; increasing the critical ratio by increasing the revenue by introducing new and improved types of service and instrumentalities—primarily those that the customer uses and is aware of directly. The numbers and types of these are legion and include such things as more-attractive and -convenient telephones, push-button pulsing, improved intercommunication methods, faster and better private-automatic-branch-exchange methods and equipment, handling of data, and many others.

Usually, the economic problem facing the engineer is how much revenue must be taken in to make the venture profitable. He usually does not have to specify the actual charges, but he must have a clear idea of what their minima must be. In doing this he must pay attention, not only to the investment, but particularly to the expense factor. The component of expense most likely to be affected materially is depreciation. Other components (such as maintenance and interest) are also affected, but usually to a lesser extent.

The reason for this is simple; many types of new services, features, and instrumentalities involve junking older equipment and, if the operation is to be profitable, the revenue from the new things must be sufficient to pay for this through increased depreciation expense or otherwise. To take a very simple example, consider the introduction of a new type of telephone so attractive that many people will want it, even at a premium rate. Now, every telephone that is bought over and above the actual station gain (plus a few that are destroyed or stolen) means that another telephone must be junked or kept in dead stock. Hence the revenue for the new set must be sufficient to pay for this increased junking; the actual rates should probably be somewhere above this minimum, since not everything that is offered turns out to be a howling success, and the successful ones must carry the duds as well as pay for their own effects on depreciation expense.

On the whole, experience is clear that if new offerings are well planned and all factors are properly weighed, they can become a significant factor in the revenue and profitability of an operation. For example, the Bell System has reported that something like 25 percent of the exchange revenue comes from these things and, while no quantitative information is available on the profits from them, it is evident that permitting customers to choose among a number of options is advantageous both to the enterprise and to the customers. While an organization that is still struggling to meet basic demands would have less urge to introduce new things, this does not mean that doing so would not be good business. To paraphrase what one leader in such an organization has said, "If we have to supply a telephone to a customer anyway, there is no reason why we shouldn't make him happy by giving him what he wants and is willing to pay for."

8. Summary

If the reader has gathered the impression from the foregoing that money—how much, how to get it, and what to do with it—ranks right along with technology as a primary consideration in telecommunications engineering, he couldn't be more correct. He would also be correct if he concluded that the wisdom with which money is invested is of critical importance to the economic health of the enterprise. More specifically, the primary objective is to invest money so that the critical ratio

$$\text{Critical Ratio} = \frac{\text{Revenue} - \text{Expense}}{\text{Investment}}$$

is a maximum now and forever.

In principle, this is simple. He must make flexibility to cope with whatever service needs may arise a fundamental of his planning, not just an afterthought or a minor factor in the hope that service needs will not change or that he can predict the changes. He must increasingly use types of plant the costs of which are largely fabrication. He must decreasingly use types of plant the costs of which are largely raw materials and field labor. The costs of the former go down with respect to the latter with time and they can provide greater flexibility.

If then, in addition, he does his very best to control working costs, his problem is solved and the enterprise will have a long and happy life.

9. Appendix—A Few Notes on Depreciation

Boiled down to fundamentals, depreciation can be said to be the monetary aspects and consequences of throwing plant away. Since the types and amounts of plant provided by engineers determine how much plant must be thrown away and when, depreciation is an important consideration in engineering, and vice versa.

It is not the intention here to discuss the many theoretical and accounting aspects of depreciation nor to participate in the many arguments about them; the engineer can find out more than he really wants to know from the extensive literature and the numerous speeches on the matter. Rather it is intended merely to discuss what it means and how it affects, and is affected by, engineering.

In fact, what depreciation accounting does from the standpoint of the engineer is merely to provide quantitative monetary meaning to some things that common sense says are so, for example:

(A) That when a piece of plant is displaced, the service and revenue which it has been providing disappears but the investment which has been made in it does not; the only capital recovery (in terms of money in the till) associated with the *actual displacement* is the "net salvage" (that is, the difference between the amount which is realized from the sale of this displaced plant and the cost of removing it) which may be either plus or minus.

(B) That, because of this fact and the fact that (with few exceptions such as land, et cetera) all plant must be thrown away some time, enough money must be set aside from revenues annually to cover the loss associated with displacement of plant when it occurs, if the capital structure is not to be seriously eroded.

(C) That the smaller the amount of investment in plant per unit of service and revenue, and the longer its useful life, the smaller will be the amount of money which must be set aside annually for capital recovery and the better off economically both the enterprise and its customers will be.

9.1 How Depreciation Works

While there are wide differences in accounting methods among countries, most of them at least appear to give about the same overall financial indications in terms of gross and net book values, operating results, et cetera. Therefore there is no reason to discuss these methods in detail, but it might be worth while to mention one of the main differences to facilitate understanding of annual or other reports prepared by different organizations.

This difference is in how the dividing lines are set between displacements and replacements which are handled as operating expenses (usually maintenance) and those which are handled as capital expenses—that is, charged to construction and depreciation. Probably all countries charge very small expenditures (for example, replacement of a relay spring or a relay) to maintenance, but some of them move into the capital area at a fairly low level of expenditures while others continue to handle current displacements and replacements as operating expenses up to high levels.

The effects of these differences show up primarily in the sizes and compositions of construction programs; expenditures charged to operating expenses do not usually show up in construction programs, so that countries where large expenditures are handled through maintenance or other operating accounts tend to show smaller construction programs relative to those in countries where such expenditures are handled through the capital accounts.

However, since the end results are independent of the accounting philosophy, the engineer may be interested in the philosophy, but he need not be too concerned about it. Also, because the end results are the same, any basis can be used in discussing how depreciation works; in the following, it is assumed that large expenditures associated with plant displacement are handled as capital expenses.

As revenue comes in from customers, a part of it is set aside (designated as depreciation expense or appropriation, or some name having a similar connotation) to the end that as plant is displaced the associated capital is recovered. The amount so set aside depends primarily on how much has been invested and what its average useful life is expected to be. It is also affected by how "recovery" is defined; for example, in some countries it is defined as the original investment; in others, as the purchasing power of the original investment; in still others, it may be something else.

Part of the money thus set aside is used to recover the capital represented by the plant currently being displaced or written off. The other part is added to the reserve or fund (or whatever else it may be called) that has been accumulated to recover capital when write-offs occur in the future. *Both* parts are usually invested in new plant; that is, the total amount is used to finance part of the current construction program.

The net effect of this process is that, when money is invested in new plant, the gross book value grows, but usually by an amount less than the amount invested in order to reflect the fact that some plant has been displaced, so that the total plant at the end of the period is smaller than the sum of the plant at the beginning and the plant which has been bought during the period. Since not all of the depreciation expense is used for current write-offs, the depreciation reserve also grows as it must to reflect the fact that the total plant (which must be written off eventually) has grown. Net book value (which is the difference between gross book value and depreciation reserve) usually also grows, but since its growth is the difference between growth in gross book and in depreciation reserve, it may vary over a wide range.

A crude, but reasonably accurate, way to look at the significance of the process is to think of gross book as the monetary value of the plant in being at any time; that is, the plant available to earn *with.* Net book is a measure of the monetary value of the plant which has been financed from sources other than depreciation; that is, the plant which must be earned *on.*

Depreciation reserve is a monetary measure of the plant which has been financed by money taken from revenue from subscribers. It also is well to remember that depreciation reserve is not kept as cash; it is invested in plant so that current depreciation expense must always be big enough to finance current write-offs plus desirable growth in depreciation reserve.

The importance of gross and net book values and depreciation reserve, and of the way they grow, on long-term economic health of the enterprise is self-evident. But, from the standpoint of this document, it is even more important to consider how they are affected by, and affect, engineering.

9.2 Engineering Connotations

One of the important things which the engineer must recognize is that, while the gross book value is a monetary measure of the plant in being, it says nothing about the ability of the plant to provide service and produce revenue. That is, a well-engineered plant having a given gross book value will be able to provide much more in the way of amount, quality, and scope of service than a plant having the same gross book value but which has been less effectively engineered.

In like manner, a low net book value may be the result either of excellent engineering in the past, which has produced a plant with high serviceability and a low rate of displacement, or merely of a depreciation expense rate which has been so high as to build up a large depreciation reserve despite less-than-excellent engineering. In this connection, it is important for the engineer to recognize that depreciation expense money does not grow on trees; it must be extracted from the pocketbooks of subscribers, and the amount which must be extracted is bound to have an effect on the enthusiasm (or lack thereof) with which subscribers view the service and the amount of it they buy.

Thus the engineer must strive to produce a plant which has high earning capability per unit of investment and which at the same time keeps the amount (in *absolute* terms) of money which must be extracted from subscribers for depreciation expense reasonably low. The amount of depreciation expense in absolute terms depends on the amount of plant which must be written off eventually (roughly gross book minus some items, for example land, et cetera, which may be considered not depreciable) and the rate at which it must be written off.

To get the lowest possible combination of the *amount* which must be written off eventually and the *rate* at which it must be written off, it is important to consider *why* plant gets thrown away at all, that is, the root cause of depreciation in a monetary sense.

9.3 What Causes Plant to be Written Off

The original—and still popular—concept of depreciation was that it was to compensate for wear and tear, that is, for physical deterioration of plant. However, aside from causes external to the plant itself (such as storms, fires, floods, earthquakes, and theft and other acts of man), this turns out to be a relatively minor cause. Well-maintained plant of the types used in telecommunications operations will (with a few exceptions such as wood poles, et cetera) perform its original functions unimpaired almost indefinitely.

A second—and still popular—concept was that advances in technology make plants obsolete. This again is not a primary cause, except as these advances act to permit new and different functions or greatly reduce operating expenses. There is no point in throwing away plant and buying new simply because the new plant is more sophisticated or glamorous; this can be justified only if the new plant can do things that the old plant could not do or do them very much cheaper.

Actually the major reason for throwing plant away is that (because of type or location) it can no longer provide the services that users want or that it can do so only at exorbitant cost. To put it another way, the major reasons for depreciation of plant lie in changes in the *functions* that must be performed and requirements that must be met rather than in physical deterioration or advances in the art. Perhaps a few examples taken from the previous text will illustrate these points.

Probably the simplest example is in switching, and the most-evident phase of switching is mechanization and its portent. There was nothing physically wrong wtih the thousands of manual switchboards that have gone into the junk heap; they just couldn't provide the qualities and types of services that people wanted, and the costs of operating them were obviously headed for the sky. The portent is equally clear; only those types of automatic systems that have the ability to provide very-high-quality service of a very-wide scope under a wide variety of conditions can survive for long. This is independent of what particular kinds of hardware they are composed.

A somewhat similar but also somewhat different situation exists in the transmission field. Just as it was abundantly clear some years ago in switching that manual operation was doomed, so it is now abundantly clear that long audio circuits will increasingly fail to meet the wants of customers in many areas. In this case, it usually is not necessary to throw plant away because carrier can be added to existing cables; rather the problem lies in building up of large gross book investments in audio cables which have limited service and revenue capability, and of large net book investments with corresponding large earnings requirements.

An example of depreciation because of location is afforded by standing-still expenditures. A piece of outside plant might have to be displaced and new plant built because of a new road, or a telephone and its wiring may have to be taken out in one place and a new telephone and wiring put in somewhere else merely because a customer has moved. The new plant may be precisely like and perform the same functions as the old, but there is an economic loss just the same: even if the displaced plant can be reused, the labor costs (which may exceed the material costs) are lost.

Still another example is the increased junking of older type telephones and other equipment on subscribers' premises brought about by new and more desirable types. In many of these cases, only the telephone itself is junked and since it represents only a relatively small proportion of the initial installed cost, the loss is not excessive and can be more than made up either by savings in loop plant (if the advantage of the new type is primarily increased efficiency) or by properly selected *premium* charges (if the advantage is primarily increased attractiveness from the users' viewpoint). This is an area in which forced depreciation often requires comparatively little capital expenditure and, if properly planned, is profitable to the enterprise and advantageous to the subscribers.

9.4 Effect of Age on Write-Off

Occasionally one runs into the idea that if a particular piece of plant is old, there is less economic penalty involved in throwing it away than if it is new. This, of course, is not so because as long as the plant can perform its allotted function, it is just as useful when it is old as when it is new, and throwing it away reduces the amount of plant available to produce service just as much as if it were new. Depreciation usually recognizes this by basing depreciation rates on life expectancy of *classes* of plant and by charging the same amount regardless of whether a *particular piece* of plant is 1-day or 50-years old when it is written off.

The fact that the economic penalty involved in throwing away a particular piece of plant is independent of its age does not militate against the advantage of long useful life for a class of plant or for the plant as a whole. That is, the longer the average life, the lower the depreciation rate that must be charged and the better the chances will be that the write-off rate actually experienced will be lower than the estimated rate on which depreciation expense has been computed. Thus, the longer the average useful life, the larger the depreciation reserve and the lower the net book value become.

9.5 Benefits to Customers

Obviously, as already discussed, if plant is so engineered that the total amount that must be written off is minimized and the theoretical average life (on which depreciation rates are based) is maximized, the customer benefits because less money must be abstracted from his pocketbook to be set aside for depreciation. Even if, because of superlative engineering or otherwise, the rate at which capital must be recovered turns out to be lower than was anticipated in setting depreciation rates, the customer as well as the enterprise benefits.

Depreciation accounting gives quantitative meaning to this fact through its effect on gross and net book and depreciation reserve. With low write-off rates, depreciation reserves grow rapidly so that net book grows much slower than gross book. The effect is cumulative; with lower earning requirements (lower net book) more money can be set aside for depreciation without increasing the money abstracted from customers, which further slows down growth in net book, which further increases the difference between earning requirements and revenue capability, which permit more of the revenue to be set aside for depreciation and profits, which . . .

Thus, as time goes on, a larger and larger amount of construction can be financed by depreciation money and profits and in the long run the customers will pay less or will get more service for the money they pay. The salubrious effect of a sound depreciation policy, together with sound engineering, is discernible in many organizations and is clearly visible to the naked eye in some.

9.6 Why Should the Engineer Care?

In their day-by-day work, most engineers have no reason to worry about depreciation as such except as it affects the relationship between the numerator and denominator of the critical ratio.

However, if the engineer can get a clearer picture of how his daily work affects the amount and timing of plant write-off, and of how this in turn affects the economic health of the enterprise, he may get a better appreciation of the value of superlative engineering or at least be less likely to be led astray by incorrect economic reasoning.

At least, this is the raison d'être for the foregoing.

H. R. Huntley was born in Neillsville, Wisconsin, on 29 December 1894. He received a B. S. degree in electrical engineering from the University of Wisconsin in 1921.

He joined the Wisconsin Telephone Company (an Associated Company of the Bell System) in 1917 where he worked on transmission matters including design of local and long-distance plant, inductive and structural coordination of telephone and power systems, protection of telephone plant against lightning, contacts with power circuits, electrolysis, et cetera.

In 1930 he joined the American Telephone and Telegraph Company where, for a number of years, his work covered much the same ground as in Wisconsin but on a consulting basis for the whole Bell System. Later he became, successively, Assistant Chief Engineer in charge of several areas of work, Director of Customer Product Planning, which combined the engineering and marketing aspects of instrumentalities on customers' premises and service features which affected customers directly (such, for example, as new forms of telephones, key equipments, private automatic branch exchange service, data transmission, et cetera) and, finally, Chief Engineer.

Since his retirement from the Bell System in 1960, he has been an independent consultant and has worked with a number of organizations including the International Telephone and Telegraph Corporation.

He has published numerous articles dealing mainly with planning of telecommunication systems and the nature of engineering and its relation to other management functions.

Geneen and Stone Honored by Belgium

Harold S. Geneen, chairman and president of International Telephone and Telegraph Corporation, was decorated on 1 October 1966 with one of Belgium's highest honors when Paul Van Den Boeynants, Prime Minister of Belgium, in behalf of King Baudouin of Belgium, bestowed on Mr. Geneen the title of Commander of the Order of the Crown.

The decoration was in recognition of outstanding services rendered, particularly through the contribution to the Belgian economy of Bell Telephone Manufacturing Company. This associate of International Telephone and Telegraph Corporation maintains its headquarters in Antwerp and operates 10 factories employing 13 000 people in Belgium.

At the same ceremony, the Prime Minister named Admiral Ellery W. Stone a Commander of the Order of Leopold II. A vice-president and director of the International Telephone and Telegraph Corporation, Admiral Stone served from 1961 through 1964 as president and is now vice-chairman of the corporation's European management headquarters in Brussels.

Crosspoint Elements and Relays with Miniaturized Reed Contacts

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In modern semi- and quasi-electronic space-division-multiplex switching systems, fast-operating mechanical contacts are mainly employed in crosspoint matrixes. As the number of crosspoint contacts required makes their cost of great significance, not only operating speed but other performance features must be considered [1]. Our *H 50* reed contact is shown to be satisfactory as a crosspoint contact. In large production these contacts are so inexpensive that quasi-electronic switching systems, with suitable control equipment, are comparable in cost to conventional systems. With satisfactorily controlled automatic manufacture of such contacts, these systems can be virtually maintenance-free.

1. Crosspoint Requirements

The following solution is based on the characteristics of a crosspoint with existing reed contacts. The discussion, however, covers in detail only those solutions having acceptable costs and the necessary operating reliability. Innumerable other solutions have been presented in the patent literature. However, many of these proposals turn out to be technically inadequate, unsuitable for mass production, or too expensive.

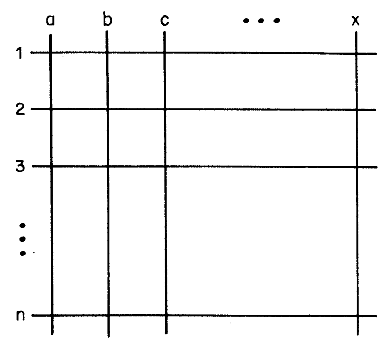


Figure 1—Crosspoint matrix with n inputs and x outputs.

In the crosspoint system shown in Figure 1, it must be possible to connect any wanted output $(a,b,\ldots,x)$ to any of the inputs $(1,2,\ldots,n)$. It must be possible to choose the number of inputs and outputs independently of each other to suit both economy and traffic theory. The maximum number of simultaneous connections must correspond to the smallest number of outlets in either the row or column. Double connections (operation of two crosspoints in one line or one column of the matrix) must be possible, but even under extreme service conditions unintentional double connections must be safely prevented.

2. Types of Crosspoints

The requirement that double connections be preventable excludes in practice all methods based on the simple linear addition of the actuating energy over two coordinate structures. Distribution of magnetic energy over two coordinates falls into this category as shown in Figure 2. Purely magnetic methods always suffer from difficulties caused by stray flux.

For linear addition of the actuating energy in the crosspoint (Figure 3), double connections

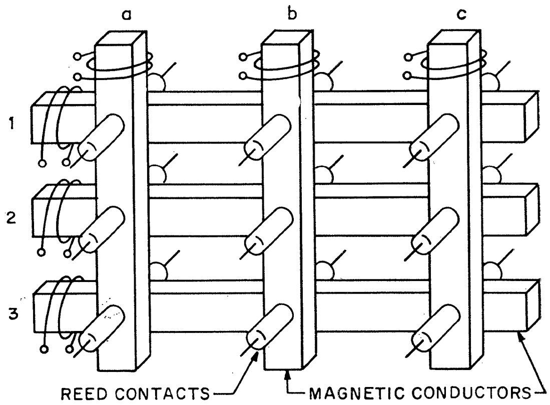


Figure 2—Crosspoint matrix with simple linear addition of the actuating energy distributed to two coordinate directions.

are avoidable only at considerable expense unless the magnetic materials have nonlinear properties. Influences that may lead to double connections include variations of the operating voltage, of the coil resistance, and of temperature. Since one crosspoint element normally contains several contacts, additional influences within each crosspoint are the differences in the operate and release requirements of the individual reed contacts, the relative position of each contact within the crosspoint, and the mutual magnetic influence of the contacts on each other. Finally, during the life of a reed contact—mainly when making and breaking current—operating values may change from the initial state, particularly when the requirement for shortest possible switching time compels some overexcitation to be provided.

The service conditions must be chosen to assure operation of the crosspoint contact even if all unfavorable influences coincide. When calculating the worst-case condition, it will be recognized immediately that with linear addition of the actuating energy in the crosspoint element, the operation of unintended crosspoints is unavoidable.

Designs are not considered in which electromechanical links move permanent magnets that in turn control the reed contacts. These mechanical links lengthen switching time, are additional sources of trouble, and require maintenance. Thus—apart from cost—they certainly do not offer the same level of reliability as the solution presented here. The following patterns of classification are presented in Table 1 [2–7]. Types 1 and 4: marking in two coordinate directions (crossed long coils or series-connected single coils). Types 2 and 3: crosspoint elements with single coils. Types 1 and 2: crosspoints with continuous hold current. Types 3 and 4: latching crosspoints (holding by remanence). Types 1 and 4: division into crosspoint elements without electrical connections between coordinates, which therefore need not be decoupled. Types 2 and 3: crosspoint elements constituting such a connection and which require decoupling measures. In the illustrations for types 2 and 3, electric current coupling of the actuating lines exists over the entire switching grid. The simple interruption of the lead to the wanted coordinates may not produce positive release of a connection, and further decoupling from the system may be required. This, as is known, can be done by rectifiers or by additional contacts. In large crosspoint matrixes, it may be necessary to limit the reverse current of these decoupling rectifiers to guarantee positive release of the crosspoints under the most unfavorable operating conditions.

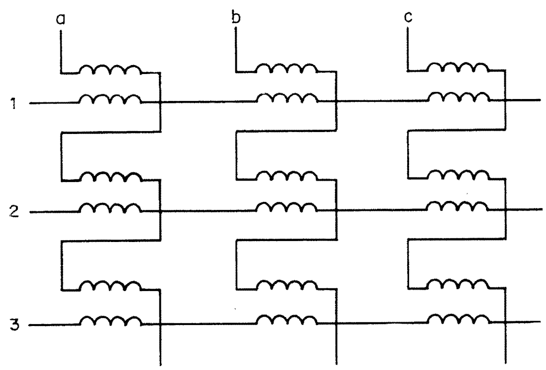


Figure 3—Crosspoint matrix using linear addition of electromagnetic energy distributed to two coordinate directions.

2.1 Functional Principles

Type 1 of Table 1 shows continuous current holding, without requiring electrical decoupling. In this design, long intersecting coordinate coils each receive half the necessary magnetic excitation. Division into series-connected single coils does not change significantly the principle of the long coils shown but does provide greater flexibility in the structure of matrixes. At the point of intersection, the magnetic field is strong enough to close the reed contacts. As already mentioned, the simple linear contribution by each coil of 50 percent of the necessary excitation does not permit control over the entire range of tolerances encountered. However, by suitable design of the magnetic circuit, use of iron having nonlinear properties, and suitable

TABLE 1

Principles of Crosspoint Elements for Reed Contacts

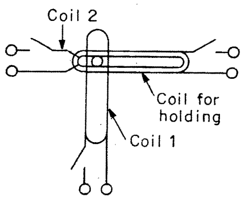
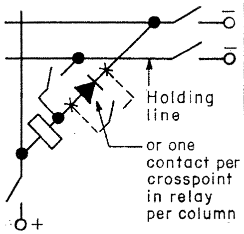
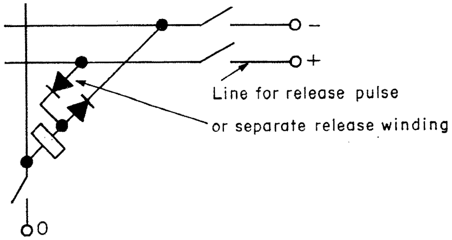
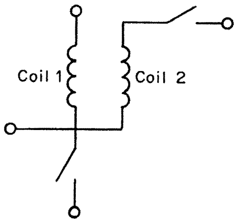
Type	1	2	3a	3b	3c	4
Electrical circuit						
Coils	crossed long coils	1 coil				2 coils
Kind of holding	holding by constant current		latching relays (holding by remanence)			
			1 magnet		2 magnets	
			permanent magnet biased	half-hard magnet to be magnetized and demagnetized [7]	1 permanent magnet 1 reversible magnet	2 reversible magnets
Examples	Siemens [2]	Standard Elektrik Lorenz mounting-strip type [3]	Western Electric [4]		Western Electric bipolar ferreed [5]	Western Electric ferreed [6]; Le Matériel Téléphonique (Section 2.2; Figure 6)
Operate	current direction has no influence, but is the same direction in all coils	current direction has no influence	current flows in 1 direction only	current direction has no influence	current flows in 1 direction only	coincidence of ends of pulses is necessary. With 4 coils and appropriate excitation, this coincidence is not necessary
Release	Interruption of the current		operate pulse +, release pulse −			excitation of only 1 of the 2 coils in optional direction
			or operate and release by pulses of same direction but of different magnitude			

TABLE 1.— *Continued*

PRINCIPLES OF CROSSPOINT ELEMENTS FOR REED CONTACTS

Maximum limit for operate current	unwanted operation	thermal limits only				
Maximum limit for release current			danger of make-again. Pulse of 20 milliseconds for release of 80-millimeter contact	release pulse should about equal operate pulse, otherwise make again		thermal limits only
Operate time	a few milliseconds					about 0.3-millisecond current pulses [7]; about 3 milliseconds until contacts operate
Decoupling in a matrix	magnetic decoupling by appropriate magnetic circuits (no electrical connection between the coils)	holding contact per crosspoint and rectifier or one contact per crosspoint in relay per column	two rectifiers or one rectifier and separate release winding			no decoupling necessary
Particulars	complicated magnetic circuit for magnetic decoupling difficulties in mastering the operating conditions and contact tolerances. Large holding power due to the coordinate coils dimensioning of holding coils for constant current		coil dimensioning for pulse excitation only	development of special magnetic material necessary		the contact *237 B* described in [5, 6] is not allowed to make and break current. Mutual magnetic influence by a stray field may disturb. Due to large contact forces of the *H 50* contact (used in the design of Figure 6) making and breaking current can be allowed; no disturbing influence of the stray flux can be observed
Flexibility (combining of matrices of different sizes)	poor	good				

Note: References [2] through [7] are in Section 6.

shape and position of the coils, considerable improvement is attainable. The difficulties posed by the magnetic circuit are clearly evident from the rather large number of patents dealing with this subject that have been granted in Germany alone.

Type 2 of the table shows continuous current holding, with electrical decoupling necessary. Every crosspoint element has a single coil which is directly triggered. The decoupling diodes necessary in such a matrix can be replaced by additional contacts of a marking relay associated with each column.

Type 3 shows holding by remanence of a directly triggered single coil, operating by current pulses, and using two decoupling diodes. The decoupling diode for the operate current pulse can be replaced—as in type 2—by one contact on one marking relay per column. The diode for the release current pulse can be eliminated when using a separate release winding but this has little effect on cost.

Types *3a* and *3b* use only one magnet. In type *3a*, every crosspoint has a hard permanent magnet adjusted so it will just hold the reed contacts closed but is not strong enough to close contacts that are open; this is called magnetic bias. For closing or opening, an aiding or an opposing pulse is necessary, each of about the same amplitude. Operation is also possible with opposing pulses only; for closing, however, a very large pulse is necessary.

Type *3b* concerns a half-hard magnet that is magnetized to saturation for operating the reed contacts. For release of the reed contacts, the magnet is demagnetized to a residual value well below the release field of the reed contact. Current pulses of different polarities are necessary for releasing and operating the reed contacts.

Another design, shown in Figure 4, uses magnetic material with two standard reciprocal magnetic preference directions. This material, however, cannot be considered as having reached the final development state. Two different windings are used for closing and opening the reed contacts.

With regard to the principal structure of the magnetic circuit, type *3c* of Table 1 is equivalent to the ferreed described in [6] but with the difference that a hard and a half-hard magnet are used. The half-hard magnet is driven into the two states of saturation by current pulses. For opening and closing the reed contact, different polarity pulses are necessary.

In type 4 every crosspoint element contains two half-hard magnets, as shown in Figure 5, which are driven arbitrarily by pilot pulses into the two states of saturation. According to the relative magnetizing direction of the magnets, the reed contacts close (magnetic directions opposing each other) or open (magnetic directions aiding each other). The coils within each line or column are connected in series. When exciting one column or one line only, all reed contacts open or remain open regardless of the current polarity [5, 6].

With appropriate material (ferrite) for the half-hard magnets, types *3b*, *3c*, and 4 can be used as a "time transformer." In that case a very short pulse (a few microseconds) is sufficient for actuation and the contacts will be switched, according to the type of reed contacts used, about 0.5 millisecond after this "reversal of magnetism." The remanent flux must be sufficient for closing the reed contacts [6] (not only for holding as in type *3a*).

2.2 Survey of Possibilities

A critical survey of matrix operation of crosspoint element designs shows the following (refer to Table 1).

In type 1, for safe operation, exact tolerance analyses must be established to prevent the unintended operation of crosspoints even in the worst case. Here the maximum possible excitation that might occur must be considered according to the influences mentioned before. Despite a special design of the magnetic circuit that uses the nonlinear properties of the iron, it may be necessary to use selected contacts with extremely low hold excitation, a fact which is unfavorable with regard to standardization and life expectancy when switching loads. Long coils not only require relatively high power for operate and hold conditions, but they are also difficult to adapt to different matrix sizes.

All latching crosspoint designs (types 3 and 4) require additional storage capacity in the system control, or 1 additional contact per crosspoint, to be able to recognize all paths available for

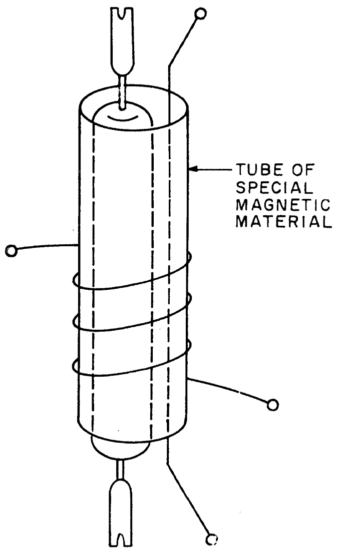


Figure 4—Crosspoint element using a tube of magnetic material having two directions of easy magnetization.

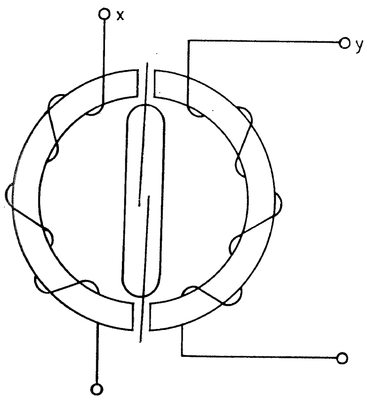


Figure 5—Principal structure of the ferreed.

marking. When a connection is terminated, the crosspoint elements of type 3 must be returned to their idle state. In type 4, however, it would be sufficient to disconnect the input and output of the path, even if it ran through several matrixes.

The ferreed design (type 4), on marking one crosspoint, causes any other crosspoint associated with the same x or y coordinate to return to idle if still switched through up to this moment. Thus no definite operation is necessary, as in type 3, to return to the idle state those crosspoints that are no longer required for a connection. It has not yet been proved, however, whether idle connections, which might even extend over several matrixes, have a disturbing effect on crosstalk. Holding without current can be of some advantage, such as in systems using concentrators where, in general, the necessary continuous current for holding the crosspoints (as in type 1 or 2) is not available. However, it is scarcely a problem to supply the current needed for holding. On the other hand, in all other systems the saving of current by using latching crosspoints is not necessarily of major significance. Saving of current would mean less than about DM 0.40 per day for 1000 lines in the quasi-electronic system *HE-60 L* [8].

Thus, bearing in mind the possible small decrease in power supply costs of the exchange and the possible increase in control circuits for latching switches relative to electronically held switches, it is improbable that the choice between latching and nonlatching designs would normally be determined solely by these factors.

Type 3*a* presents difficulties in positioning the permanent magnet with respect to the reed contacts to obtain the required operate and release values. Reoperation may occur from excessively strong release pulses. There is also an essentially smaller contact force than for holding with operate ampere-turns. These conditions are acceptable for correctly adjusted reed contacts of normal size (80 millimeters) but can be troublesome with miniaturized reed contacts. For these smaller reeds the contact force can be such that contact resistance is highly dependent on it. This becomes more damaging with time because of contact erosion [9].

With the "magnetic bias," the breakdown voltage across the open contacts is somewhat smaller (about 10 percent) than for the reed separation alone. Finally, the need for a rather long release pulse should be mentioned. With 80-millimeter reed contacts the release pulse should be about 20 milliseconds, which is influenced by mechanical oscillation of the reeds.

Type *3b* avoids the danger of insufficient contact forces, but it is difficult in production to control the tolerances on operate values in such a way that safe opening of all contacts is guaranteed. If for reasons of cost an electrically isolated release winding is to be avoided, decoupling rectifiers must be included in the matrix. Their leakage currents in conjunction with the always present residual field of the magnets (the difference between the magnetic fields of the hard and half-hard magnets) can have a disturbing effect. Finally, with too high a release amplitude, reoperation may occur and the contacts may then remain closed.

Today, variants that use material having two preferential directions of magnetization (Figure 4) can hardly be designed economically because of the relatively high excitation required and other difficulties.

The cost of type *3c,* which certainly can be mass-produced in reliable operating form, is too high in comparison with type 2.

Circuits of type 4 (shown in Figure 5) have been described in the literature and, among other things, have been developed with emphasis on time transformation. The quickly reversible magnetic materials (ferrites) needed for this purpose have a relatively small energy content for a practical range of dimensions. The proposed reed contacts must therefore operate with relatively low magnetic flux and hence with correspondingly small contact and restoring forces [9]. As the average relative permeability of the magnetic circuit is necessarily low, a relatively high stray flux results and increases the sensitivity to external magnetic fields. This in turn requires rather large gaps between the crosspoint elements or the introduction of adequate magnetic screening. Without such measures there is danger that, when marking a crosspoint, the switching magnetic peaks may disturb data transmission on neighboring circuits. Because of the small forces, the reed contacts mentioned [7] ought not make and break current.

The operating specifications [7] published up to now, however, do not permit the value of this component as a time transformer to be rated very highly. If, as in most space-division quasi-electronic switching systems discussed today, a time transformer is not needed, half-hard magnetic material with a much higher energy content can be used with considerable advantage. This permits the use of miniaturized contacts with substantially higher forces, which for this reason do not possess the disadvantages mentioned. Finally, the cost appears to be relatively high compared with type 2, as four windings are necessary and two special grades of iron had to be developed.

A suitable miniaturized reed contact is the *H 50* [9], which allows latching crosspoints to be produced at relatively low cost. Such a crosspoint element, developed by Le Matériel Téléphonique, with three *H 50* contacts is shown in Figure 6. These contacts may make and break current, which might have a favorable effect on system control by reducing costs.

3. Choice of Crosspoints

When weighing cost, operating tolerances, and difficulties in production, a simple type 2 crosspoint element is a favorable solution for most applications. Only thermal limits exist for the maximum operate currents in the coil, erroneous operation is not possible, and the adaptability to different matrix sizes is extremely good. For these reasons this type of crosspoint element (Figure 7) has been used in the *HE-60 L* system [8].

One design requirement concerns the smallest unit that can be considered optimal. A large fixed matrix of perhaps 10 × 5 crosspoints, as offered by some manufacturers, seems to limit flexibility, whereas single elements may represent an unnecessary refinement. A crosspoint strip consisting of 4 or 5 crosspoints as a basic unit, from which all sizes of matrixes may be assembled, can be considered a good compromise. Finally, the choice of the smallest replaceable unit is influenced by the performance reliability of reed contacts. The ability to replace a single reed contact must not be regarded as an unalterable requirement.

Figure 8 shows a crosspoint strip designed with regard to the considerations mentioned above. It contains 5 separate crosspoint elements, each with 4 reed contacts of the *H 50* type. A printed-circuit board that carries the multiple wiring on one side serves as a base. In addition, the crosspoint housing includes the necessary decoupling diodes. The volume of such a crosspoint element with 4 type *H 50* contacts is only about 23 cubic centimeters (1.4 cubic inches). The design chosen requires at least one side of the matrix to be divisible by 5. Since cost as a function of matrix size in switching systems shows a rather

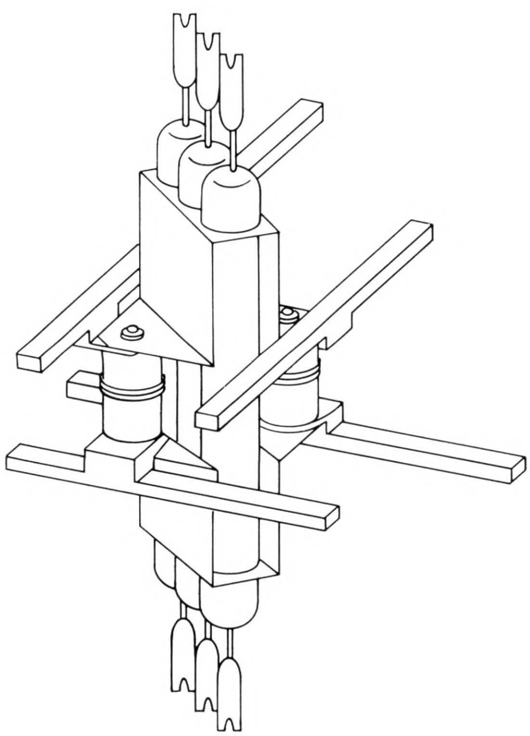


Figure 6—Latching crosspoint element of Le Matériel Téléphonique using 3 type *H 50* reed contacts.

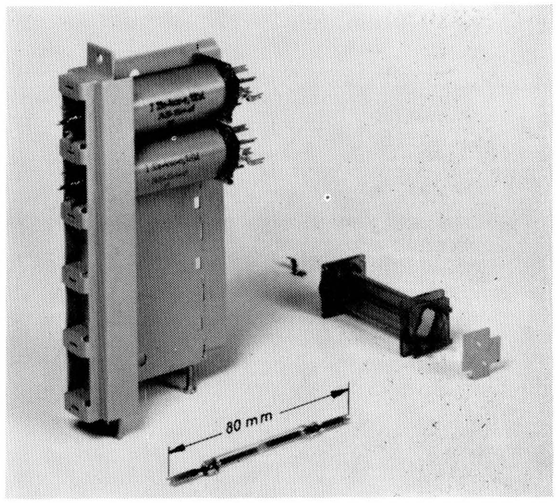


Figure 7—The coil form at the right holds 2 of the 80-millimeter (3.1-inch) reed-contact elements. A crosspoint strip to hold 5 complete reed switches is also shown.

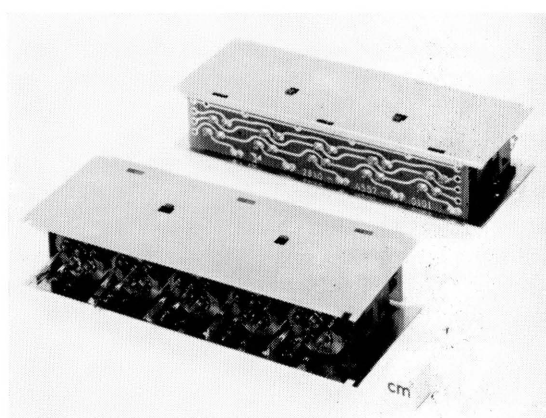


Figure 8—Crosspoint strip holding 5 crosspoint elements, each with 4 type *H 50* reed contacts for continuous hold current.

flat minimum, it is no problem to use this basic unit economically in all switching networks.

Figure 9 shows how crosspoint matrixes can be combined from such strips into plug-in units, which may also incorporate for functional reasons the associated control circuits with their electronic components. Depending on the structure of the system chosen, a basic crosspoint strip with 4 crosspoints of only 3 contacts each (Figure 10) has been developed [10].

Basic components suitable for all space-division systems are now available: latching crosspoint (Figure 6), crosspoint strip for operation with continuous current with 5 crosspoints of 4 contacts each (Figures 8 and 9), and crosspoint strips for operation with continuous current with 4 crosspoints of 3 contacts each (Figure 10). The *H 50* element, featured by its relatively high contact force, is the basis for all designs. There are no cases requiring special production and test procedures.

4. Miniaturization

The effect of component miniaturization must be considered for the entire exchange. Thus if only a new speech network is considered while all remaining equipment stays of conventional size, no major advantage is gained by using contacts smaller than 80 millimeters with respect to the overall apparatus room area. However, if the volume of other parts of the system is also reduced, this situation changes radically. Thus there is great incentive to apply miniaturized reed contacts to at least part of the control circuits in addition to the speech paths.

The relatively high closing and opening forces of the *H 50* reed contact makes it very useful for switching in control circuits. However, a fundamental problem of all miniaturized electromagnetic components is that the reduced winding volume makes it necessary to use fine-gage wire. Unfortunately, such wire is not only expensive but also more difficult to process. On the other hand, in modern quasi-electronic switching systems considerably lower voltages (24 volts) are available, such as for transistors, compared with the battery voltages (48 or 60 volts) used in electromechanical offices. If this low voltage is used in internal control circuits, it is possible to return to the same gages of

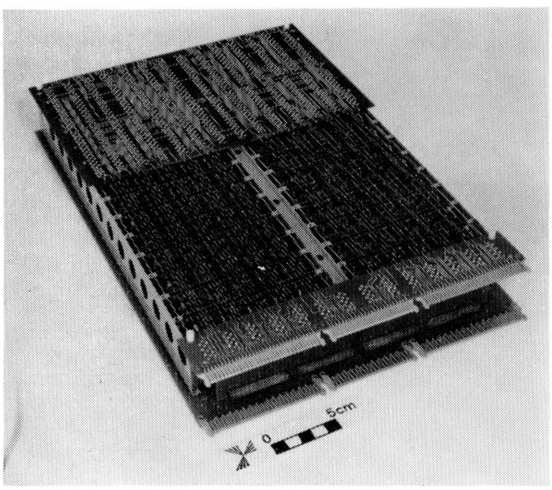


Figure 9—Matrix consisting of crosspoint strips of the type shown in Figure 8.

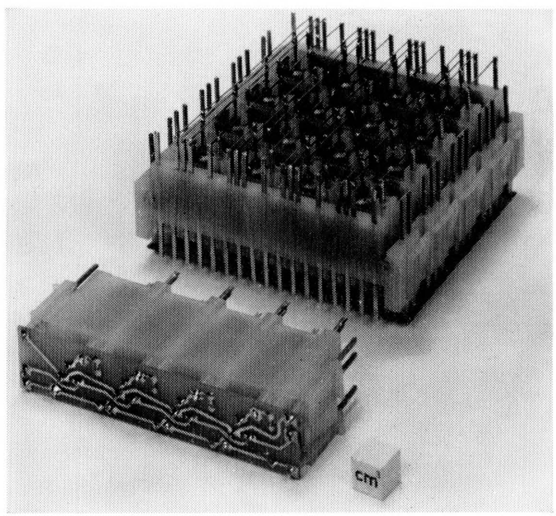


Figure 10—Crosspoint strip holding 4 crosspoint elements, each with 3 type *H 50* reed contacts for continuous hold current. The crosspoint matrix shown consists of 4 crosspoint strips with 4 crosspoint elements each.

wire that are commonly used for windings now. This low voltage offers still another advantage: The number of reliable operations of a reed contact depends considerably on the voltage to be switched, as indicated in Table 2. All tests were made without spark-quench circuits; with spark-quench, correspondingly higher numbers of operations can be achieved.

The full battery voltage (60 volts in Germany; 48 volts in other countries) can be retained for the line circuits, which generally will not exceed 1×10^6 operations during the life of an office [1]. Internal circuits that are not directly connected to the line circuits and which must perform a significantly higher number of operations can be designed for 24-volt operation. As Table 2 shows, adequate reliable life is achievable for this service with the miniaturized *H 50* contact even without spark quench. Thus it is certainly possible to employ the *H 50* contact as a universal type in a considerable part of all control circuits.

Tolerance analyses of the control circuits show the power quotient* of each relay to be used. These analyses show that in a considerable percentage of cases relays with a relatively small power quotient (relatively small copper volume) will serve the purpose.

Taking this result into consideration, a relay series for *H 50* reed contacts with a relatively small power quotient has been designed for use on printed-circuit boards. Figure 11 shows relays with 1, 2, 3, and 4 type *H 50* make contacts. The following contact combination using the described relay design can be made by adding a permanent magnet: relays with 2 break contacts; relays with 1 make and 1 break contact; relays with 1 break contact. Relays with a higher number (6, 9, 11, and 13) of type *H 50* contacts are being prepared.

* The power quotient is defined as the ratio of permissible maximum power at the operating ambient temperature of the relay coil to the just-operate power at 20 degrees Celsius. The permissible maximum power is limited by the materials used. The possible number of relay windings and their mode of operation depend on the power quotient.

TABLE 2

SWITCHING CAPACITY OF *H 50* CONTACTS, WITHOUT SPARK-QUENCH CIRCUITS

Load	Number of Operations Without Sticking*	
	60 volts	24 volts
100 milliamperes per resistor	$\sim 1 \times 10^6$	$\sim 100 \times 10^6$
1 ampere per resistor	not possible	$\sim 5 \times 10^6$
20 milliamperes per relay that controls 9 *H 80* contacts	$\sim 2 \times 10^6$	$\sim 30 \times 10^6$
8 milliamperes per relay that controls 4 type *H 80* contacts	$\sim 10 \times 10^6$	test going on
30 milliamperes per relay that controls 4 type *H 50* contacts	not tested	$\sim 30 \times 10^6$

* A contact has stuck when it has not opened 5 milliseconds after interruption of the coil current.

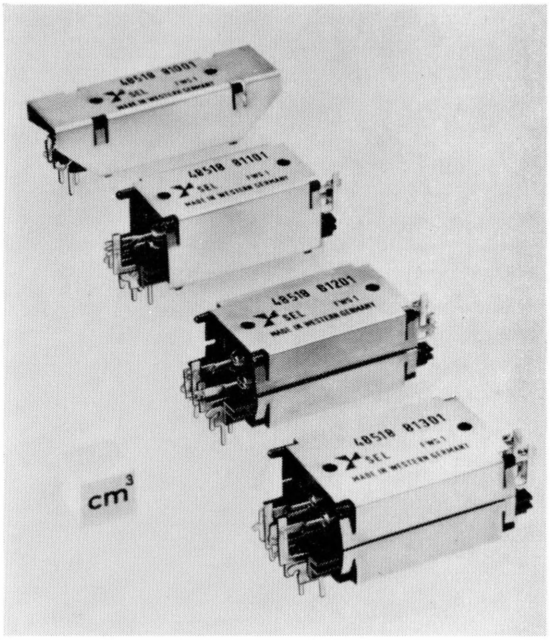


Figure 11—Relays for various combinations of *H 50* reed contacts.

In the rare cases where relays should offer a higher switching reserve (larger power quotient), relays with the *H 80* reed contact may be used [11]. Those relays possess an adequate power quotient for nearly all practical purposes.

Since the switching capability of a miniaturized reed contact is, of course, smaller than that of an 80-millimeter contact, the larger contact will also be employed when especially large numbers of operations are required. Moreover, the influence of reed size on total apparatus room area becomes proportionally even greater in systems using the newer fully electronic integrated-circuit techniques and memory-controlled central processors [10].

5. Conclusions

The foregoing considerations favor a few optimal crosspoint elements, out of an abundance of possible solutions, for use in modern space-division switching systems. The *H 50* contact is suitable for crosspoint elements of this kind and can also be employed efficiently in control circuits, thus being deemed a universal contact. The relays developed for this miniaturized contact are well suited for mass production. They save space not only in the speech network but also in the control part of the switching systems.

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Heinz Rensch was born in Dresden, Germany. He received a degree in communication engineering from Professor Barkhausen's Institute in 1937. Since that time, he has been with the International Telephone and Telegraph System except for the war years.

Mr. Rensch has worked extensively in radio, acoustics, and telephone systems and components.

Semielectronic Reed Crosspoint Telephone Switching System *10-CX*

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1. Introduction

The *10-CX* semielectronic telephone switching system applies advanced technology to small, medium, and large public telephone exchanges—comprising terminal, transit, toll, and mixed exchanges—to handle the complete range of traffic volume encountered in practice. A toll version will be used for traffic centers handling many thousands of erlangs.

Advantage is taken of the unique features of centralized electronic control, and especially those inherent to a stored-program processing system, while achieving economy for an initial capacity as small as 1000 subscriber lines.

This, combined with easy on-site expansion, brings the unparalleled possibilities of electronic switching within the economic scope of practical telephone systems.

The *10-CX* system, as shown in Figure 1, comprises four main parts.

(A) A multistage link switching network of miniature dry-reed crosspoint assemblies arranged in matrices, with associated relay circuits such as line, trunk, and junctor circuits.

(B) Electronic peripheral circuits containing buffer registers, scanners for extracting information from the switching network, and access circuits for controlling the marking and switching operations in this network, in accordance with the instructions dispatched by the central processors. These circuits, in fact, form the interface between the switching network and the central-control part.

(C) The central processors, each comprising a memory system and logic circuits for the following main telephone tasks: collecting information on the states of lines, trunks, junctors, and links; detecting changes of state; assembling for each call all such additional information as line class and routing information necessary for determining the action to be taken with respect to this call; selecting suitable idle paths through the network; dispatching switching orders to the network; and checking the correct execution of these orders. In addition, the central processors are programed to perform operations as needed for cooperation with the input/output devices and for the operation, administration, and maintenance of the exchange. These operations include call charging, routine test, service, and traffic observation.

(D) Suitable means of man-machine communication for maintenance, test, observation, and for introducing any change that might be required during operation.

Outstanding features of the central processors are simplicity, compact construction, high-speed operation, and high intrinsic reliability.

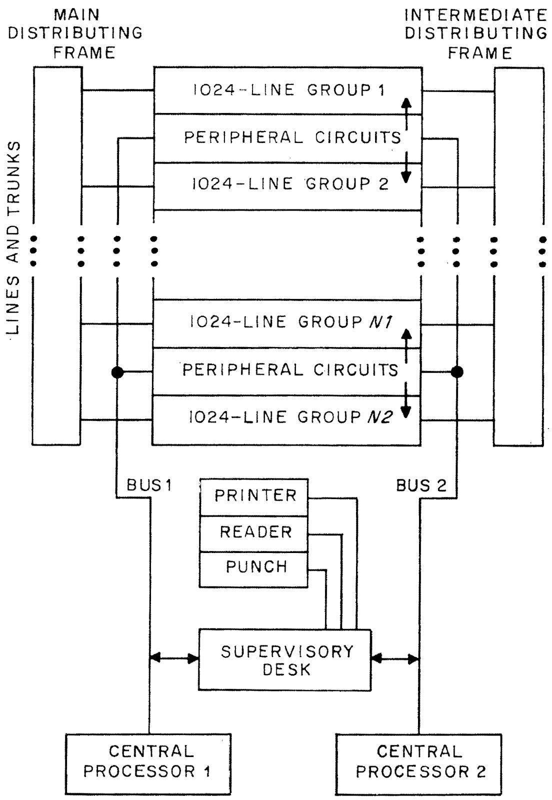

Figure 1—Modular network and central control of *10-CX* system.

To ensure round-the-clock operation, the central processor and the central part of the peripheral circuits are provided in duplicate. Each processor is connected to the peripheral circuits by its own independent peripheral bus system.

2. Switching Network

2.1 Crosspoint Assemblies

Among mechanical crosspoint contacts, sealed dry-reed contacts [1] seem most compatible with high-speed electronic control. They resemble electronic contacts in that they are protected against climatic influences, are designed for long unattended life (hundreds of millions of no-load switching operations), may be mounted on plug-in printed-wiring cards, have switching times of the order of 1 to 2 milliseconds, and can be assembled into switching matrices of any suitable small size with later expansion if needed. They are easily adapted to the word formats and memory patterns used in the common-control processors.

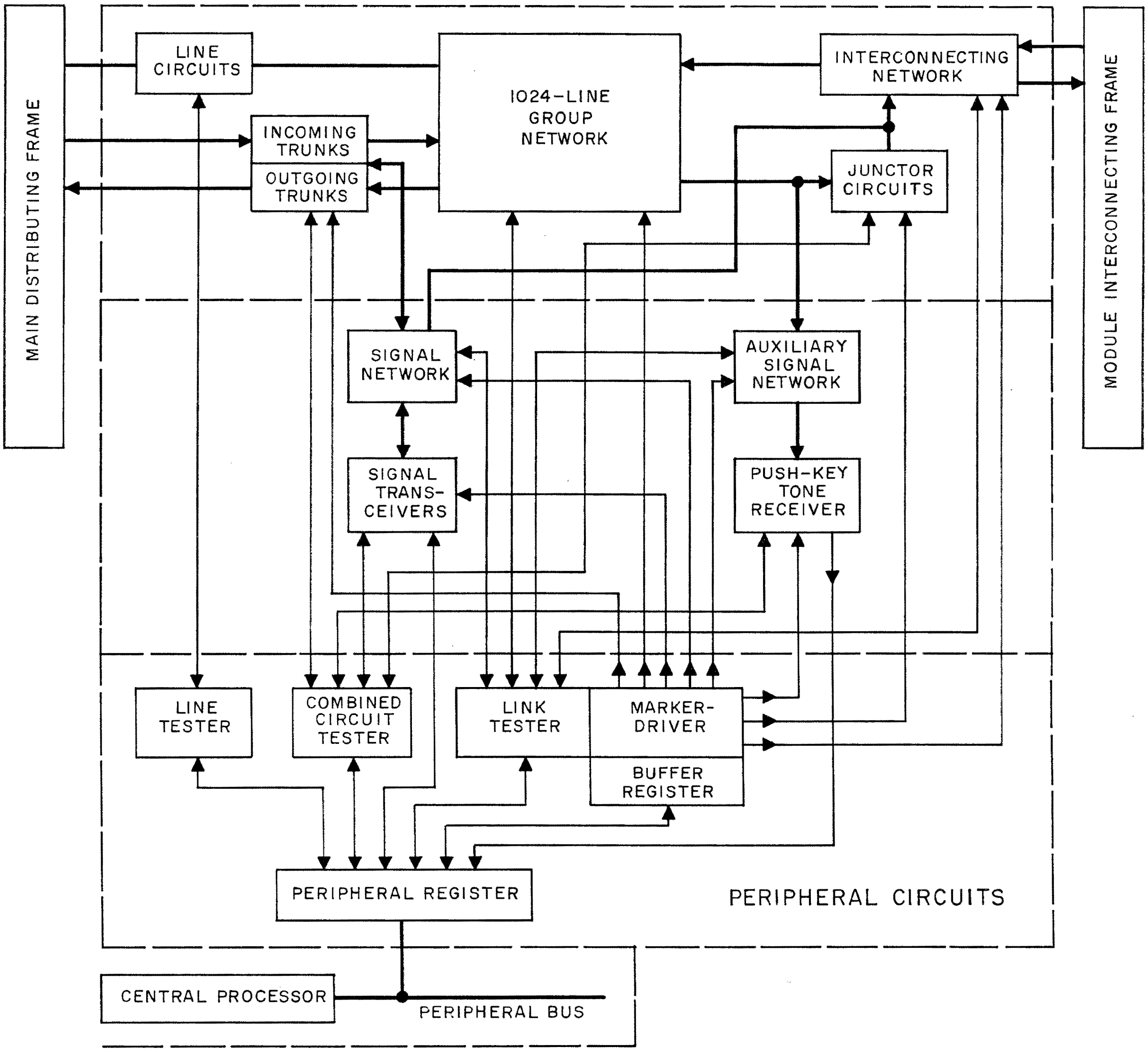

Figure 2—Peripheral package.

Each crosspoint in the *10-CX* switching network has three or five reed contacts within a common single-winding coil for operation and holding. Two or four reeds are used in 2-wire or 4-wire speech paths, respectively, whereas the remaining reed is connected in series with the coil to establish a latching circuit that may include up to four crosspoint coils in series.

At the junction between the coil and the latching contact of each crosspoint, an isolating semiconductor diode is provided through which actuating potential can be applied to one end of the coil when setting up a connection [2]. This is more fully explained in Section 3.3.

2.2 Line Group Module

To achieve economy for small offices, combined with easy on-site expansion, the switching network is composed of self-contained line group modules, each serving 1024 lines and up to 96 incoming and 96 outgoing trunks.

As shown in Figures 1 and 2, a pair of such line group modules, combined with common groups of signal transmitters and receivers, and provided with a set of peripheral circuits for communication with the central processors, form a peripheral package serving two basic groups of lines and trunks, that is, 2048 lines and up to 192 incoming and 192 outgoing trunks.

As shown more clearly in Figure 3, each line group module is a self-contained unit comprising a combined line and trunk link network, a block of full-availability junctors, a small outgoing trunk link network, and an additional network for interconnection of modules.

The line and incoming trunk terminals appear on the left side of the line and trunk link network, and the junctor input-path and return-path terminals appear on the right side thereof. One and only one path extends between any left-hand terminal and any right-hand terminal of the line and trunk link network; consequently each path, and any section thereof, is fully identified by the identity of the terminals between which it extends; the same is true for all other networks.

Line, trunk, and junctor terminals are grouped

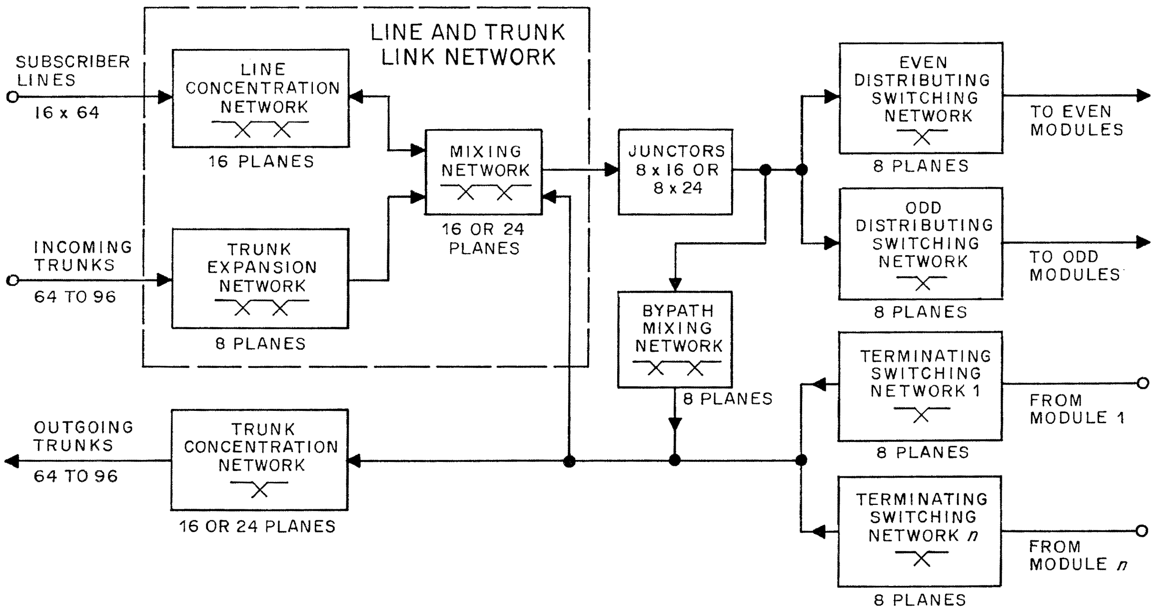

Figure 3—Line group module.

in powers of two, according to a binary coordinate system; the same coordinates can be used in various arrangements for identification of network terminals, intermediate links, switches, and crosspoints.

The line and trunk link network is composed of partial networks, each of which can be visualized as a stack of standard planes; each plane is a 2-stage link arrangement providing full single-path accessibility between each input and each output; adjacent stacks are interconnected so that each plane in one stack has access to one terminal of all planes of the other stack and vice versa.

As shown in Figure 3, these partial networks are a line concentration network, an incoming trunk expansion network, and a mixing network. In a typical *10-CX* terminal exchange, the line concentration network is a stack of 16 concentration planes, each having 64 inlets and n outlets; the trunk expansion network is a stack of 8 planes having up to 12 inlets and n outlets; and the mixing network is a stack of n planes with 24 inlets and 16 outlets, where n is normally 16 but may have other values such as 12 or 24 in exceptional cases of low or high average line traffic density.

The concentration and expansion ratios of the line concentration network and the trunk expansion network, respectively, are chosen to approximately equalize the traffic densities in the both-way line and single-way trunk traffic flows merging in the mixing network.

The outgoing trunk link network is a stack of n 1-stage or 2-stage trunk concentration planes, each having, for example, 8 inlets and 4 outlets.

Normal service and supervisory functions are performed on all calls with the aid of a single full-availability block of $8n$ general-purpose junctors per line group module. As each of these junctors can be used for any line or incoming trunk within the line group, high efficiency (up to 80 percent) can be achieved.

Junctor output terminals are given access to the outgoing trunk link network, and re-entrant access to right-hand terminals of the line and trunk link network, through a small 2-stage bypath mixing network whereby each junctor has a choice of 16 paths through the outgoing trunk line network and 16 return paths through the line and trunk link network. In this way a junctor, seized in preselection to serve a calling line or incoming trunk, can be used again for call termination in roughly 75 percent of the cases; in the remaining cases a new route is selected via another free junctor.

For interconnection of N such line group modules, the *10-CX* system provides an intermediate distributing frame and two small 1-stage switching networks (distributing and terminating) per module, connected in parallel with the input and output terminals, respectively, of the bypath mixing network.

In a fully equipped peripheral package, the distributing switching network is split into two equal networks for connection to odd and even modules, respectively, whereas the terminating switching network is an expandable network comprising as many partial networks in parallel as there are modules to be interconnected.

Making allowance for this minor adaptation, the package can be said to be a truly self-contained standardized unit, independent of the size of the exchange.

Typically for an assumed value of total incoming traffic of about 180 erlangs, this package comprises 25 600 speech crosspoints (12.5 crosspoints per line).

For signaling purposes, as shown in Figure 2, one or more additional networks are provided in common for the two line groups, for concentration of signal traffic towards pooled signal transmitters and receivers; normally the number of crosspoints contained in these networks will not exceed 1.5 per line.

2.3 Network Associated Relay Circuits

Figure 2 shows the relay sets normally associated with individual network terminals—namely, line circuits, junctor circuits, trunk circuits, and signal transmitting and receiving units. As a rule, owing to the use of electronic time-sharing control techniques, the hardware contained in these circuits as well as their space requirements are substantially reduced compared with conventional systems.

Transistors and other static components are used for detecting external analog signals (such as loop openings and closures, or alternating-current and/or tone signals), and converting them into digital signals for use in the central processor; reed relays are used for transmission of direct current, alternating current, or tone signals to the distanct exchange and for storing various states. As are the crosspoints of the network, these reed relays are pulse operated in accordance with switching instructions from the central control and then remain locked under control of a local circuit until they are reset on orders from the common control.

The line circuits each contain a high-impedance supervisory current bridge across the line loop, a cutoff relay for this bridge, and two scan points for testing the respective states of the line loop and cutoff relay.

Junctor circuits perform all service and supervisory functions normally handled by cord circuits in conventional systems. These circuits supervise originating and terminating line loops, supply battery feed to subscriber stations, repeat dial pulses, supply tones to subscriber telephone receivers, supply current to called-subscriber ringers, and detect answer condition to terminate ringing current.

For these purposes the junctors each comprise 2 feeding bridges, reed relays for holding, connection of tones, tripping and through-connection, and 3 scan points for testing busy–idle state, originating, and terminating line loop condition, respectively.

Trunk circuits each comprise a feeding bridge, 3 to 5 reed relays (depending on type of trunk) for exchange of loop signals with the corresponding circuit in the distant exchange and for storing states, and 2 scan points for testing states. Outgoing trunk circuits have an additional scan point for busy–idle testing.

Signal receivers and transmitters are designed in accordance with the specifications for inter-register signals. The receivers are designed to receive either tone or pulse signals and present them to the central processors in coded form, each code representing a numerical digit. The transmitters accept such digits from central control and convert them into the required pulse or tone signals.

Tone signal units are completely passive; all code checking and timing functions are carried out by common control, which causes these units to be scanned at regular intervals.

For calls from subscribers provided with push-button sets, a group of special tone receivers is provided which is accessible through the line and trunk link network in parallel with the junctors. When such a call is recognized, a path is normally set up toward a free junctor and extended through the auxiliary signal network to a free push-button tone receiver. Throughout the dialing phase the supervisory functions are taken over by the latter.

3. Peripheral Circuits

3.1 General

The *10-CX* switching network and central processors have been organized with a view to reducing the interface between them to its simplest form and to minimize the amount and complexity of the peripheral hardware. This in fact is not only economical in cost and space, but also contributes largely to high reliability as well as easy maintenance. As shown in the lower part of Figure 2, different circuits are provided to implement the two basic functions of the peripheral circuits: The line tester, the link tester, and the combined circuit tester extract information from the network and associated circuits, while the marker-driver sets network paths and relays.

These circuits respond to interrogation and switching orders issued by the central processor. With the processor they communicate via one peripheral register per package, closely associated with each peripheral bus system, and working at processor speed.

3.2 Testers

Interrogation orders each contain an operation code, device code, and address of a group of 16 circuits or links to be tested. On receipt of such an order in the peripheral register, the device code and address are decoded; an interrogation pulse is generated, and the interrogation result is made available in the peripheral register within microseconds. In fact, this operation is fast enough so that it can be integrated in the program sequence of the processor without interruption.

As lines, links, and circuits are usually tested in groups of 16, the number of different test points is limited and permits the use of 6- to 8-bit address codes, which are decoded in a compact 2-stage decoding matrix. The scan result is transferred to the processor via the peripheral register in the form of a word of 16 binary bits and compared with the previous scan result stored in the memory. Any change so detected will initiate appropriate processor action.

As the name indicates, the line tester is used for interrogating lines to detect service requests and/or for checking. The combined circuit tester is used for interrogation of the scan points associated with junctors, trunks, and signaling units. The scan points are grouped according to categories, each group being scanned cyclically, according to a flexible real-time schedule stored in the processor memory, at a rate in keeping with specified signal recognition time limits.

The link tester is addressed selectively by the processor whenever the latter, having received all relevant information relating to a given call, proceeds to select a free path between two given network terminals.

In each test the busy–idle state of 16 links is determined, most or all of which can be used for the connection; in a sequence of such tests, carried out in successive link groups, 16 possible paths are surveyed in a single operation. If necessary, several successive attempts are made, using a strategy specifically designed to minimize the total number of tests required, even during maximum traffic load. According to statistical evaluation supported by simulation, the total testing time per connection can thus be kept, on the average, at a small fraction of a millisecond.

3.3 Marker-Driver

Whereas the testers provide information about the state of the network and its associated relay sets, the marker-driver effects changes of state in accordance with orders from the central processor. Each switching order contains all information required for the operation to be carried out. This information is kept in a separate buffer register throughout the operation, while the peripheral register normally remains available for interrogation of circuits or links not affected by the switching operation.

As the marker-driver represents one of the major system components, its traffic-handling capacity is very important. In the *10-CX* system the high switching speeds of reed crosspoints and relays result in low occupation times and correspondingly high traffic-handling capacity of the marker-driver. Moreover, the simplicity of the marking procedure (explained below) is reflected in the simple and compact construction of the marker.

3.3.1 *Marking Procedure*

Figure 4 shows the marking wires and the horizontal and vertical holding wires of a crosspoint matrix (the tip and ring conductors and contacts have been omitted).

When positive marking potential is applied to vertical holding wire 1 and pulling potential (ground potential or lower) to marking wire 1, the left upper crosspoint coil is operated and closes its hold contact, causing the positive marking potential to be propagated on horizontal holding wire 1 toward a matrix in the next switching stage.

Thus, by first connecting positive marking potential via the marking contact to one end of the path to be established, and then applying pulling potential sequentially to the marking multiples of the wanted horizontals in all succeeding stages, the desired connection is set up.

Finally, by closing the holding contact at the marked end and disconnecting the positive marking potential at the marking contact, a series latching circuit is established between ground and negative battery in which all crosspoints along the path are locked under the control of the holding contact.

It will be seen that this holding circuit is unaffected by any later application of pulling potential to one or more of the marking multiples. Release of this connection can ultimately be effected simply by opening the holding contact which is located in the feed junctor.

In paths extending to subscriber line circuits, the left-hand load resistor is replaced by the cutoff relay, which is thus energized automatically on the establishment of a connection. Thus no separate means for access to line circuits is required.

As the propagating positive marking potential is effective each time in one matrix only, at each switching stage the pulling potential may be applied in all matrices simultaneously. This reduces to 4 to 8 per stage the number of marking multiples to be selected for connection of pulling potential.

For carrying out path setting orders, the marker-driver comprises an address decoder and access relays for access to positive marking points, 4 small access matrices for access to pulling multiples, and a sequencer for sequential operation of said matrices. It also has auxiliary circuits that check its operation and aid in rapid fault location.

Total occupation time for path setting orders is less than 20 milliseconds, even for the longest paths.

For carrying out relay setting orders, the marker-driver contains address decoders controlling access relay matrices for access to

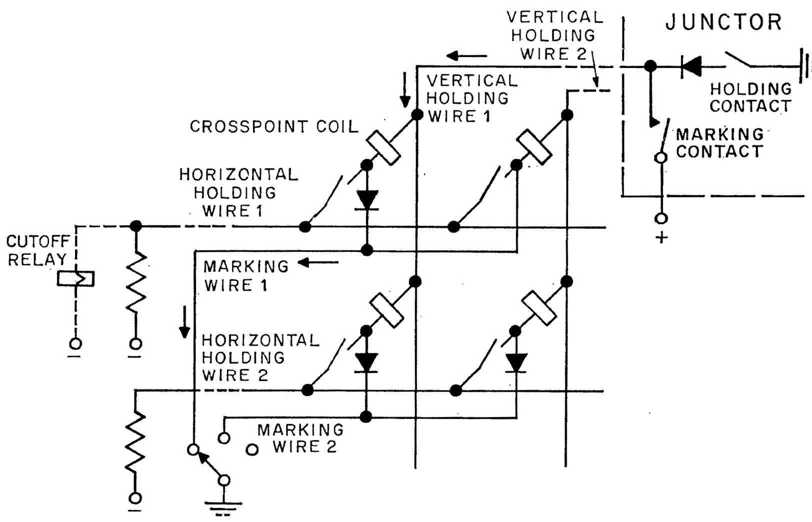

Figure 4—Marking procedure in a crosspoint matrix.

trunks, junctors, and signaling units. Total occupation time for such orders is a few milliseconds.

4. Central Processor

Simplicity of hardware and software, compact construction, high-speed operation, and high intrinsic reliability have been the principal design objectives for the *10-CX* central processor. It comprises two completely independent, self-contained real-time data processors, each communicating with the network packages and input/output devices via its own multiconductor peripheral bus system. Each processor has access to every part of the telephone network and a capacity sufficient to handle the specified traffic. The control panel of the central processor is shown in Figure 5.

4.1 Processor Characteristics

Each processor can be described as a stored-program controlled binary data processor, comprising memory, data registers, arithmetic unit, and control unit, and having facilities for indirect addressing and indexing. To achieve high traffic-handling capacity, multilevel interrupt facilities are incorporated. Moreover, the instructions have been selected and the program organization established particularly with a view to speeding up the execution of repetitive network operations, such as scanning and comparison of the scan results and reducing the number of instruction words involved in less-frequent operations.

Basically the order structure comprises 63 instructions, 13 of which are memory reference instructions, whereas the remaining 50 define various logic operations, such as AND, OR, EXCLUSIVE OR, ADD, SUBTRACT, SHIFT, TRANSFER, et cetera. Simplicity is further achieved by using a single memory system in each processor for program instructions, translations, and variable call data. This memory comprises stacks of ferrite-core matrices driven according to the coincident-current technique. Memory capacity is extensible from a basic 8192 words of 16+1 bits each, to 65 536 words in modules of 8192 or 4096 words. For a 10 000-line terminal exchange, about half the maximum size will normally be sufficient.

High speed and compact construction have been achieved by the use of diode-transistor-micrologic integrated-circuit packs, 824 of which are used in either processor.

Logic speed is 5×10^6 steps per second. The basic instruction cycle is defined by the memory read–write cycle, which is 2 microseconds. Access to any memory word takes 750 nanoseconds. The instructions normally used take 1 to 3 basic cycles.

For large traffic switching centers a faster machine is available.

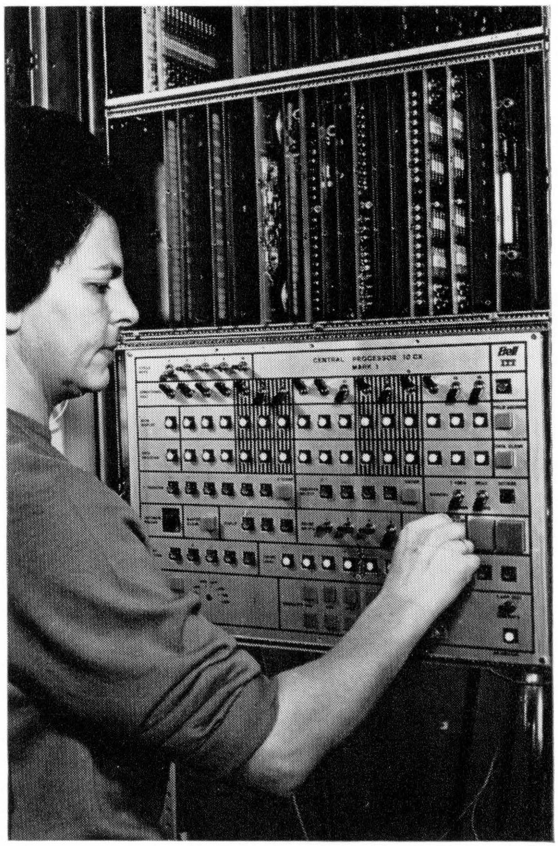

Figure 5—Control panel of the central processor.

Multilevel interrupt facilities are provided for real-time working, with priority levels set by program. One interrupt line is operated by a clock to initiate urgent repetitive operations, such as scanning of trunks and junctors, at intervals sufficiently frequent for line and trunk loop states to be updated in time during dialing and signal-pulsing procedures. Other interrupt lines are available for marker-drivers, to announce the end of a marking or relay-setting operation and to request new instructions, and for input/output devices such as teleprinter, reader, and punch.

4.2 Provisions for Reliable Operation

4.2.1 *Independent Processors*

The duplicate processor system is organized on a "load-sharing" basis; this implies that though both processors are capable of treating all calls completely independently, each will take an equal share of the traffic load.

Line and trunk scanning for new calls is carried out by each processor in turn, while the other processor is processing the calls it has detected previously. Whenever one processor detects a new call, it sends a message to the other processor, containing the identity of the calling line or trunk. Then, relating to the same line or trunk, similar messages are sent on each major event, such as dial tone connection, through-connection, answer, and release. Therefore at any time either processor will be aware of the state of progress of the calls handled by the other processor, including the identities of lines, trunks, and junctors associated with these calls. It can refrain from interfering with these calls or, in exceptional cases, can take charge of these calls if necessary. Because of this strategy, either processor can work truly independently of the other, so that true hardware and software duplication is achieved.

In the exchange system, each processor is capable of handling the maximum rated traffic; between them, when both are active, they can cope with overload of 60 to 80 percent. Alternatively, on a statistical service quality basis, in view of the high reliability of these very compact processors, it would seem entirely feasible to accept a load 40 or 50 percent higher as the normal busy-hour condition. In this case a certain degradation of service would occur in the rare event of a processor being out of service during peak traffic conditions, which might happen not more than once a year on the average.

In addition to duplication, the following reliability features have been incorporated.

(A) A power-failure protection feature.

(B) A memory parity system, whereby each word is parity checked on readout from memory.

(C) The use of low-priority on-line routine test programs, which are carried out whenever time is left.

(D) The use of the most reliable components and techniques available.

However, the primary basis for reliable around-the-clock operation resides in the outstanding simplicity and compactness of the *10-CX* common-control system as a whole, made possible by the specific features of the *10-CX* switching network and the way it is controlled. Evaluation of system fault incidence, made on the basis of very conservative data on component failure rates, has shown that systematic malfunction in a system comprising 1 processor, its peripheral bus system, and the associated peripheral registers, is so rare that ample time will be available even in unattended exchanges for fault location and repair before the probability of double fault becomes significant.

4.3 Software

The software package provided with the *10-CX* processor system comprises on-line operational programs and off-line diagnostic programs.

4.3.1 *Operational Programs*

The operational programs consist of call processing, on-line checkout, and man/machine communication programs. The call processing program is a composite system that includes the following.

(A) Interrupt programs, for collection of network data, screening said data by comparison with previous results, and preparation of call treatment.

(B) Functional programs, each related to a specific phase in the treatment of each call.

Communication between these programs is provided in the form of buffers and tables in memory.

For coordination of functional programs a system of program linkage tables is stored in memory, and consequently is subject to modification in the case of new or changed exchange specifications. This implies the possibility of inserting new functional programs during operation of the exchange, especially for changing conditions of interworking with distant exchanges or new categories of subscriber lines requiring special treatment, introduction of line concentrators, centralized private-automatic-branch-exchange facilities, et cetera.

On-line checkout programs include the following.

(A) Base-level routine test programs, carried out if there is no other work, to check that all goes well.

(B) High-priority takeover programs to ensure, in the event of apparent breakdown of one processor, that the other processor takes charge of the abandoned calls.

(C) Fault printout programs to provide a written indication of the fault so detected.

(D) Mutual check programs to constantly monitor the correct functioning of both processors.

(E) A program for updating the call data in a processor, to be used when the processor is to be restarted after having been out of service.

Call charging programs can be adapted for recording charge data on paper tape, magnetic tape, drums, or for transmission of such data through teleprinter or other data channels to an accounting center.

Some traffic and service observation programs are permanently on-line. Others (as well as preferred routine test programs) can be chosen from a large variety provided on paper tape and introduced to be carried out on-line on a temporary basis at the convenience of the telephone administration. Facilities are provided for easy introduction of such programs.

On-line man/machine communication programs permit the introduction at all times of new or changed line and route translations, subscriber line classes, et cetera, as well as printout of the new data for checking.

Off-line diagnostic and checkout programs are provided on paper tape. They constitute the tools for fault location and checkout in a processor, a network package, reader, punch, or teleprinter after repair.

4.4 Automatic Reload

As a special feature, particularly for unattended exchanges, the *10-CX* processor includes an automatic regeneration system including a high-speed tape reader, whereby a faulty processor is automatically disconnected and loaded with a series of test programs. If no fault is detected, it is reloaded with the operational programs, updated, and reconnected.

In this way, if the fault was of a transient nature, the system will restore itself without human intervention. The occurrence will be indicated by appropriate printout.

In case of repeated dropout or failure to pass the automatic tests, an alarm is given and also transmitted, together with a short indication of the fault encountered, to some attended monitoring station.

5. Man-Machine Communication

In the *10-CX* system there are no exposed moving parts. Mechanical crosspoint and relay contacts are all protected in sealed glass enclosures. The operation of the system cannot be seen and is almost inaudible.

Maintenance in the customary sense, as practiced in conventional switching centers, is totally absent. Manual measurements, using multimeters or portable oscilloscopes, should be discouraged to exclude man-made interference.

For these reasons, adequate man-machine communication means are provided as an integral part of the *10-CX* system, to be used for supervision and control, quality observation, tests, alarm in case of malfunction, as well as for extraction or introduction of data stored or to be stored in the memories.

Adequate use of this equipment will permit running the exchange, including updating of route and line information or similar data. In case of extensions or new facilities to be installed, it is possible to effectuate the necessary program adaptations from a centralized supervision desk without touching any contact, circuit component, or lead in the switching equipment.

In case of faulty operation, the same equipment will be instrumental in locating the faulty part and checking after the fault is corrected.

5.1 Processor Use Off-Line

After a processor has been disconnected from the system, it normally employs the following units.

(A) A lamp and key panel for manual introduction of instructions and data and for display of the contents of some of the registers.

(B) A teleprinter for introduction and/or printout of program instructions and data words.

(C) A paper-tape reader for loading programs into the memory.

(D) A paper-tape punch for production of program or data tapes.

5.2 Processor Use On-Line

For on-line working, a common supervision console is provided and contains the following devices.

(A) A supervision panel.

(B) Automatic test and control equipment.

(C) A high-speed paper-tape reader (300 characters per second).

(D) A teleprinter with low-speed reader and punch.

The supervision panel comprises switches and push buttons for manual control of the system, lamps for visual control of its operation mode, alarm lamps, and common equipment for simultaneous communication with both processors.

The automatic test and control equipment includes the automatic reload and restart system discussed in Section 4.4, an automatic test call sender and receiver for constant supervision of the quality of service and alarm in case of malfunctions, and a simplified test call sender for checking the operational state of the processors.

The high-speed tape reader is intended mainly for the automatic loading of test programs and reloading of the operational program in the event of a fault during an unattended period.

The teleprinter is used during operation of the exchange to introduce new route and line data, and also to print out for checking or in case of faulty operation.

6. Reliability

Most of the reliability features of the *10-CX* system have been treated in preceding sections. As reliability has been built in at all levels, this aspect cannot easily be considered separately. This section will therefore be limited to a short summary of the measures and safeguards incorporated to ensure uninterrupted fault-free service over very long periods of time.

6.1 Component Parts

(A) Choice of high-grade long-life components, proved in extensive life tests.

(B) Sealed reed contacts.

(C) Silicon semiconductors.

(D) Planar epitaxial transistors.

(E) Use of integrated circuits in the processors.

(F) High-stability resistors and capacitors.

(G) High-quality connector plugs in accordance with the standard equipment practice for ITT Europe [3].

(H) Wrapped connections for all subrack and rack wiring.

(I) Flow soldering for all other joints.

(J) Reliable double-sided printed-wiring boards with connections through plated holes.

6.2 Circuit Design

(A) Careful design to avoid spreading of faults.

(B) Worst-case design.

(C) Derating of components.

6.3 System Design

(A) Duplication of all circuits serving more than 64 subscribers.

(B) Complete independence of duplicate parts.

(C) Reduced number of components.

(D) Compact construction.

(E) Extensive automatic supervision and fault detection.

(F) Fault location aids.

6.4 Automatic Fault Detection

(A) Code checking and other on-line test circuits in the peripheral circuits.

(B) Memory parity check.

(C) On-line routine test programs.

(D) Mutual probe and check programs.

(E) Artificial call senders and receivers.

(F) Fault printout.

(G) Automatic off-line test, reload, and restart.

Manual maintenance aids include diagnostic programs, updating programs, and key and lamp panels.

7. Facilities

The *10-CX* system provides all administration and subscriber facilities that are customary in present-day telephone practice, including calling-subscriber identification. In addition, as a standard facility, it provides the capability to use push-button sets on any or all subscriber lines, to trace malicious callers, to provide absentee service, et cetera.

A key to the optional introduction of all kinds of new facilities and services is the provision of unlimited line classes. As a standard, 33 different line classes are available, with the possibility of accumulating up to 6 different classes per subscriber, and this can easily be extended.

Such new facilities can easily be implemented by appropriate additions to the operational program. Some examples which can be introduced are abbreviated dialing, automatic transfer, temporary bar on incoming calls, subscriber-controlled restrictions, and centralized private-automatic-branch-exchange facilities.

Various facilities for exploitation and maintenance have been discussed in Sections 5 and 6.

8. Equipment

Reed crosspoints, relays, and electronic components are uniformly mounted on plug-in cards [3]. A standard building block of 4 reeds is shown in Figure 6. In the switching network, 96 three-contact or 64 five-contact crosspoints are assembled on book-shaped plug-in units, which may be seen in Figure 7. Internal connections are partly wire-wrapped, partly flow-soldered.

In the peripheral circuits, logic assemblies are composed of Minibell * logic blocks mounted on standard printed-wiring cards. A special honeycomb-like structure is used for mounting logic gate diodes in various combinations. Reed relays are mounted with associated electronic components on printed-wiring cards.

In the processors all logic circuits are implemented with dual-in-line integrated-circuit packages. Special photographic techniques have been developed for mounting these packages on printed-wiring cards and connecting them by flow-soldering.

Coordinate-type point-to-point wiring is used extensively, whereas conventional bound cables are used in the switch bays in some cases.

For all plug-in equipment units, automatic testers will be available.

9. Conclusion

The *10-CX* system is the first stored-program-controlled reed crosspoint switching system offered in Europe, and it has been presented in this paper in a fully developed state, ready for large-scale production and for application in existing telephone networks. Its most striking features are its competitive position throughout the range of office sizes, its modular construction providing easy on-site expansion, its adaptability to various situations and requirements, substantially reduced space requirements (about half those of existing systems), and all the flexibility inherent to the use of stored-program control. On-site maintenance is reduced to supervision, fault location, and replacement of a plug-in unit. The system can safely work without continuous attendance.

10. References

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* Standard of Bell Telephone Manufacturing Company.

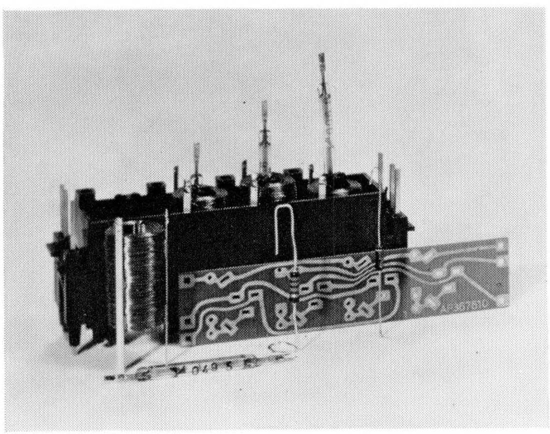

Figure 6—Standard building block containing 4 reed crosspoints.

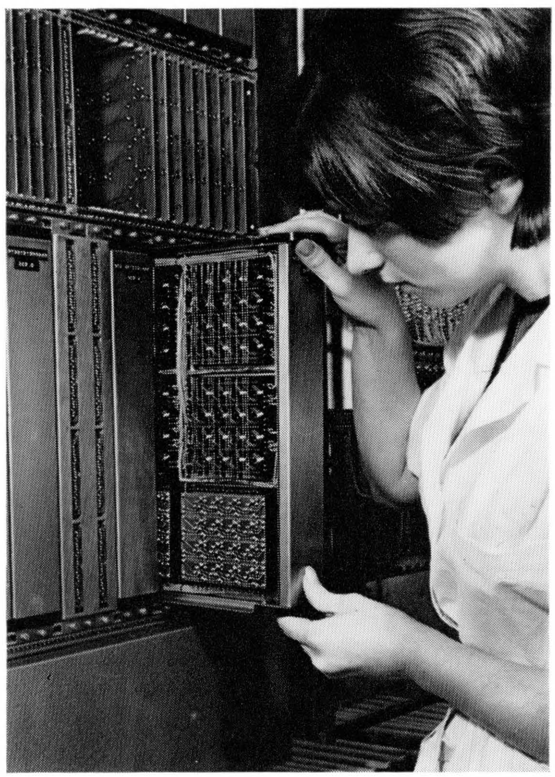

Figure 7—Plug-in line switch unit containing 6 sets of 4-by-4 crosspoint matrices.

2. Belgian patent 570 716.

3. F. Beerbaum, J. Evans, and F. Leyssens, "Standard Equipment Practice for ITT Europe," *Electrical Communication,* volume 39, number 2, pages 199–211; 1964.

Hans H. Adelaar was born in Amsterdam, The Netherlands, on 10 February 1916. He received his degree in electrical engineering from the Technische Hogeschool in Delft, The Netherlands.

Mr. Adelaar became a patent examiner with the Government Patent Office at The Hague for several years, then joined Bell Telephone Manufacturing Company in 1946 to work on electronic applications in telephone switching systems.

After having contributed to the design of the first semielectronic exchange of Ski near Oslo, he was appointed head of the electronic switching department in 1957.

Along with his collaborators he was honored by the Institution of Electrical Engineers for his prominent contributions to the Conference on Electronic Telephone Exchanges in November 1960.

Mr. Adelaar is a member of the Royal Netherlands Institute of Engineers.

Jean L. L. Masure was born in Antwerp, Belgium, in 1927. He obtained the degree of civil engineer in electricity at the Louvain University in 1950.

He joined Bell Telephone Manufacturing Company in 1953 as a development engineer in the electronic switching department, where he worked until 1964, first as circuit engineer and later as engineer responsible for system design. Among other assignments he contributed to the development of the *8A* semielectronic system and of the time-division-multiplex fully electronic system.

He is presently Chief Engineer of the switching division for sales in Belgium and was appointed project manager of the *10-CX* system in May 1965.

History of Inertial Navigators and Some Thoughts on Research Management

P. C. SANDRETTO

International Telephone and Telegraph Corporation; New York, New York

Our first recording of the law of inertia appears in a paper by Galileo (1564–1642) called "Two New Sciences" where he wrote:

"... any velocity once imparted to a moving body will be rigidly maintained as long as the external causes of acceleration or retardation are removed, a condition which is found only on horizontal planes; for in the case of planes which slope downward there is already present a cause of acceleration; while on planes sloping upward, there is retardation; from this it follows that motion along a horizontal plane is perpetual; for, if the velocity be uniform, it cannot be diminished or slackened, much less destroyed."

However, in 1687 when Sir Isaac Newton published his "Philosophiae Naturalis Principia Mathematica," this law was formalized and stated that the force acting on an object is the product of its mass and acceleration. The deflection of a spring is proportional to the force applied to it; therefore, if we attach a spring to a known mass and note the deflection at the time we attempt to move the mass, the acceleration applied to it may be measured. Expressed algebraically, the law is

$$F = Ma$$

where F is the applied force, M is the mass, and a is the acceleration.

The speed V of a vehicle, however, is the ratio of the change of distance s with time t. That is,

$$V = \mathrm{d}s/\mathrm{d}t$$

or

$$\mathrm{d}V/\mathrm{d}t = \mathrm{d}s^2/\mathrm{d}t^2.$$

But, acceleration is the rate of change of speed with time

$$a = \mathrm{d}V/\mathrm{d}t$$

therefore

$$a = \mathrm{d}s^2/\mathrm{d}t^2.$$

Putting these equations together, we have

$$s = \int\int a dt^2$$

that is, by merely measuring the deflection of a spring attached to a known movable mass which is located within the vehicle and performing a double integration, we will know how far we have traveled. ... What a startling and almost unbelievable solution to the navigation problem!

Early in 1931, a young engineer in the Paris laboratories of the International Telephone and Telegraph Corporation looked at these equations and wrote

> "Le principe fondamental de l'invention est d'assigner a trois masses, trois axes sur lesquels les accelerations peuvent être mises en direction dans l'espace par un des moyens. L'un peut être maintenu constamment vertical, les deux autres horizontaux, par exemple NS pour l'un, EO pour l'autre.
>
> "Les composantes de l'acceleration générale sur les trois axes, intégress deux fois, donnent les composantes de l'espace sur les axes, qui déterminent par leur résultante l'espace parcouru."

Translated into English, this is:

"The fundamental principle of this invention is to have three masses, each assigned to an axis along which the forces of acceleration act. The direction of the three axes can be held fixed in space by any known means. One axis can be maintained vertical and the other two horizontal; for example, north-south for one axis and east-west for the other axis.

"When doubly integrated, the components of the acceleration measured along the three axes provide three vectors, the sum of which determines the path in space traversed by the vehicle."

So there it was, in simple terms, the principle of what is probably the most unique navigation system ever produced by man!

While the acceleration can, in theory, be measured by noting the deflection of a spring, such a device would be far too crude for a practical system. The accelerometers must measure the slightest movement since even the smallest quantity multiplied by a time-squared term will result in a very appreciable error. In addition, the measurement must be linear over a range of 100 000 to 1. Our inventor summarized the problem as follows.

"Achieving a practical solution boils down to the problem of developing practical devices *A*, *B*, and *C*, which will measure the acceleration and which will adequately perform the first and second integrations."

He then proceeded to describe a number of devices for performing these tasks, but the only remaining sketches are shown in Figure 1.

"The device *A* which evidences the acceleration and the device *B* which integrates this acceleration can often be incorporated in a single device.

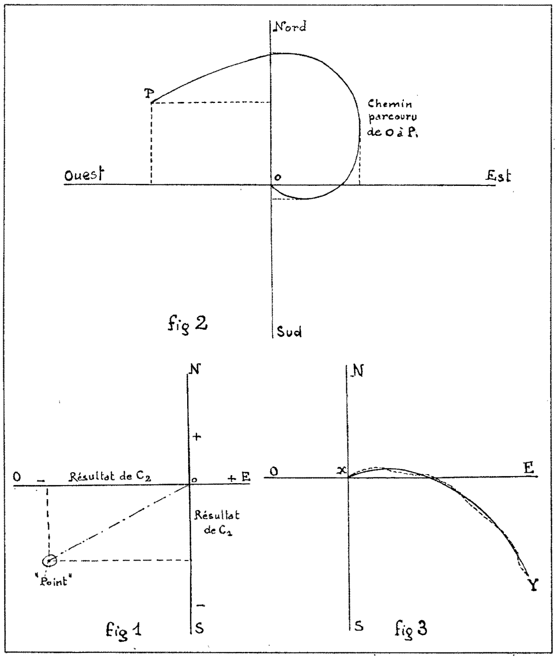

Figure 1—Only remaining sketches from the original disclosure.

"Let us consider sustaining tuning forks D_1 and D_2 exhibiting identical frequencies.

"Let us establish a mechanical link between the mass M_1 (mounted on an elastic blade L_1 in such a way that it can move only along the desired axis) and one of the tuning forks in such a manner that a displacement of the mass M_1 generates a variation of the frequency of the above-mentioned tuning fork in a way determined by the direction of the displacement. The phase difference or the frequency difference in cycles and fractions of cycles between the perturbed tuning fork and the unperturbed tuning fork, will indicate after a time *t*, the speed at this time *t*. One can evidence this phase difference or the number of periods and fractions of periods as follows:

"The tuning fork controls the rotation of a synchronous motor. On the rotor of this motor and at the end of its axle is fastened the stator of a second synchronous motor that is energized by the perturbed tuning fork, but which rotates in the opposite direction.

"The axle *K* of the second motor remains therefore motionless as long as the frequencies of the tuning forks are identical. It rotates in one or in the other direction when the second tuning fork is perturbed.

"The total angle (or the number of revolutions or fractions of revolutions) through which this axle rotates depends on the characteristics of the installation and provides a measure of speed that is proportional to a constant.

"The device *C*, which will integrate as a function of time the rotation of the axle *K*, can be an electric counter measuring a quantity of electricity, and therefore integrating a current intensity as determined by the rotation of the axle *K* linked with a variable resistor or a potentiometer that controls currents.

"The quantity of electricity measured will provide a measure of the distance that will have been traveled through.

"A complete embodiment of the device is obtained when similar systems are used with respect to mass M_2 and, if necessary, with respect to mass M_3. It is clear that the fixed-frequency tuning fork and its synchronous motor can be common to any two or to the three devices A, B, C.

"The possibilities offered by modern physics will permit other realization of the integrating devices, without changing the general principles underlying this invention.

"Very small movements up to very large movements of the masses fixed to elastic blades, or to springs of any kind, can be evidenced by one of the following means:

"1. Variation of the electric capacitance between mobile plates attached to the masses, and fixed blades. The variation of the capacitance can change the frequency of an oscillator.

"2. Variations of inductances, or variation of the mutual coupling between inductances, some of which are fixed and the position of others depending on the masses.

"3. Variations of magnetic fluxes and variations of magnetic permeability.

"4. Displacement of a magnetic flux, generating a variation of the current in a magnetron.

"5. Variations of the intensity of a current by means of the variation of the resistance between two electrodes in an electrolyte, one of these electrodes being fixed and the position of the other depending on the mass.

"6. Variation of the electronic current in an electron tube, one of whose electrodes is controlled mechanically or electrically by the movements of the masses.

"7. Variations of flow of a liquid or of a gas.

"8. Variations of the frequency of oscillation of a pendulum or of the oscillating balance wheel of a chronometer.

"9. Action of the masses on gyroscopes in view of obtaining integrating precessions.

"10. Action of masses on luminous fluxes controlled by mirrors or shutters. Transformation of the luminous flux into variable current by means of a photoelectric cell.

"11. Methods according to which the displacement of the mass is possible only between certain limits at which a system similar to a regulator is actuated and pulls the mass back to its original position. The integration of the effect of pulling the mass back to its original position, or which maintains it there, furnishes a measure of the speed proportional to a coefficient. This result can be obtained by one of the following methods.

"The mass being in equilibrium and mechanically linked to a magnetic armature, which is mobile between two electromagnets, a displacement of the mass brings about, by means of a contact or by any other means, the passage of a current into the electromagnet whose action is necessary to pull the mass back in its position of equilibrium.

"Normally, the mass will vibrate at a certain frequency, but the algebraic sum of the currents circulating in the two electromagnets will be zero.

"If the mass is pulled in a direction, a direct current will appear, proportioned to the energy necessary to maintain the mass in its position of equilibrium. The integration of this current by means of a counter of quantities of electricity will furnish a value proportional to the velocity. These systems, which we will call reaction-systems, can be realized electromechanically, as explained above, or electrostatically by means of capacitive attraction, or electromechanically by means of electric motors, or electrodynamically by means of coupled inductances. The general principle underlying these systems is that the effect of a displacement of the mass is to pull it back to its original position by means of an effect conditioned by the displacement. The integration of the effect furnishes a value proportional to the velocity. This effect can be of electrical, mechanical, or chemical nature. The principle presupposes a separate source furnishing a kind of energy necessary for the production of this effect.

"12. Chemical Methods: The quantity of electricity furnishing a value proportional to the velocity can be obtained by means of a chemical effect, such as the deposition of a body contained in the electrolyte which is traversed by said current (weight of the body) or by the electrical charge of a chemical system involving the storage of electricity.

"13. Calorific Methods: The integration of a current can be achieved by measuring the number of calories dissipated by this current in a resistor placed inside a perfectly heat-insulated box.

"14. Mechanical Methods: The integration of mechanical displacement along an axis can be obtained by means of mechanical integrators and ball-planimeters.

"15. In view of eliminating errors of all kind due to temperature differences, the complete equipments, or part of them, can be heat-insulated or maintained at a constant temperature by means of a thermostat, and use can be made of metals such as invar, elinvar, and constantan."

Of the methods given above, those described under 9 and 11 are used in all of today's inertial navigation systems.

One of the most serious problems faced in the practical design of an inertial navigator is that of overcoming the effect due to gravity. As is well known, gravity is (at altitudes near the earth) an acceleration equal to 32.2 feet per second every second. Thus, a component of gravity of only 0.1 degree would produce an acceleration value of 0.56 foot per second per second. In 1 hour, the distance error produced would be $(3600)^2 \times 0.56$ or 138 miles (220 kilometers). On first consideration it would appear that this problem could be solved completely by mounting the accelerometers on a platform mounted on pivots and controlled by a pendulum that would be expected to point vertically; that is, in the direction of maximum gravitational force. A pendulum, however, is itself a mass mounted at the lower extremity of an arm; thus it is acted on by the force of acceleration and, in fact, a later inventor suggested the use of a pendulum as an accelerometer. The second solution for maintaining horizontal orientation that suggests itself is the use of a gyroscope. A gyroscope used for this purpose, however, behaves in what can be considered as the opposite extreme of a pendulum. It has no regard for gravity as it holds its orientation with regard to inertial space alone.

The requirements for spatial orientation are not satisfied by holding only the vertical fixed for, as our inventor pointed out, it is necessary to determine the components of the distance traveled in at least two directions to determine the present position. That is, starting at some known point *P*, it is necessary to measure the component of the distance traveled along a direction running north and south of *P* and another measurement along the direction east and west of *P*, so that the two vectors can be added to give the distance and direction from starting position *P* to the present position *X*. In simpler terms, it is not sufficient to determine the distance traveled, but the direction traveled must also be known if one is to know present position.

How accurately is it necessary to hold (or know) the direction in the horizontal plane? As is well known, a gyroscope precesses with time. A stability of 1 degree per hour exceeded by far the performance of aircraft gyroscopes of the 1930 era. Such a gyroscope mounted on an aircraft traveling at 600 miles per hour would cause an error of more than 10 miles in the horizontal position after 1 hour of flight.

To hold a fixed north-south orientation, Hermann Anschutz-Kaempfein in 1908 and Elmer Sperry in 1911 invented the gyroscope compass and, for the first time, transformed the gyroscope from a toy to an instrument with a practical purpose.

Figure 2 shows two views of a gyrocompass located on the equator and so arranged that in position 1 it is oriented to point north. The gyro maintains this orientation as it moves north, so in position 2 it points to the sky and is therefore useless. As has been previously stated, the use of an additional gimbal that is attached to a pendulum would cause the axis of the gyroscope to always be at right angles to a line pointing to the center of the earth so long as there was no motion of the vehicle. This solution will be satisfactory near the equator if acceleration is negligible, as on a slow-moving ship, but near the poles there will be two forces acting on the gyrocompass. Gravity acting on the pendulum will try to keep the axis of rotation of the gyro perpendicular to a line drawn to the center of the earth at the same time that the gyroscopic force will attempt to keep the gyro in its initial orientation in space (neglecting the coriolis force, acceleration, and other secondary effects). The resultant of the two forces causes the compass to point away from true north. This phenomena became known as the "North Steaming Error."

In 1906 Anschutz, troubled by the above-described problem, contacted Professor Maximilian Schuler. Professor Schuler developed the theory that a pendulum with a natural period of 84 minutes would be free from the effect of acceleration. This principle became known as "Schuler Tuning" and was incorporated in marine gyrocompasses as well as most present-day inertial systems. The principle is illustrated crudely in Figure 3. If the pendulum were Schuler tuned, moving the pendulum from its vertical position would cause it to oscillate back and forth around the axis indicated at a period of 84 minutes. Actually a period of 84 minutes is very difficult to attain. In marine usage, pendulums with liquid passing through complicated systems of ports gave long, but not necessarily 84-minute, periods.

In inertial systems, the 84-minute period is achieved through an electromechanical system. The reading of an accelerometer is assumed to be due to gravity, so a force is applied to the platform to cause it to be "corrected." The result is an overcorrection that causes the platform to tilt in the opposite direction. Time constants are adjusted to produce long periods. The result of Schuler tuning is to change completely the error equation. With Schuler tuning, instead of the error increasing continuously

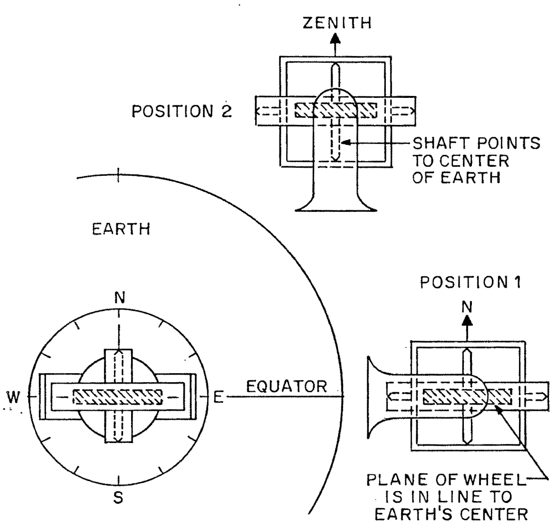

Figure 2—Gyrocompass pointing north when at the equator (position 1) will maintain its spatial orientation when moved to position 2 where it will point to the sky and be useless for azimuth indication.

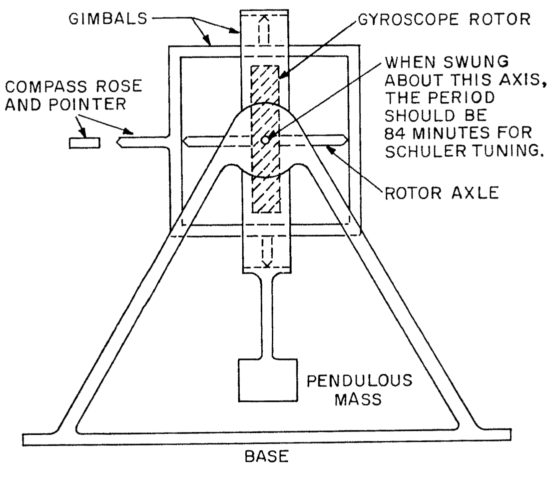

Figure 3—Schuler tuning employs a pendulum having a period of 84 minutes that when moved from its vertical position causes an oscillation about the indicated axis. The error does not continue to increase with time but oscillates back and forth at the Schuler period.

with time, it oscillates back and forth at the Schuler period. The result is that the maximum error is limited.

Schuler tuning achieves a very valuable result but does not obviate the necessity for gyros with very-low precession, but more will be said about this requirement later. Let us now look back at our inventor's 1931 description to see if he shows an awareness of the problems of spatial orientation described above, and we find several references to the solution of the problem. In one paragraph he states:

"Let us use a gyroscope or magnetic compass or a repeater of a gyroscope, gyrocompass, or any device, the characteristic of which is to maintain spatial orientation in the horizontal plane in spite of the rotations and translations of the vehicle on which it is mounted."

In another paragraph he states:

"If on the other hand one has taken the precaution of placing the masses M_1 and M_2 on a mechanism that insures an appropriate verticality, an airplane can (for instance) climb or descend without altering the indications which then depend solely on the horizontal components of the accelerations."

The above quotations and other material in the description leave no doubt of the inventor's awareness of the necessity for maintaining verticality and spatial orientation. On the other hand, the description also raises the question of why, having treated the problems of measuring acceleration and performing the integration function in such detail, the inventor did not give more-detailed descriptions of how he proposed to solve these other problems.

Henri Busignies, General Technical Director of the International Telephone and Telegraph Corporation, the inventor, was a new and young employee with Laboratoire Central de Télécommunications in 1931 when he conceived the inertial navigator. The services which had to evaluate the invention expressed the view that this latter involved the manufacture of a type of equipment in which the company was not engaged. Further, in that depressed period, patent costs had to be saved and so it was decided not to have the idea patented. Under such circumstances it is not surprising that the inventor did not expand his views further. A further study of the problems involved in perfecting the inertial navigator and the construction of models would, no doubt, have led him to consider the "North Steaming Error," Schuler tuning, and the floated gyro, which had been produced by American Bosch Arma as early as 1920 and by Anschutz earlier, all leading to a solution for obtaining the required precision, as it is well known that further efforts always result in rich rewards when the fundamental idea is sound.

On January 10, 1934, three years after Busignies wrote his description, Johann Maria Boykow, a German actor and one-time naval officer, filed for a patent on his "Instrument for Indicating Navigation Factors." This patent, which did not issue until February of 1938, consists of 17 finely printed pages and 31 drawings (one of which is shown in Figure 4) and is probably the governing patent in this field. It is, therefore, interesting to compare Boykow's rather remarkable patent with Busignies' earlier work.

As has been stated previously, Busignies felt that the most-important problem to be solved was that of measuring the acceleration forces accurately and performing the double integrations. This appreciation of the problem is very accurate for it is necessary to measure forces *linearly* over a very large range of values and integrate each value with extreme precision. Busignies suggested 16 solutions to the problem and, as has been pointed out above, at least two of these have been used in practical systems.

Boykow suggested a single solution. He proposed the use of an electric motor with a case that was free to rotate about the axes located at either end of the case. At one point on the case, he attached a proof mass. As the acceleration forces acted on the mass, the case rotated about its axes. To the case was also attached the arm of a potentiometer. Once the arm moved from its zero current position, power was supplied to the rotor of the motor. The reaction to the rotor torque caused the case of the motor to move in a direction opposite to that to which the acceleration had forced it and the power was removed. Thus, the acceleration force had caused some motor rotations and reactions, but the rotor had to continue to rotate if it were to continue integration over the time of vehicle motion. For this purpose Boykow attached a large flywheel to the rotor, but even with this device, friction would cause the motor to stop under conditions of zero acceleration (or deceleration) even though the vehicle continued in motion.

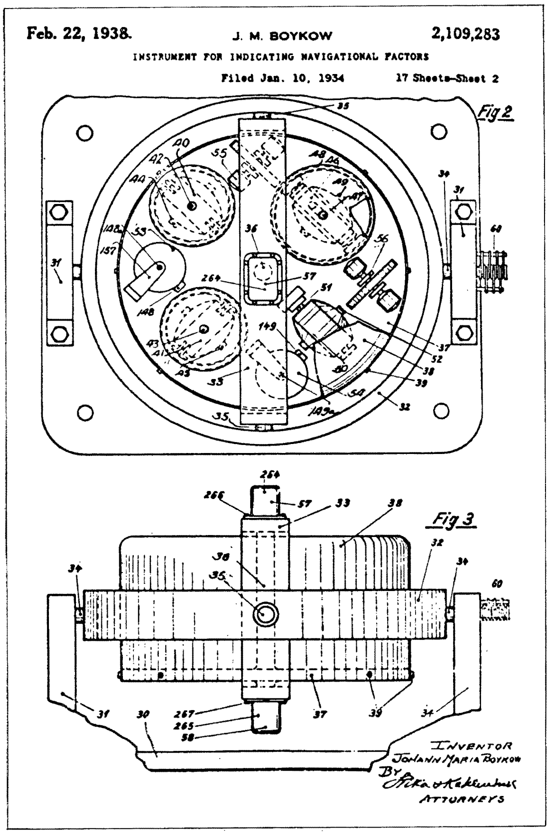

Figure 4—Drawing from Boykow patent.

Boykow maintained that as the rotor slowed, there would be a reaction that would cause the case to move the potentiometer contact from the neutral center and supply a pulse of power that would keep it at its initial speed. To minimize friction, Boykow vibrated all of the shafts and bearings. He provided a feedback system by arranging the body of the potentiometer so that it was moved by what he called a "Moment Generator." This mechanism was essentially an electromagnet capable of producing rotary motion in two directions. This magnet was energized via the same potentiometer that energized the accelerometer/integrator motor. Thus, movement of the potentiometer arm (caused by the acceleration) underwent an initial reduction, thereby decreasing the current applied. However, when the potentiometer arm was attempting to return to its zero position, a spring overcame the action of the moment generator and allowed the potentiometer to supply current later than otherwise would have been the case. An eddy-current generator supplied damping to the moment generator. The purpose of the moment-generator mechanism was to provide smoothing action of the rotor and frame motions to prevent overshooting and undershooting which might produce an oscillatory condition.

The motor rotations were counted with a counter calibrated in miles. As ingenious as the Boykow integrator was, it was probably (in principle at least) the weakest part of his invention. On the other hand, his stable platform was outstanding in its appreciation of the spatial orientation problem. His platform employed two gyros each having a single degree of freedom to control the platform so that it would be level. A third gyro was used to orient the platform in azimuth. There was a gyro with three degrees of freedom which controlled the other gyros via "torquers." All gyros were of the floated type and had their bearings vibrated to minimize friction. Boykow also provided compensation for the apparent rotation of the earth. His description follows.

"The compass gyro is fitted with a device for compensating the apparent rotation of the earth. This apparent rotation results from the fact that the craft equipped with the apparatus according to the present invention moves over the surface of the earth which latter thus appears to be rotating backwards below the craft. The apparent rotation of the earth may be regarded as having two components, one with north-south direction and one with east-west direction. The east-west component of the apparent rotation of the earth does not cause a deviation of the compass from the north-south direction since this component is either added to, or subtracted from, the true rotation of the earth depending on the course direction. The north-south component of the apparent rotation of the earth, however, causes such a moment on the gyrocompass that the pattern tends, under the influence of this moment, to position itself transverse to the north-south direction (parallel to the axis of the north-south component of the apparent rotation of the earth). Therefore, it is necessary to compensate at the gyrocompass the moment originating from the north-south component of the apparent rotation of the earth in order to cause the gyrocompass to keep its north-south direction."

Busignies and Boykow suggested the use of quite similar position plotters.

In spite of inquiries, this writer has been unable to determine what happened to Boykow and his invention. Apparently he and his work were not well known in electronic navigational circles. Perhaps this condition attained because of secrecy imposed by his government. His ideas apparently underwent development because the drawings which accompanied the patent were accomplished in a way which indicated manufacturing details. It is known that the German *V2* rocket employed inertial guidance, which may have stemmed from his work.

As mentioned above, Busignies terminated his work. This incidence brings up the important problem of how management can determine that a highly imaginative new idea which is far in advance of the current state of the art should be recognized, accepted, and sponsored so that it may be brought to commercial fruition. Certainly, in 1931, no amount of market research would have been able to forecast that Busignies' ideas could open up a \$500 000 000 annual market 20 to 25 years later. The market did not exist in 1931 and there was no standard by which it could be compared. The decision was thus made that the product did not fit into the company's existing markets and manufacturing facilities and the Patent Counsel decided not to file. In retrospect, the decisions could be criticized (particularly the lack of patent protection and of a preliminary study) because, in fact, the company's major customers were governments which were the same entities that later purchased millions of dollars of inertial navigators. Also the company did have facilities for manufacturing precision tools, which capabilities could have been adapted to the manufacture of inertial elements. The fact that the concept was so daring and so in advance of its time seemed to have escaped the management's consideration when it was balanced against the then-existing great depression.

Could a preliminary study have been encouraged based on the concept of science for science's sake? Would the French or some other government have been willing to sponsor the work? Whether the above or any other channel existed whereby the development might have been encouraged instead of stopped must forever remain a matter for conjecture. Of this only are we certain—that the decision prevented the corporation from having in its hands a means for certain entry into a market that was to beggar the then-existing entire company sales. To preserve a little of a memorable, though little-known, achievement and to stimulate thinking on the best ways to lead early major inventions to success is the purpose of this paper.

Peter C. Sandretto was born on 14 April 1907 in Pont Canavese, Italy. He received from Purdue University a B.Sc. degree in 1930 and the degree of electrical engineer in 1938. He studied business administration at Northwestern University and was graduated from the Command and Staff School of the United States Army.

From 1930 to 1932, he designed aircraft radio equipment at Bell Telephone Laboratories. He was superintendent of the communication laboratories of United Air Lines from 1932 to 1942. From 1942 to 1946, he served in the United States Air Force, advancing to the rank of brigadier general.

In 1946, he joined International Telephone and Telegraph Corporation and later became vice-president and technical director of Federal Telecommunication Laboratories. In 1960, he became deputy executive of the United States Defense Group of the corporation and in 1963 transferred to its United States North American Area Staff. He served as acting president of ITT Kellogg Telecommunications Division. He is presently director, engineering controls, and also serves as technical director of avionics on the staff of the General Technical Director.

General Sandretto is a Fellow of the Institute of Electrical and Electronics Engineers, a past vice-president of the Institute of Navigation, a Member of the Institution of Electrical Engineers (British), and a Member of The American Institute of Aeronautics and Astronautics. He has lectured extensively in many parts of the world and is the author of two books, the more recent being "Electronic Avigation Engineering."

Bildröhren and Ablenkmittel (Picture Tubes and Deflection Components)

Electrical and mechanical data on picture tubes and deflection components manufactured by Standard Elektrik Lorenz are presented for the industrial development engineer. Practical hints on the handling of picture tubes are included for those servicing equipment.

It covers not only tubes presently installed in new television receivers by the set manufacturers, but older types back to 1953 are included in abridged form.

A review of the technical functions of deflection systems including horizontal-line transformers and linearity controls is followed by electrical and mechanical data on designs intended for initial installation in television sets.

This manual is 21 by 15 centimeters (8.3 by 5.9 inches) and is available on request to Standard Elektrik Lorenz, 66 Platenstrasse, 8500 Nuernberg, Germany.

Pentaconta 32 Telephone Switching System for Rural Networks

E. EKBERGH

Standard Radio & Telefon AB; Barkarby, Sweden*

1. Introduction and System Philosophy

The Pentaconta† *32* system represents the latest generation of our rural crossbar systems and was laid out after a series of design symposia initiated in early 1964. The fundamental objectives of the system were as follows.

(A) Maximum flexibility for extension by use of standard plug-in shelves allowing extensions in steps of 32 lines up to about 3000 lines.

(B) Wiring simplification by maximum use of bare-wire multipling of the crossbar switch.

(C) Efficient use of the switching matrix on local and incoming calls by releasing that path over which a register is seized as soon as the digits have been dialed into the register.

(D) Control simplification by eliminating the group selector stages.

Additional objectives were simplicity of operation, short installation and testing time, minimum and quick maintenance, and long life.

Using existing Pentaconta components, the system design specification was approved in June 1964. The design was completed and manufacturing information issued in time to deliver the first exchange—a 600-line unit—in August 1965. It has an ultimate capacity of about 3000 lines with major building blocks of 768 lines and sub-blocks of 32 lines. Maximum both-way traffic per line is 0.14 erlang. Subscriber line loop may be up to 1500 ohms and its leakage resistance may be as small as 20 000 ohms. Dial speed may be either 10 or optionally 20 pulses per second, each with a tolerance of ± 20 percent. Dialing make/break ratio may vary between 40/60 and 60/40. The cabinets are 930 $\times$ 225 $\times$ 2400 millimeters (36.6 $\times$ 9 $\times$ 94.5 inches) in size and have a light tropical finish.

*The author is now with Standard Telephones and Cables Limited, London, England.

†Registered trademark of International Telephone and Telegraph Corporation.

2. System Capabilities

The Pentaconta *32* system handles local, incoming, outgoing, and transit calls. It marks different classes of service and different types of incoming lines. It uses free numbering, in which there is no dependence between equipment location and directory number (calling line identification is used with complete storage of the calling line identity).

The system also uses a centralized route analyzer and a number translator common to all registers.

3. Extra Features

Without any changes in the basic system, multifrequency code signaling, centralized call accounting, and conversation privacy on 2-party lines can be provided.

4. System Layout

The Pentaconta *32* system is based on the use of standard Pentaconta relays and small crossbar switches with 10 verticals, 7 horizontal bars, and a 10-wire multiple (that is, with 10 contacts per horizontal position). See Figure 1. The system is built up with plug-in units both for the relay sets and for the crossbar switches forming the speech paths.

The primary stage is built up in blocks of 32 terminals or outlets, of which 11 are 4-wire and 21 are 3-wire connections. The 4-wire connec-

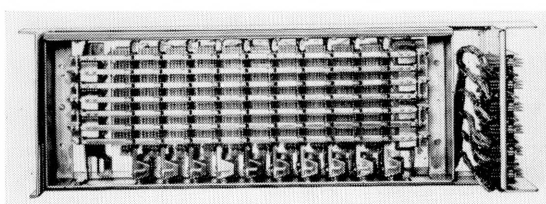

Figure 1—Crossbar switch used in Pentaconta *32* telephone switching system.

tions can be used for trunks and/or subscribers, whereas the 3-wire outlets are only for subscriber lines.

4.1 Single-Stage Version

Exchanges from 32 to 96 or 128 lines—depending on traffic—comprise only primary switches, with subscriber lines connected to the 32 multiple positions and trunks and local feed junctors connected directly to the verticals, as shown in Figure 2.

Register access is offered both from the trunks and from the local feed junctors. Both open and closed numbering can be used with blind occupation to the main exchange. In blind occupation, an originating call from an end exchange can seize a register in the parent exchange and get dial tone. This connection is maintained for an outgoing call but dropped for a local call, which will be taken over by a local register. If all lines to the parent exchange are busy, the local register will give dial tone and complete a local call or it will give a busy signal for an outgoing call.

Each trunk goes to 1 vertical in every 32-line unit, whereas each local feed junctor goes to 2 verticals in every individual unit. Thus the number of verticals is determined by the number of trunks and local feed junctors needed to meet the traffic requirements in each case. If more than 10 verticals are needed, a crossbar switch can be added per 32-line unit.

Figure 3 shows a small rural exchange arranged to interwork with a Pentaconta *32* parent exchange on a multifrequency signaling basis.

4.2 Two-Stage Version

The 2-stage version of the system is shown in Figures 4 and 5. It comprises a primary stage

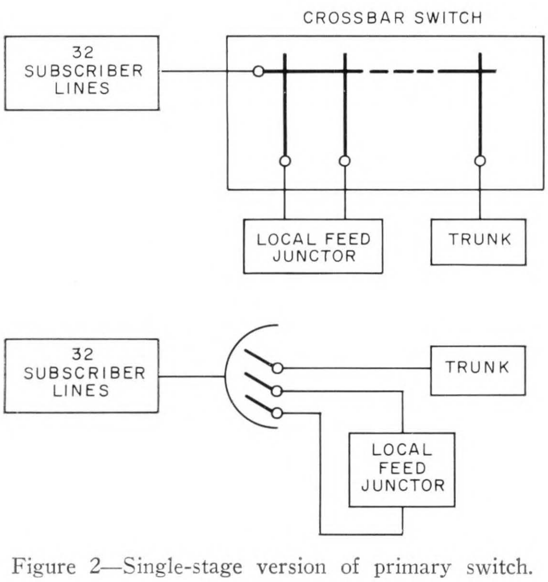

Figure 2—Single-stage version of primary switch.

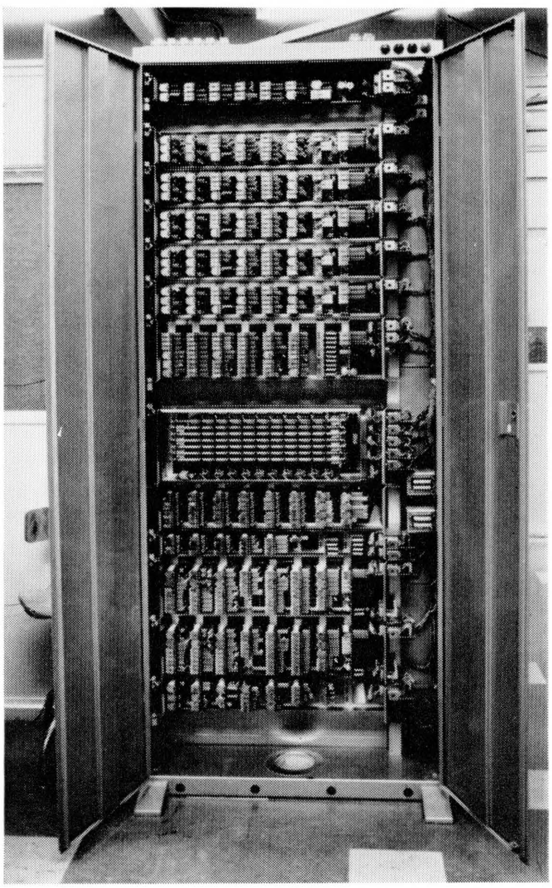

Figure 3—Small rural exchange with 32 subscriber lines connected.

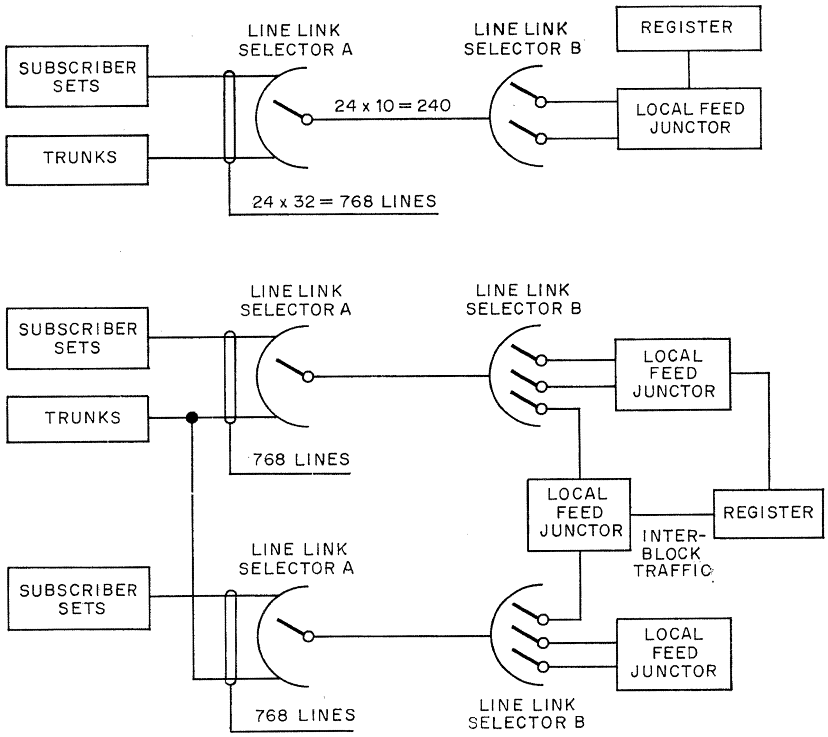

Figure 4—Two-stage version of primary switch. At top is the single-block exchange with a maximum of 768 terminals. Below it is a 2-block exchange.

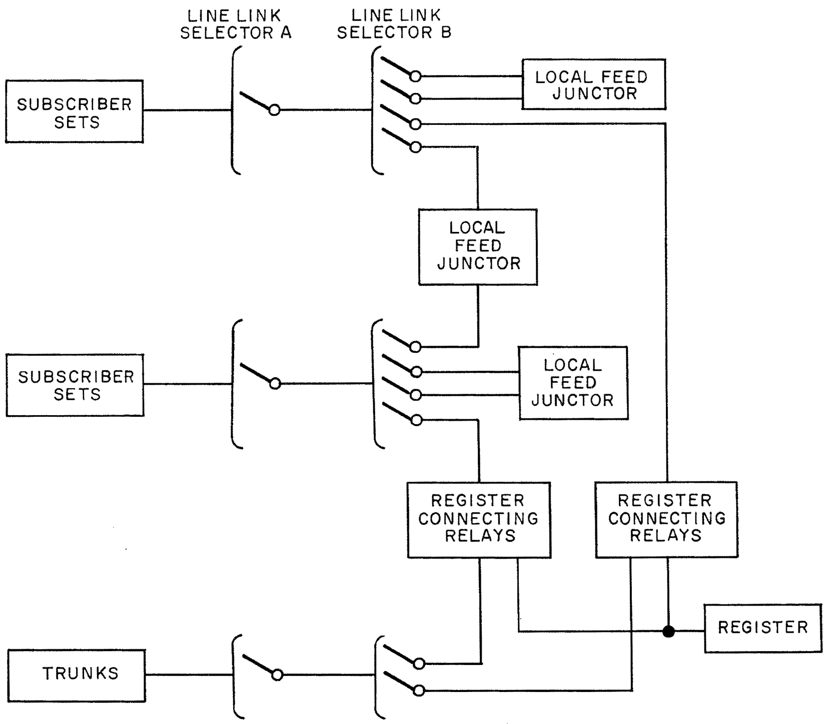

Figure 5—Multiblock exchange with separate trunk stage.

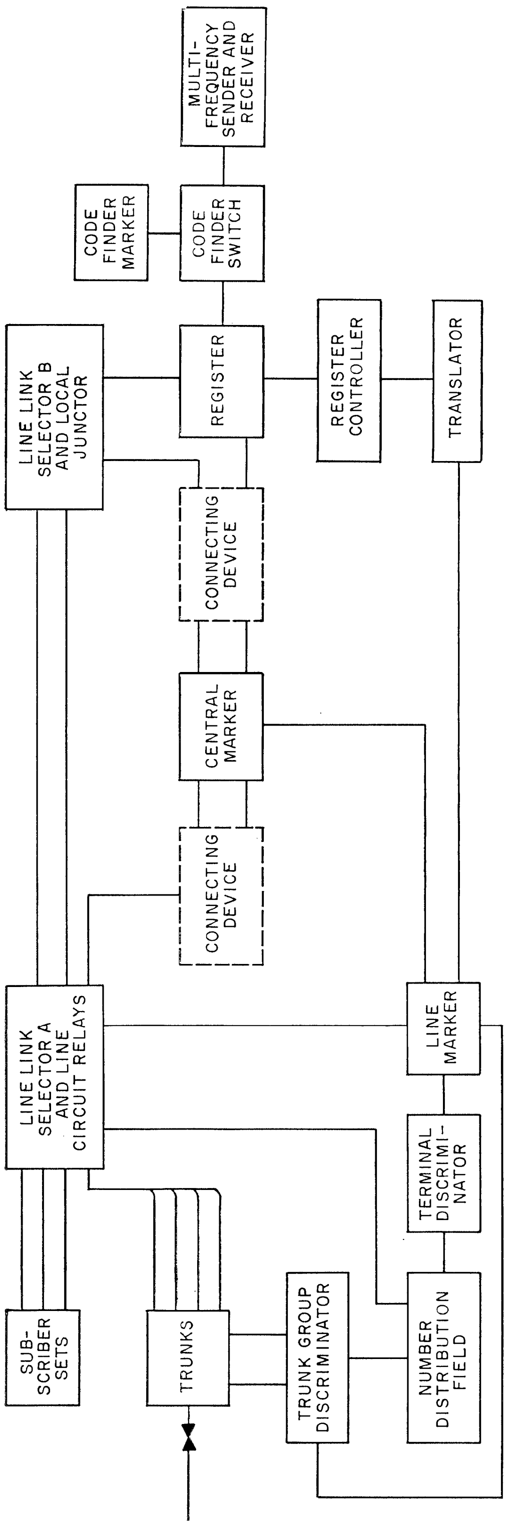

Figure 6—Block diagram of Pentaconta 32 system.

for connection of subscribers and trunks, and a secondary stage to which the local feed junctors are connected. The primary stage is arranged for connection in units of 32 subscribers and/or trunks located in 3 levels of the multiple. The secondary-stage verticals are arranged for 2-level selection with changeover bar, and can consequently connect $6 \times 4 = 24$ primary verticals which may be located in 24 different primary switches with full access to 32 outlets (subscribers or trunks). Thus the maximum capacity of one major building block is $24 \times 32 = 768$ lines connected to the line link selector *A* multiple, the lines being either subscribers or trunks. The line link selector *A* stage in a major building block is built up of a maximum of 24 crossbar switches, which means 240 links between the line link selector *A* and line link selector *B* stages. The number of local feed junctors and secondary switches (line link selector *B*) depends entirely on the traffic load of the exchange.

For exchanges where one block is not sufficient, more line blocks can be added up to a capacity of approximately 3000 lines. The traffic between the blocks is routed via interblock local junctors of the same type as the internal local junctors.

If the external traffic is exceptionally high, the layout shown in Figure 5 is chosen, with the trunks connected to a separate block and with register access via simple register connecting relays located in each link between the subscriber-lines block and the trunks block.

Figure 6 shows the main parts of the system. The line link selector *A* and line circuit relays comprise 1 crossbar switch and line and cutoff relays for 25 subscriber lines. Line link selector *B* and local junctor consist of 1 crossbar switch and relay equipment for 5 local feed junctors.

The central marker tests for suitable idle paths through the exchange after having received and stored information about incoming and outgoing terminals in line link selector *A*. It sets line link selector stages *A* and *B*. The line marker's main function is to store and translate information and transfer it to the central marker. The connecting devices are needed only in multiblock exchanges.

The terminal discriminator is used on an originating call to transform the position identity in line link selector *A* to a directory number (hundreds, tens, and units), and on a terminating call to transform a directory number to equipment location in line link selector *A*. The trunk group discriminator connects test circuits for trunks on outgoing calls.

5. Mechanical Design

The mechanical design of frames, bays, and cabinets uses many practical concepts to make the exchange especially suitable for rural automation, ease of installation being of utmost importance.

This has been achieved by: the use of small plug-in units to facilitate transport and handling, manufacture, test, installation, maintenance, and flexibility of the system; the use of a modular system for the plug-in frames to facilitate full utilization of bay space; the use of factory-made interconnection cables between frames in the bay and the terminal strips on top of each bay, the cables being delivered separately and the cabinets assembled on site; the options of back-to-back or back-to-wall mounting of bays; and the prefabrication of interbay cables.

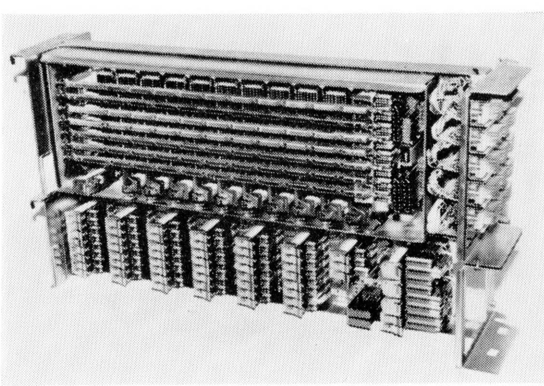

Figure 7—Line link selector *A* and line circuit relays.

Figure 7 shows the line link selector *A* frame, and Figure 8 the plugs and jacks used.

6. Power

The power consumption for a Pentaconta 32 exchange can be calculated according to the following equations.

6.1 Exchange with Multifrequency Signaling

$$I = 2.5 + A_L \times 0.3 + A_I \times 0.6$$
$$+ A_O \times 0.4 + A_T \times 0.5 + A_{REG} \times 1.0$$

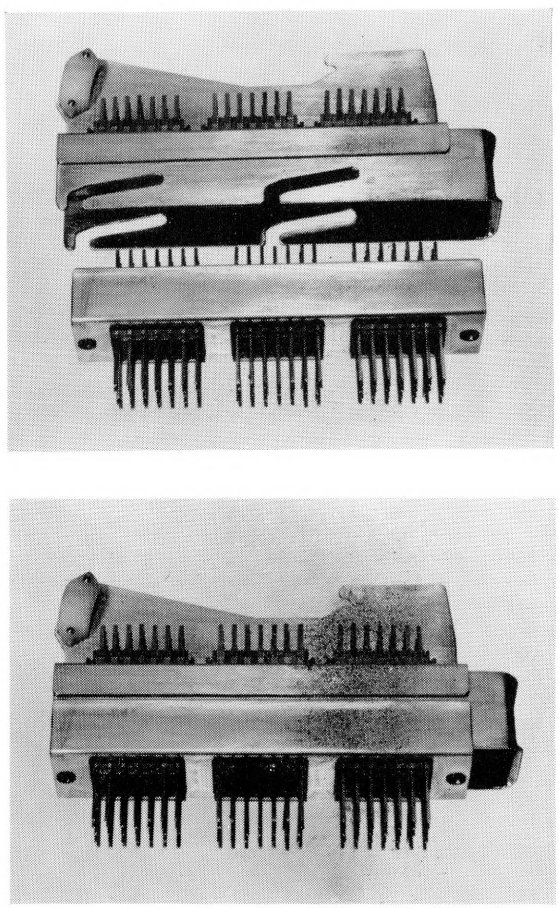

Figure 8—Plugs and jacks, separate and engaged.

where

$$I = \text{power consumption in amperes}$$
$$A_L = \text{local traffic in erlangs}$$
$$A_I = \text{incoming traffic in erlangs}$$
$$A_O = \text{outgoing traffic in erlangs}$$
$$A_T = \text{transit traffic in erlangs}$$
$$A_{\text{REG}} = \text{register traffic in erlangs.}$$

6.2 Exchange without Multifrequency Signaling

$$I = 1.0 + A_L \times 0.3 + A_I \times 0.6 + A_O \times 0.4 + A_T \times 0.5 + A_{\text{REG}} \times 1.0.$$

I gives the capacity required for the rectifiers. The capacity of the exchange battery is generally taken as $5 \times I$ ampere-hours.

7. Installation and Testing

The use of plug-in units and prefabricated cables throughout the system makes it possible to reduce the time for installation and testing of an exchange to between 1 and 2 hours per line, depending on exchange size and skill of personnel. Two test boxes with supervisory lamps and keys have been designed.

8. Supervisory Devices

For supervision, a portable self-contained traffic recorder and an exchange tester for routine tests of traffic paths through the exchange are provided.

9. Conclusion

The Pentaconta *32* system is offered as a solution to the problem of an extensible rural exchange, maintaining as it does the majority of equipment connections and expanding by plugging in standard equipment shelves using prefabricated cables. In this way the different layouts in Figures 2, 4, and 5 can be achieved simply as the traffic changes.

Evert Ekbergh was born on 16 May 1928 at Härnösand, Sweden. He graduated from the Telecommunication Administration school for technical clerks in 1950 and received the degree of Master of Science in electrical engineering in 1954 from the Royal Institute of Technology of Stockholm.

After nearly 8 years of administrative work, system evaluation and planning, and traffic analyzing with the Telecommunication Administration, he joined the engineering staff of Standard Radio & Telefon in 1956 as assistant chief switching engineer. He became chief switching engineer in 1961 and was later responsible for design and export of public telephone systems. He joined the Standard Telephones and Cables (Great Britain) Crossbar Division in 1966 as chief engineer.

Mr. Ekbergh is a member of the Swedish Association of Engineers and Architects.

Mobile Radio Equipment *SEM 25*

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P. BAMBERG
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1. Introduction

The *SEM 25* mobile radio equipment has been developed for general use in ground vehicles. Transmitter power is 15 watts and frequency modulation with peak deviation of 15 kilohertz is used. The frequency range of 26 to 70 megahertz is divided into 880 crystal-controlled channels with 50-kilohertz spacing. Power is supplied by a 24-volt battery in the vehicle.

Design requirements included simplest possible operation, 10 preset operating frequencies, and automatic antenna tuning from inside the set. These requirements for preset frequencies and for tuning while the vehicle was in motion are only a small step away from a fully remote-controlled system. The control unit may be attached to the front panel of the transmitter-receiver or it may be separate. This unit contains all controls for frequency selection and the necessary switching functions.

In addition to meeting the frequency-stability requirements, it was especially important to avoid spurious emissions from the transmitter and to achieve the highest possible linearity of the receiver input circuit.

A frequency-control circuit keeps the first oscillator of the receiver at its rated frequency, thus providing the required frequency stability. The entire receiver is used as the frequency-control circuit for the transmitter.

A "coarse-fine" tuning system is used in all frequency-control circuits. The coarse system brings the frequency within the range of the fine system, which then tunes to the exact frequency.

All 3 stages of the transmitter operate at the output frequency to avoid spurious emissions. The master oscillator is directly frequency modulated and under unmodulated conditions is retuned to the center frequency by the receiver discriminator.

The receiver must meet strict linearity requirements to avoid cross modulation from strong input signals. It uses an input band filter, a ring modulator in the first mixing stage, and an 8-crystal 11.5-megahertz filter at the input of the first intermediate-frequency chain. Diodes protect the input transistor against extremely high input voltages at the receiving frequency.

Where mechanical stability is especially important, use is made of pressure castings of light metal. The components are mostly arranged on printed boards. The equipment is fully transistorized with the exception of the 3 transmitter stages. Heat conduction is adequate to keep temperatures within acceptable limits.

2. Transmitter-Receiver

2.1 Frequency Range

The required range from 26 to 70 megahertz is divided into 880 channels each 50 kilohertz wide. The first oscillator tunes from 35.5 to 58.45 megahertz. Operating above the signal frequency, it produces an intermediate frequency of 11.5 megahertz for the signal band from 24.00 to 46.95 megahertz. Operating below the signal frequency, it similarly covers from 47.00 to 69.95 megahertz. The signal range from 24 to 26 megahertz is not used.

2.2 Tuning

The transmitter and receiver are tuned by adjustable inductors. They consist of cylindrical coils whose inductance is changed by the movement of high-frequency iron cores. The coils are wound to produce a linear relationship between the position of the cores and frequency. This type of tuning produces more-uniform amplification over the frequency band in the receiver input and gives a more-favorable reactive power in the transmitter compared with adjustable-capacitor tuning. Double-core tuning also simplifies symmetrical design of balanced circuits in the transmitter.

2.3 Block Diagram

Figure 1 is the block diagram of the transmitter-receiver.

The receiver is designed as a double-heterodyne unit. To improve the interchannel modulation characteristics, a ring modulator is used as the first mixing stage, followed by an 8-crystal filter at the 1st intermediate frequency of 11.5 megahertz. The main selectivity of the intermediate-frequency amplifier is concentrated in the crystal filter. The intermediate frequency is converted from 11.5 megahertz to 470 kilohertz in a second crystal-controlled mixing stage. The second intermediate-frequency amplifier drives the limiter-discriminator, which controls the squelch circuit and provides input to the audio-frequency amplifier.

The exact frequency of oscillator 01 is determined by the frequency-control unit. In mixer M3, frequency between 46.5 and 47.45 megahertz is generated by beating the frequency of oscillator 01 with a pulse spectrum out to 11 megahertz derived from the 1-megahertz crystal oscillator 04. All frequencies between 46.5 and 47.45 megahertz are accepted by the filter, amplified, and fed to mixer M4. Here they are

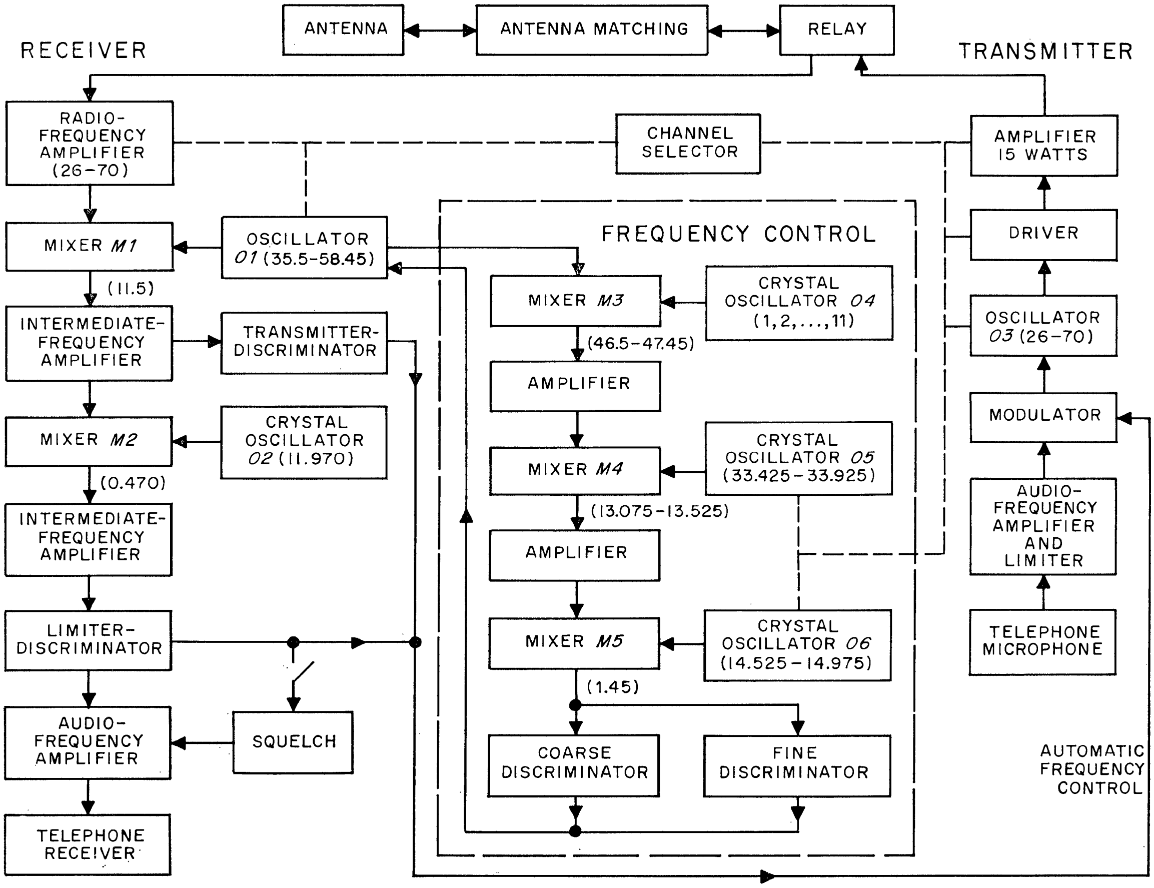

Figure 1—Block diagram of *SEM 25*. The numbers within parentheses are in megahertz.

mixed with one of two crystal outputs of oscillator 05, producing a frequency between 13.075 and 13.525 megahertz. After filtering and amplification, this frequency is converted by mixer M5 to 1.45 megahertz by mixing with one of 10 crystal frequencies, spaced 50 kilohertz apart, of oscillator 06. The 1.45-megahertz output goes to wide-band ($\pm$80 kilohertz) and narrow-band ($\pm$1.2 kilohertz) frequency discriminators. After adequate filtering, the sum voltage of both discriminators goes to the diode that controls the frequency of oscillator 01.

The frequency-control circuit will be effective if the frequency of oscillator 01 is within $\pm$180 kilohertz of the required frequency. The tuning slope is 1:1000, that is, a frequency deviation of 100 kilohertz in oscillator 01 results in a deviation at the discriminator of 100 hertz.

The 440 tuning steps required of oscillator 01 are obtained as follows: 22 steps by double use of the spectrum frequencies 1 to 11 megahertz, 2 steps by the 2 crystals of oscillator 05, and 10 steps by the 10 crystals of oscillator 06.

This frequency-control circuit has the advantage of fewer spurious emissions than a simple frequency-synchronization circuit, because of the low cutoff frequency of the fine discriminator.

The transmitter is directly frequency modulated and held to the assigned frequency by the receiver discriminator. Compared with transmitters that use multiplier stages, this circuit has the advantage of being free of spurious emissions.

The driver and the final amplifiers are balanced circuits using output tube *QQE03/12*. A push-pull output stage was chosen because it creates fewer harmonics. The output is coupled to the antenna by two tuned wide-band transformers, one for the upper and one for the lower band. A selective antenna tuning unit provides further suppression of harmonics.

Power is supplied to the transmitter by a separate subunit. It contains a direct-current converter for anode and other voltages. Variations of battery voltage from 21 to 29 volts and of the load are compensated for by changes in the switching time of the converter. The transmitter tubes receive filament voltage from the battery.

The transmitter can be operated at two power levels, 1 watt and 15 watts, by controlling the operating voltage on the final stage.

3. Remote-Control Unit

The frequency selected at the remote-control unit operates two servo systems as shown in Figure 2. The first servo loop controls 44 steps at 1-megahertz spacing, the second 20 intervals of 50 kilohertz each.

In the control unit there is a series of resistors of equal value that make up two of the four arms of a resistance bridge for each servo loop. The correct tap between resistors is selected by the frequency-control knob. The other two arms of each bridge are in the main equipment in the form of a 3-terminal precision adjustable resistor, the contact arm of which is controlled by a motor through suitable gearing.

The bridge voltage source is at 400 hertz. If the frequency-control knob is moved, the bridge becomes unbalanced and a voltage appears across the detector terminals. This voltage is amplified and goes to the control winding of a 400-hertz motor. The motor balances the bridge by rotating the shaft of the bridge resistor in the correct direction. The various tuning elements in the set are simultaneously driven by the motor. At balance, the voltage goes to zero and the drive motor stops. A tachometer generator is coupled to the motor to provide feedback to the amplifier to stabilize the system.

The 1-megahertz and the 50-kilohertz bridges are operated separately in that sequence using the same servo amplifier and drive motor. A Maltese gear arrangement for the 1-megahertz range moves that control in steps. The gearing for the 50-kilohertz tuning is linear. Thus the drive system transmits equal angular steps for the megahertz control and is smoothly adjustable for the kilohertz range. The latter controls the cores in the adjustable inductors and will set frequency within ±50 kilohertz, well in the range of the coarse discriminator.

For preset channels, a drum with 10 longitudinal slots is rotated to an indicated channel. Sliders in the slots are positioned to actuate contacts that switch in the required bridge resistors for that channel.

A third bridge is controlled by the megahertz servo to actuate a separate motor drive in the antenna unit, to tune that circuit.

4. Antenna Tuning Unit

Figure 3 is the block diagram of the antenna tuning unit. The tuning information is transmitted from the communication set over a bridge servo system. Each of the 44 steps at 1-megahertz intervals corresponds to a position of a rotatable disk that permits a separate pair of setscrews to control the adjustable inductor and capacitor in the π network.

The circuit for matching the characteristic impedance of the high-frequency cable (50 ohms) to that of the antenna over the wide frequency range of operation is shown at the bottom of Figure 3. The adjustable capacitance C, in parallel to the antenna and the fixed inductance L, permits a wide range of reactance to be covered to bring the active component of the antenna resistance to the rated value. The

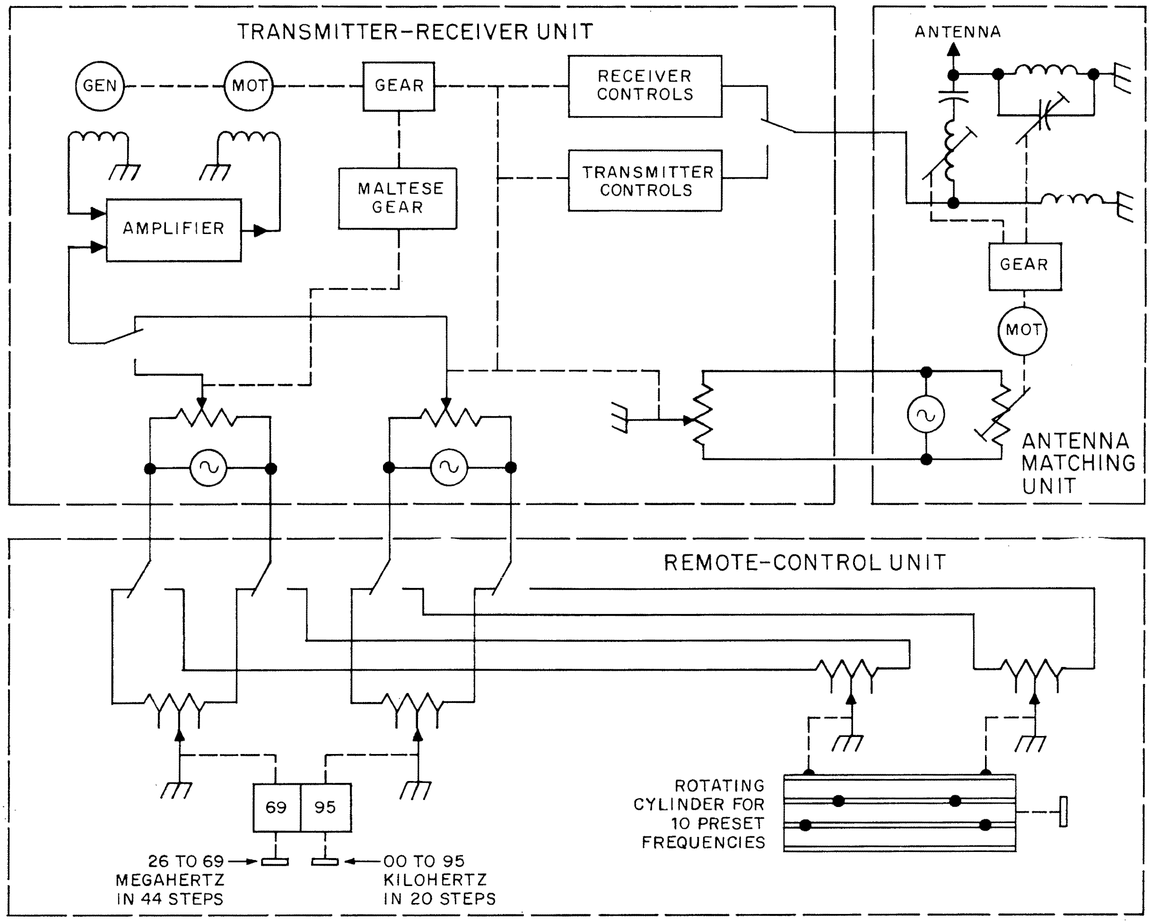

Figure 2—Remote-control system for channel selection and tuning.

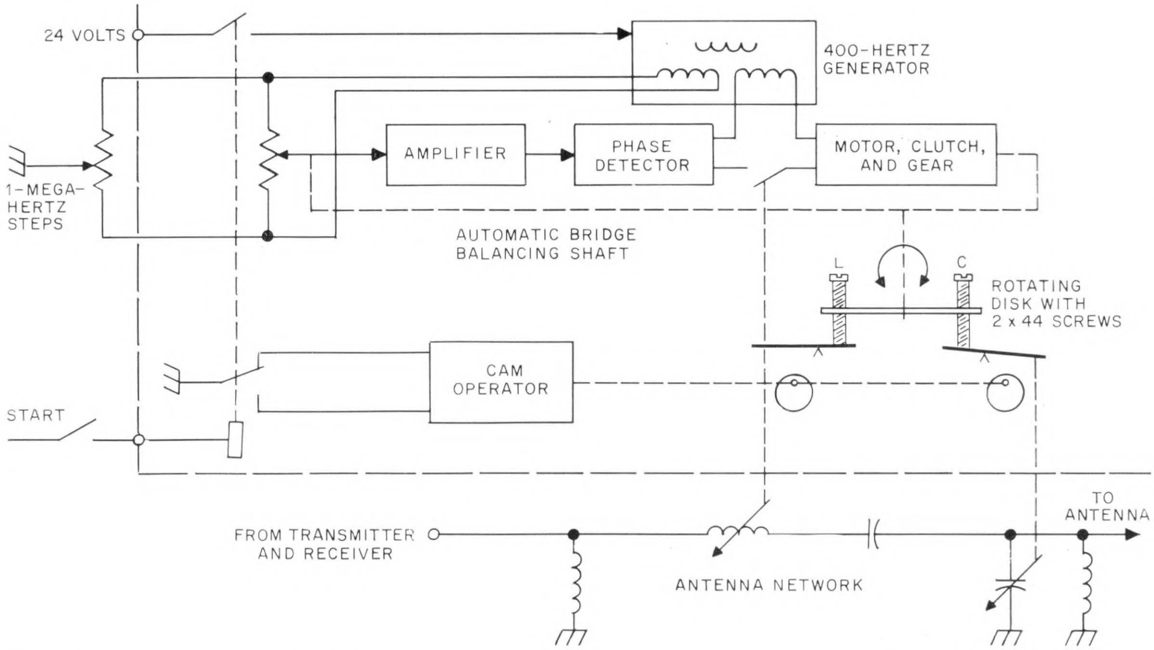

Figure 3—Antenna tuning unit. Adjustment for each of 44 steps of 1-megahertz each is by 2 screws that control the adjustable inductor and capacitor in the antenna network. The cams push the arms away from these setscrews and close the switch to the motor when the disk is to be rotated for a new channel.

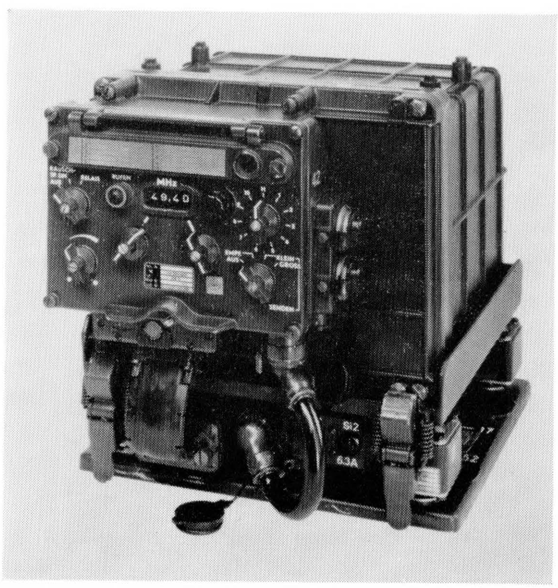

Figure 4—Transmitter-receiver with control unit attached.

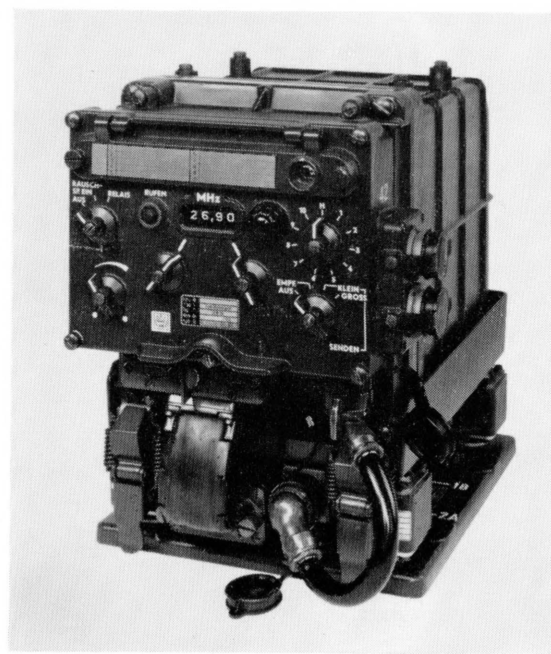

Figure 5—Receiver with control unit attached.

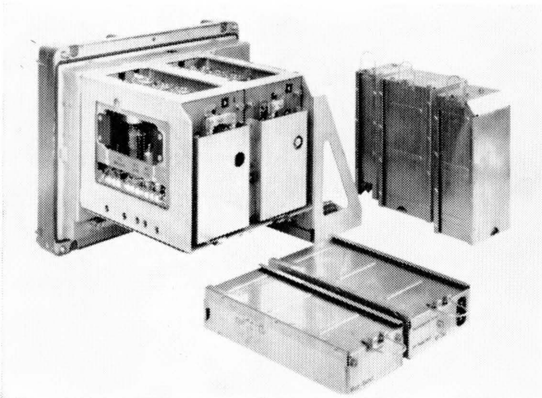

Figure 6—Transmitter-receiver, interior view.

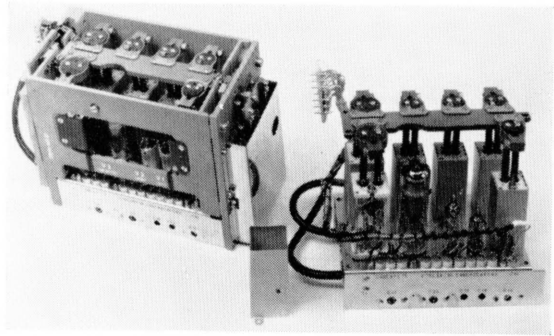

Figure 7—At left is the complete transmitter tuning stage, while at right is a partly disassembled unit.

inductance in parallel to the input of the tuning circuit extends the tuning range to antenna resistances lower than 50 ohms occurring at $\lambda/4$ resonance in the lower frequency range.

The π network permits a 2.5-meter (8.2-foot) rod antenna to be used on all vehicles. The trimming is done once during installation with the use of a reflectometer connected between the tuning unit and the communication set.

5. Design

5.1 Transmitter-Receiver

The complete transmitter-receiver is shown in Figure 4. The subunits are housed in a strong waterproof metal cabinet. The front panel has no controls. It is operated from a remote-control unit that may be fixed to the front panel or separated as much as 8 meters (26 feet) from it. A single receiver can be derived by omitting the transmitter portion, as shown in Figure 5.

To protect the assembly against mechanical stress, it is locked onto a shock-absorbing mounting frame that contains parts of the power supply and carries all connectors to the vehicle. The equipment assembly and the frame are connected by a ribbon cable that can be plugged in on both sides.

The equipment is divided into three easily replaceable units.

(A) Control unit with electromechanical drive.

(B) Receiver tuning unit with preamplifier and oscillator.

(C) Transmitter tuning unit with 3-stage tube transmitter.

The following subunits are of the plug-in type.

(A) Intermediate-frequency stage.

(B) Frequency-control circuit.

(C) Receiver power supply.

(D) Audio-frequency amplifier, switchable as a 400-hertz servo amplifier.

(E) Modulation amplifier.

(F) Transmitter power supply.

(G) 400-hertz generator for remote control.

(H) Relay stage.

Plug-in units (**F**) through (**H**) are placed on the frame for better heat dissipation. Figure 6 shows the arrangement of the various subunits of the transmitter-receiver. At upper left are the front panel, drive frame, and mounted transmitter and receiver; at upper right (from left to right) are the receiver power supply, frequency-control circuit, and intermediate-frequency unit; and in front are the modulation amplifier and the audio-frequency amplifier.

Figure 7 shows the basic design of the transmitter tuning circuits. On the left is the complete transmitter subunit; on the right the unit is partly disassembled to show the tuning inductors and vacuum tubes. All inductors are of the double-core type. The manufacturing variations in the iron cores and windings are compensated for by a trimming inductance. The shield of one of the final-stage inductors has been removed. In both the grid circuit and the anode circuit of the final stage (*QQE03/12*), there are 2 inductors for push-pull operation.

The tuning cores are fixed to a traverse that is adjusted over a toothed shaft from the remote control unit. The tuning is within ±50 kilohertz of the selected channel frequency to guarantee that the oscillator will be within the capture range of the frequency-control circuit.

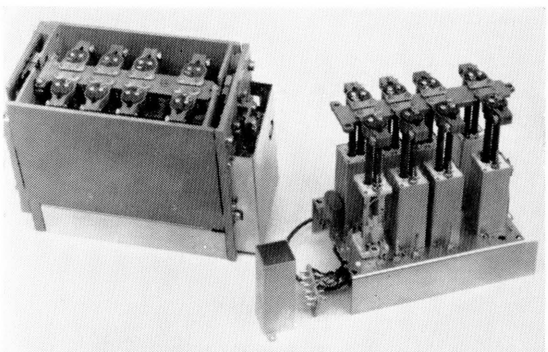

Figure 8—The receiver tuning stage is at left, and the partly disassembled receiver chassis is at right.

Figure 9—Remote-control unit, showing open cover for setting preset frequency.

Figure 8 shows a complete and a partly disassembled receiver tuning chassis. The inductors are arranged in two rows for the lower and the upper band. From left to right are the input filter, mixing stage, oscillator, and output stage. The tuning is also by iron cores attached to a traverse.

Transmitter and receiver tuning inductors have the same stroke (30 millimeters) and are coupled to the remote-control unit by gears.

5.2 Remote-Control Unit

All control functions are performed from a detachable control unit (see Figure 9).

The control unit is kept as small and as flat as possible so that it can be easily mounted within reach of the operator. It consists of a waterproof die-cast housing and is connected to the

Figure 10—Automatic antenna tuning unit and base of the rod antenna.

transmitter-receiver by the multiwire cable. The control unit can be up to 8 meters (26 feet) away from or fixed to the front panel of the transmitter-receiver. It contains the following control elements.

(A) Two switches to select the 880 frequencies and a mechanical indicator marked in megahertz that is coupled to them.

(B) Switches to select 10 preset channels.

(C) A device to switch over to the 10 preset channels.

(D) A switch labeled "off; receive; low transmitting power; high transmitting power."

(E) A switch labeled "squelch off; squelch on; relay."

(F) Volume control.

(G) Key for audio-frequency call.

(H) Scale lamp.

(I) Two sockets for the headphones.

To select the 10 preset frequencies, a switching drum with 10 longitudinal slots is provided. Each slot carries 4 sliders that can be adjusted by a tool inside the cover. The drum is rotated by a knob to select the preset channels. This knob is at top right in Figure 9.

Each of the 4 sliders actuates switching contacts on the back of the drum to perform the necessary switching functions. The selected frequency can be read from the scales above and below the adjusting slot.

5.3 Antenna Tuning Unit

The antenna tuning unit is mounted at the bottom of the 2.5-meter (8.2-foot) rod antenna (Figure 10) and is connected to the communication set by a high-frequency cable and a multiwire control cable. The control cable transmits tuning data from the communication set and operating voltage for the drive mechanism.

The tuning elements and the drive system are in a waterproof die-cast cabinet that is protected against mechanical stress by shock absorbers. Figure 11 shows the antenna tuning unit with

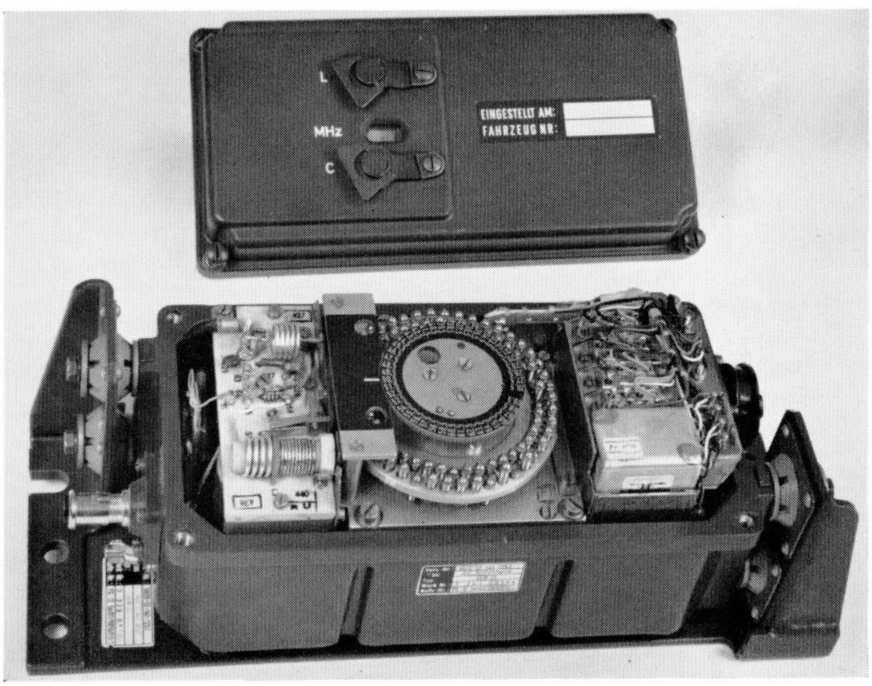

Figure 11—Automatic antenna tuning unit, cover removed.

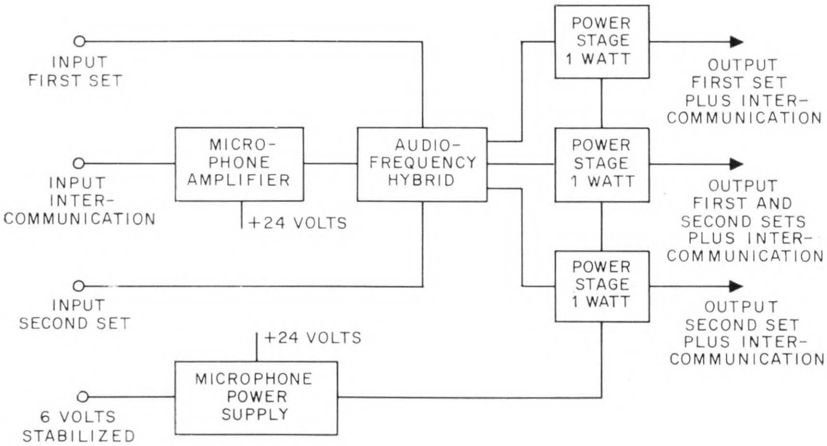

Figure 12—Intercommunication-amplifier arrangement.

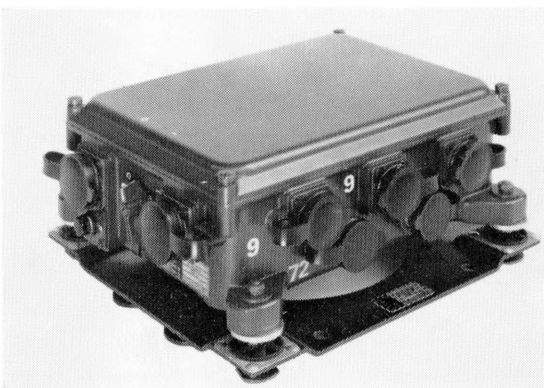

Figure 13—Intercommunication amplifier with shock-absorbing mount.

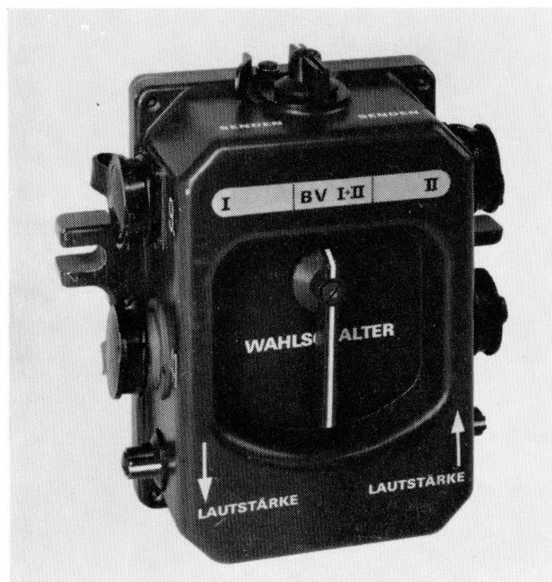

Figure 14—Intercommunication control unit.

the cover removed. To the left are parts of the tuning circuit, while in the center the disk with the 2 rows of 44 adjustable screws each for tuning can be seen. The screws are trimmed once during installation through two openings in the cover which can be locked. The trimming range is so designed that all types of vehicles are covered.

5.4 Transient Protection

If a vehicle battery is subjected to heavy loads, switching of the load may produce transients substantially exceeding the normal battery voltage and which could destroy transistors. Therefore, a transient protection switch disconnects the vehicle battery from the communication system during transients. Also, an electronic switch removes the load during a short circuit.

6. Ancillary Equipment

If several sets are interconnected to form a system, ancillary equipment is required.

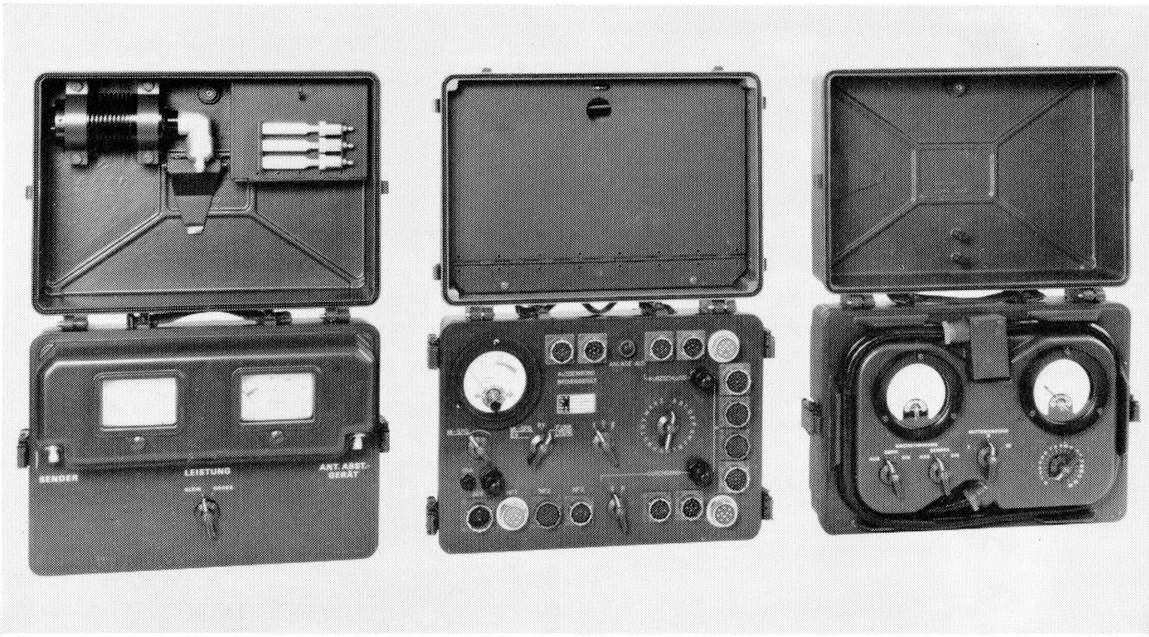

Figure 15—Test equipment. From left to right are the reflectometer, cable tester, and communication-set tester.

6.1 Intercommunication Amplifier

An intercommunication amplifier permits communication between several crew members who are supervising other communication circuits at the same time.

The intercommunication amplifier comprises 3 audio-frequency amplifiers whose inputs are coupled over a hybrid circuit (see Figure 12). It is housed in a compact waterproof shock-absorbing die-cast cabinet. All connections are of the plug-in type (see Figure 13).

6.2 Intercommunication Control Unit

The intercommunication control unit (Figure 14) connects a maximum of two operator's sets. It contains two separate volume controls and the selector switch for the connection of the three outputs of the intercommunication amplifier. The position of the switch at the top of the unit determines whether the calling station is ready to transmit. This unit is also in a die-cast case. All connections are of the plug-in type.

6.3 Local- and Remote-Control Unit

The system can be controlled and operated remotely over a 2-wire line up to 3 kilometers (1.9 miles) long by the use of remote- and local-control units. These sets also connect to the intercommunication control unit.

6.4 Test Equipment

For maintenance and repair the following test equipment is provided.

(A) A reflectometer for trimming the antenna tuning unit.

(B) A device to test the plug-in cables and the audio-frequency speech circuits.

(C) A communication-set device that narrows down the causes of failures and finds defective elements.

The test equipment is housed in waterproof die-cast cabinets. Figure 15 shows the three types of test equipment.

7. Acknowledgments

The list of contributors to the *SEM 25* equipment is too large to be named in full. Therefore, the authors would like to express their sincere thanks to all who worked on this task in the laboratories, engineering and design departments, technical offices, and workshops for their excellent cooperation.

Walter Kloepfer was born on 8 January 1909 in Rosenheim, Bavaria. He received the Diplom-Ingenieur degree from the Technische Hochschule München in 1932 and the degree of Doktor Ingenieur from the Technische Hochschule Aachen in 1950.

He joined Standard Elektrik Lorenz in May 1933 and since that time has engaged in the development of mobile communication equipment; he is chief of development for mobile and radio communication equipment at Pforzheim.

Gerhard Sidow was born on 4 April 1918 in Berlin. He studied precision mechanics and electronic engineering at the Höhere Technische Lehranstalt in Berlin.

He joined Standard Elektrik Lorenz in 1937. Since 1955 he has been in charge of the development laboratory for transmitter-receivers for portable, mobile, and airborne communication equipment.

Paul Bamberg was born on 24 June 1918 in Laibach, Yugoslavia. He received his professional training at the Höhere Abteilung für Elektrotechnik in Vienna.

In 1939 he joined C. Lorenz in Berlin. From 1945 to 1953 he was with the Austrian Broadcasting Company. He then returned to Standard Elektrik Lorenz, where he is now in charge of the development of mobile communication equipment.

Man-Made Quartz Crystal

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1. Introduction

The quartz of a piezoelectric resonator element must be monocrystalline and free from twinning*, flaws, and inclusions. Although quartz is the commonest of all minerals, its occurrence as crystals of a size and quality suitable for resonator manufacture is relatively rare. In particular, the prevalence and complexity of twinning make large crystals from most sources unacceptable.

In the early days of the resonator industry, it was established that suitable quartz could be obtained from Brazil and Madagascar, already long-established as producers of large clear quartz for optical and ornamental purposes. For 15 years or more the requirements of the slowly growing resonator industry in the United States and Europe were met almost entirely and without difficulty by shipments of quartz from Brazil, with exports from the dwindling resources of Madagascar making up the remainder.

The requirements for military communication equipment during World War 2 demanded an enormous expansion of the resonator industry. Production figures soared from a combined total output from United States, United Kingdom, and German manufacturers of less than 100 000 units in 1939 to a total of about 6·5-million in 1942 and over 30-million in 1944. (The United States contribution over this period rose from about 60 per cent to 95 per cent.) Attempts to meet the correspondingly increased demand for the raw material imposed considerable strain on the Brazilian quartz industry. Its production methods were generally primitive and transport difficulties great, the total production being made up largely of the output from a great number of small deposits scattered throughout the vast interior. In 1941, the United States and British Governments began buying quartz in Brazil, and considerable effort was devoted to enlarging and mechanizing the production and distribution industries there. Although a substantial quartz stockpile was eventually built up, the Allies experienced difficulties of supply in 1942. Germany suffered very acute shortages, particularly during the later years of the war.

Several approaches were followed in attempts at overcoming actual or expected shortages of electronic-grade quartz. Successful efforts were made at improving the efficiency of usage of the available material. Efforts to make twinned quartz usable by de-twinning processes met with negligible success. Many other piezoelectric crystals were investigated but, although some were found to have possible use in limited applications, no replacement for quartz in radio equipment was discovered. Extensive searches were made for alternative sources of suitable quartz, but only a few small localized deposits were found in Australia, Colombia, Guatemala, and the United States, and no new major source came to light. Some progress was made, however, both in the United Kingdom and in Germany, in the laboratory production of large single crystals of quartz.

2. History of Synthetic Quartz

Experimenters, particularly mineralogists, had been producing synthetic quartz by various methods for almost 100 years [1] when the war-time shortage of natural electronic-grade quartz aroused new interest in the material.

*Twinning in a quartz crystal usually takes the form of interpenetrating regions in which the crystallographic axes are parallel, but in which the electrical (polar) axes are reversed with respect to each other. Two types—optical (Brazil) and electrical (Dauphiné)—commonly occur, frequently together. The quartz lattice is asymmetric and exists in left- and right-handed forms, which are as mirror images of each other. Optically twinned crystals contain intimate intergrowths of right and left quartz with lattice planes corresponding to the major crystal faces coincident. In electrical twinning, only one structure is involved, but some parts of the crystal are as if turned through 180 degrees of arc about the optic axis compared with the remainder. In both cases, growth is continuous across the twin boundary, which is not itself visible within the crystal; twinning can sometimes be detected by texture differences or by arrangement of natural crystal faces, but is more reliably shown up by viewing the crystal between crossed polarizers along the optic axis (optical twinning only) and by etching (both forms).

With only one or two exceptions, all investigators in this period produced crystals no more than 3 millimetres (0·12 inch) long, and many of the specimens were microscopic in size. The outstanding exception was the Italian mineralogist Spezia who (unlike all others) deliberately placed in the crystallizing system a piece of quartz on which growth could take place, instead of relying on initial spontaneous nucleation.

Spezia's experimental set-up consisted of a vertical high-pressure autoclave provided with an annular gas heating element. A wire basket, which contained broken pieces of quartz, and below which were suspended other pieces of quartz (seeds), was supported in the upper part of the autoclave, and part of the remaining space was filled with sodium silicate solution. The sealed vessel was heated for up to 6 months, the top being maintained at a temperature of about 320 degrees Celsius (608 degrees Fahrenheit) or more, while the lower part of the vessel (in which the seeds were suspended) was kept at a lower temperature. Pressures were probably less than 150 kilogrammes per square centimetre (2200 pounds per square inch). During the period of an experiment there was a transfer of material from the quartz in the basket to the seeds, induced by the temperature gradient, and overall growths of up to 20 millimetres (0·8 inch) were obtained. Spezia's work was notable not only for the size of crystal grown, but more especially because his technique formed the foundation for the development of successful industrial processes over 40 years later.

After Spezia's successes, no further advance was made in growing large crystals until the matter acquired strategic importance rather than mineralogical interest, and effort was devoted towards growth of quartz for resonators. An investigation with this objective was started in 1942 in England [2].

Spezia's method was rejected at this time as giving growth rates too low for practical use. Of the several systems which had been shown to promote quartz growth, those involving temperatures of 573 degrees Celsius (1064 degrees Fahrenheit) or higher could not be considered for the production of large untwinned crystals*. With crystallization from the melt and from the vapour phase thus excluded, attention was directed toward variations of the hydrothermal technique, and an isothermal method was developed which made use of the difference in solubility between silica in the glassy and crystalline (quartz) states [3]. A process similar in principle but differing in detail was developed in Germany during the last two years of the war [4], and a production plant was set up. However, operations had progressed only a few weeks before American troops arrived, and the technique was not proved as a production process. Both isothermal processes suffered the great disadvantage that the silica glass nutrient material itself rapidly became coated with small quartz crystals, which resulted in the growth on the seed being brought to a stop within about a day. It was therefore necessary to cool and open the autoclave frequently to recharge with a fresh supply of silica glass, thus building up the required growth in layers.

There had been interest in the United States during the war in growing electronic-grade quartz, and unsuccessful attempts at growing large crystals appear to have been made. Interest remained for strategic reasons after the immediate war emergency had passed, and discovery of the German work encouraged further experiments. From 1946 onwards, projects were initiated in various government departments, academic institutions, and industrial concerns for studies of the growth and properties of synthetic quartz. Several of these projects were established under United States Army Signal Corps contracts. Although the

*The quartz lattice undergoes a rapid reversible change at about 573 degrees Celsius with slight displacement of the silicon atoms. The inversion process on cooling, particularly in a large crystal, is usually accompanied by the formation of electrical twins.

German work had provided the stimulus for the investigations, the isothermal method was soon abandoned and attention was focused once more on Spezia's temperature-gradient technique with quartz nutrient. The advantage of reversing the relative positions of growth and nutrient zones, which gave much-improved circulation of the solution and hence higher growth rates, was quickly realized. It was probably this modification which provided the key to later industrial success. Other changes from Spezia's conditions concerned pressure, temperature, and the nature of the starting solution [5–7].

A pilot plant for the large-scale production of quartz was set up under contract in 1952, and during a 3-year period produced about 2500 kilogrammes (5500 pounds) of crystals for the United States Army Signal Corps. It also provided the material for the first commercial sale of synthetic quartz in 1955. By this time, there were indications that the production and use of synthetic quartz had economic advantages. The first two full-scale production plants were commissioned in the United States in 1958 and 1960, and since that time several other plants of various sizes have come into being in the United States, Europe, and Japan.

3. The Project

Standard Telephones and Cables began experimental work on the growth of synthetic quartz in 1958. The first small crystals produced (Figure 1) were grown in 8 days and weighed an average of 8 grammes (0·28 ounce); the resultant increase in thickness of the seeds (which were plates of quartz cut approximately parallel to a minor rhombohedral face) was about 5 millimetres (0·2 inch).

Although several papers had been published on the general technique of growing "large" quartz crystals, detailed information was almost completely lacking. It was therefore necessary to devise a programme to investigate the effects of growth temperature, solution density (determined mainly by the fraction of "free" space

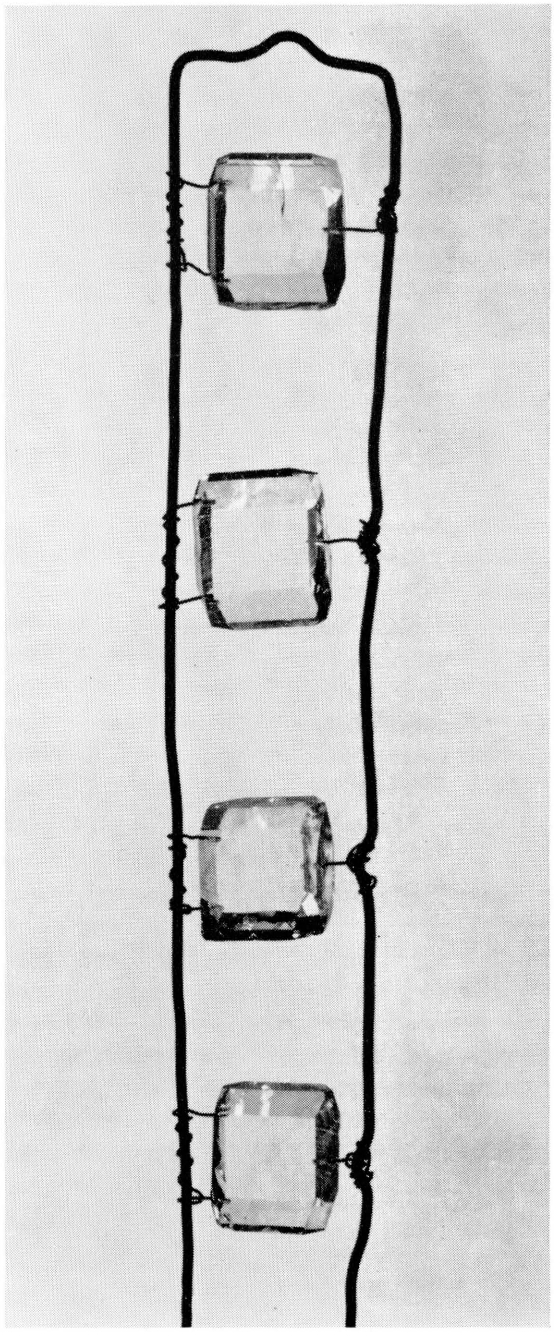

Figure 1—First crystals produced during project. These are approximately 2 centimetres square and 7.5 millimetres thick.

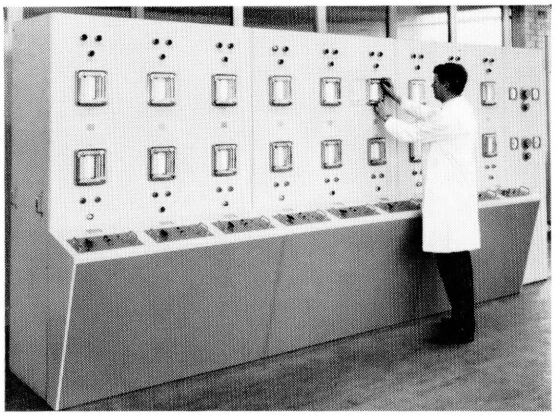

Figure 3—Control-room instrument panel with controlling recorder stations and alarm system.

Associated with the recorders is an alarm system which firstly gives audible and visible indication should any temperature or pressure vary from expected values, and secondly gives similar warning and also cuts off power from any vessel should its temperature or pressure exceed rated values.

An additional mechanical safety device, a rupture-disc assembly, is fitted to every autoclave to give protection against excessive pressure in the event of failure of the electrical devices. The rupture disc is a small domed and flanged disc of Inconel, which is retained by its flange in a tubular holder mounted on the autoclave head and is subjected to the autoclave pressure on its concave side. The disc is designed so that, at a pressure a little above the rated working pressure of the autoclaves, it will rupture and discharge the fluid content of the vessel.

5. Production Process

Nutrient material, consisting of small chips of natural quartz of fusing quality (Figure 4), is weighed into a cylindrical container of perforated steel, which is then placed in the lower half of an autoclave. Fusing-grade quartz is abundant and cheap compared with electronic-grade quartz; the problem of twinning, so important with resonator quartz, need not be considered with the nutrient material, since its crystal structure is completely destroyed during the ensuing process. Thin rectangular seed-plates of twin-free quartz, cut at a specific angle relative to the crystallographic axes, are mounted on steel frames and placed in the upper half of the vessel. The baffle plate forms the bottom member of the lowest seed frame. The remaining space in the vessel is partly filled with calculated weights of demineralized water and sodium hydroxide pellets, and the vessel is sealed and heated. The sodium hydroxide rapidly dissolves and, as the temperature rises, the solution expands and begins slowly to dissolve some quartz. Before operational temperature is reached the solution has expanded to fill the vessel completely, and as the temperature is raised further, pressure begins to build up rapidly toward its ultimate value of about 1900 kilogrammes per square centimetre (27 000 pounds per square inch). The controllers automatically bring the vessel to the required temperatures near 350 degrees

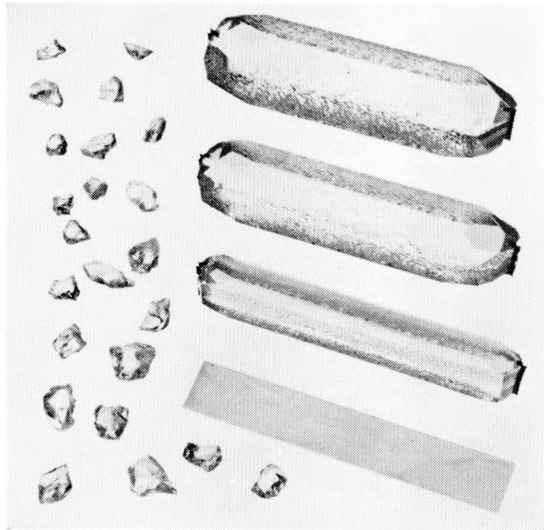

Figure 4—Natural quartz chips (left) provide the material that crystallizes from solution onto seed plates (as bottom right) to give large blocks of synthetic quartz (right). Crystals grown for manufacture of different sizes of resonator blanks are shown. Block length approximately 22 centimetres (8·8 inches).

of the autoclave initially taken up by solution), and concentration of alkali on growth rates and crystal quality. The nature of the solution was known to be important, for two general techniques had been reported. One involved the use of sodium hydroxide solution at pressures in the range of 1000 to 2000 kilogrammes per square centimetre (15 000 to 30 000 pounds per square inch), and the other used sodium carbonate solution at a pressure of 1000 kilogrammes per square centimetre or less. In each case quartz dissolves to form sodium silicate in solution, but the solutions behave differently in terms of quartz growth rates and their tendency to produce unwanted quartz nuclei. After a study of the reported merits and disadvantages of the two solutions, it was decided to employ the sodium hydroxide process. A change to Z-cut seed plates (plates cut perpendicular to the natural prism axis) was also made, since it was known that growth takes place more rapidly on such plates than on plates cut parallel to the rhombohedral faces, and the resulting crystals are of more convenient shape.

The laboratory programme established the dependence of growth rate on the growth conditions already mentioned, and the dependence of visual quality and Q factor on these same conditions plus growth rate. The detailed results are outside the scope of the present account, but it may be mentioned that Q factor was found to be a function of all growth parameters studied. This finding differs from that of Brown [8], who reported that Q factor is a function of growth rate, but for a given rate is relatively independent of the growth process.

The laboratory autoclaves had bore diameters of 3·8 and 5·1 centimetres (1·5 and 2 inches) and internal lengths of 30·5 to 61 centimetres (12 to 24 inches). Thought was given early to problems which might arise in scaling up the laboratory process to a production process, and work was started on the manufacture of pilot plant autoclaves from sections of 13·3-centimetre (5·25-inch) calibre ex-Navy gun barrels. Before manufacture was far advanced, large autoclaves of a design proved to be suitable for quartz growth became commercially available in the United States. Furthermore, laboratory results taken together with production successes in the United States appeared to assure ultimate success for our project.

The decision was therefore made to proceed straight to a full-scale production plant. Building operations were begun in mid-1962, and the first large-scale crystal-growing trials began about 12 months later. Trials continued for a year, the first production batches of quartz for manufacture of resonator blanks being delivered in September 1964.

4. Production Plant

The present plant consists of 9 individual crystal-growing units. Each unit consists of a tall, cylindrical, high-pressure autoclave (Figure 2) provided with resistance heater bands and thermal insulation, plus a control—record—alarm system for temperature and pressure. The entire installation is housed in a special building with crystal-growing, mechanical-maintenance, and crystal-cutting areas, and with separate rooms for preparation work and for electrical and electronic control equipment. The building also contains a laboratory for further developmental work and is large enough to allow considerable expansion in the number of units.

The installation was originally set up with 8 autoclaves of 15·2-centimetre (6-inch) bore and 9·5-centimetre (3·75-inch) wall thickness; the ninth vessel, added at a later date, has a 20·3-centimetre (8-inch) bore and walls 12·7 centimetres (5 inches) thick. All vessels are otherwise similar in design, measuring approximately 3 metres (10 feet) in internal length, and being sealed by a modified Bridgman-type closure. The bodies, heads, and seal rings are of low-alloy steel. The autoclaves are accommodated in pits with only that part containing the closure above ground level. This

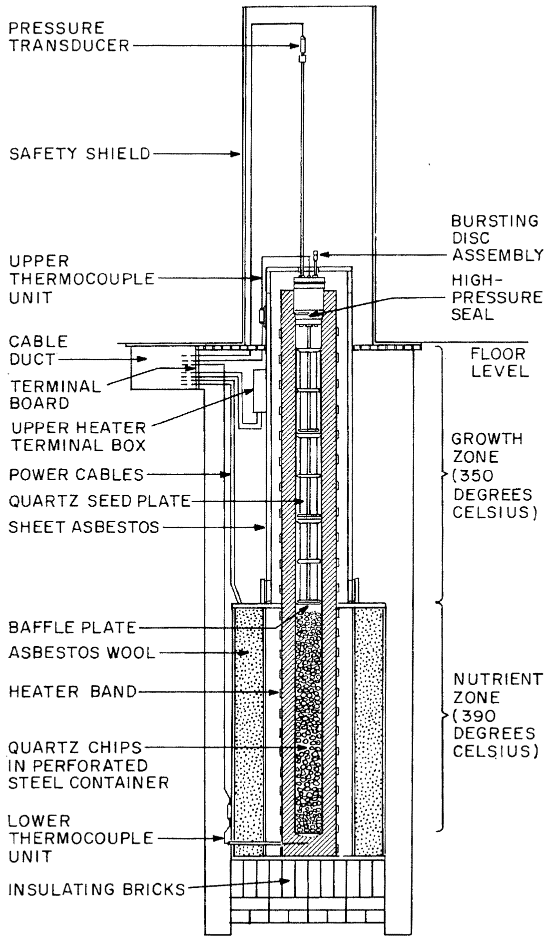

Figure 2—Diagrammatic cross-section of quartz-growing installation.

arrangement is convenient for carrying out all normal servicing operations in situ, as well as providing protection to personnel should a vessel rupture. Protection from escaping high-pressure steam, resulting either from mechanical failure of any part of the pressure equipment or from leakage at the main seal or pressure connections, is afforded by cylindrical shields placed over the pits.

The crystallization process relies basically on the creation within a single autoclave of a lower zone at elevated temperature in which nutrient material dissolves and an upper or growth zone at a lower temperature in which crystallization occurs (Figure 2). The required temperature profile is achieved by placing a flat baffle plate in the autoclave bore just below its mid-point, by having a separate control system for the heaters around each of the two zones, and by judicious use of thermal insulation and natural convection of cooling air.

Small adjustments in temperature profile initially found to be necessary were made by repositioning individual heaters. During crystal-growing runs, temperatures are normally sensed only at the upper and lower ends of an autoclave, but special runs using long internal probe tubes were carried out initially on each vessel to determine axial temperature profiles. Measurements showed that the temperature within each zone could be made substantially uniform, the temperature difference between the normal measuring positions being almost entirely accounted for by a steep temperature gradient in the immediate vicinity of the baffle plate.

For normal purposes, one duplex mineral-insulated metal-sheathed thermocouple unit is positioned in a thermowell projecting 15 centimetres (6 inches) from the head into the growth chamber, and another is placed in a hole bored in the solid bottom of the vessel. Two of the thermocouples are joined in series-opposition to measure temperature differential, and the others measure actual top and bottom temperatures. The 3 thermocouple outputs so obtained are sent to the control room (Figure 3) and converted to higher-level direct-current signals in the range 1 to 5 milliamperes, from which are derived signals for the electronic recorders; in addition, a temperature differential signal and one temperature signal are produced for operation of the two 3-term electronic controllers, which automatically adjust power to the heaters as required through combinations of magnetic amplifiers and saturable-core reactors. Each autoclave is also fitted with a strain-gauge type of pressure transducer, the output of which is treated in the same way as the thermocouple outputs to give a continuous pressure record.

Celsius (662 degrees Fahrenheit) at the top and 390 degrees Celsius (734 degrees Fahrenheit) at the bottom, and keep the temperatures constant throughout the growth period.

The temperature difference created between the two zones results in a difference in density of solution, the denser solution being in the upper zone, and this promotes interchange of solution between the zones through the central aperture of the baffle plate and around its periphery. The temperature coefficient of solubility of quartz under the prevailing conditions is positive, so that as solution from the upper zone sinks and heats up in the lower zone it dissolves more quartz. At the same time, solution rising from the lower zone raises the silica content of the solution in the upper zone and, as it cools, causes a state of supersaturation with respect to quartz, which then leads to deposition of part of the excess dissolved silica as quartz on the seeds. Thus, with convection causing continuous interchange of solution between the two zones, and the solution acting as a carrier of dissolved silica from the lower to the upper zone, the quartz chips slowly dissolve and the seed plates develop into large crystals. After 11 to 28 days (depending on the size of crystal required) power is switched off, the autoclave is allowed to cool, the closure and contents of the vessel are removed (Figure 5), and the process is repeated.

The crystals are similar in shape to rectangular parallelepiped blocks from which the corners have been removed (Figure 4). Blocks currently being produced measure between 22 and 25 centimetres (8·5 and 10 inches) in length—substantially the same length as the seeds used—and about 5 centimetres (2 inches) in width. Thickness varies between 2 and 5 centimetres (0·8 and 2 inches) and weight between 0·55 and 1·33 kilogrammes (1·2 and 2·9 pounds). Yields of up to 32 kilogrammes (70 pounds) of crystals per run are obtained from the smaller vessels.

Of necessity, the first seed plates were cut from a large, very expensive block of natural quartz, but seeds are now prepared from specially grown blocks of synthetic quartz.

6. Properties of Quartz in Relation to Resonator Use

Among the several properties which together make natural quartz so suitable as a resonator material—uniquely so, in fact, before the advent of electronic-grade synthetic quartz—are its piezoelectric character, its great chemical and physical stability, and its peculiar elastic properties. The latter include extremely high Q values, which give excellent frequency selectivity, and a combination of positive and negative temperature coefficients of elastic constants and moduli which, with suitable choice of cut, enable elements to be produced with but small frequency variation over extended temperature ranges.

The properties of natural single-crystal quartz are remarkably consistent for a natural mineral. Although some properties of certain samples

Figure 5—Removal of newly grown crystals from autoclave.

from different localities have been shown to vary because of different impurity contents or perhaps different growth conditions, the variations usually encountered are small and it has generally been possible in the resonator industry to regard the properties as being invariable. Thus, natural quartz is selected mainly by size and relative freedom from imperfections, with no reference whatsoever to the extremely important intrinsic properties of Q factor and frequency-temperature behaviour. When used for an AT-cut resonator operating at 5 megahertz*, for example, the quartz itself can be relied on to have a Q factor of almost 3×10^6 at room temperature, and of not much less than 2×10^6 at any temperature in the usual maximum resonator operating range of -55 to $+105$ degrees Celsius (-67 to $+221$ degrees Fahrenheit). Furthermore, natural quartz will yield resonator elements with frequency-temperature behaviour within normally acceptable limits when cut at specific angles defined many years ago.

The situation with synthetic quartz is very different. In the first place, crystals can be grown to almost any dimension required and size is thus no longer a problem in selecting material. Secondly, objectionable imperfections which are so prevalent in natural quartz are generally absent from synthetic quartz. Invariability of Q factor and cutting angles cannot, however, be assumed without reference first to growth conditions. The rates at which synthetic quartz is usually crystallized are very much higher than those obtaining in nature, and at these relatively high rates some properties of the material (particularly Q factor) become markedly dependent on growth rate, growth conditions, and the crystallographic orientation of the growing surface. Frequency-temperature behaviour can also vary, and some samples of synthetic quartz must be cut at angles differing by up to several minutes of arc from those used for natural quartz, to obtain comparable frequency-temperature characteristics. Curves of Q^{-1} versus temperature for some laboratory-grown specimens showing a wide range of behaviour are plotted in Figure 6 with the curve for natural quartz. In production such wide variations are not encountered, and the use of a given set of growth conditions and rate gives batches of quartz in which the properties are broadly reproducible.

In general, as growth rate is decreased, Q values increase and cutting angles move towards those of natural quartz; similar effects can be achieved (within certain limits and without reduction of growth rate) by the addition of small amounts of lithium compounds to the growth solution [9]. At very slow growth rates,

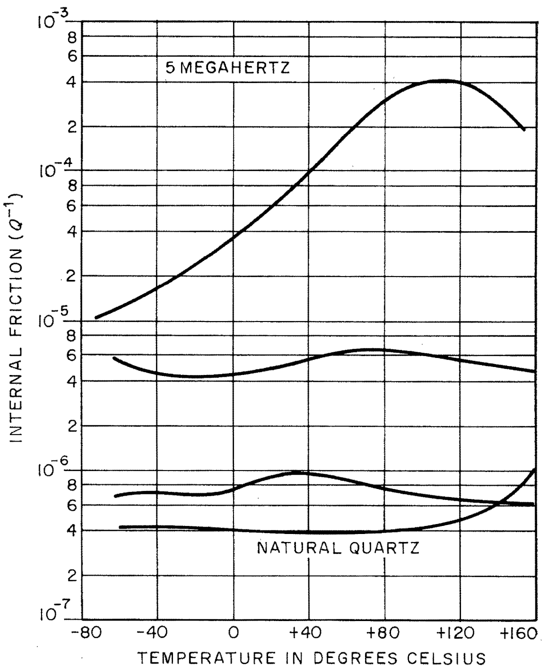

Figure 6—Internal friction (Q^{-1}) as a function of temperature for 3 laboratory-grown crystals. The equivalent curve for natural quartz is also given.

*The Q factor of quartz is generally difficult to measure, but is known to vary with temperature and frequency ($Q^{-1} \propto f$ at least over the range from 2 to 100 megahertz at room temperature). A resonator design developed by Warner for a unit operating on the fifth overtone at 5 megahertz is one of the best known for giving a true indication of the Q value of quartz itself, and has been widely used for this purpose.

synthetic quartz comparable to natural crystal can be obtained, but since the use of slow growth rates also increases production costs, it becomes relevant to consider whether material comparable in all respects to natural quartz is really essential.

Q factor is an inverse measure of energy losses sustained by a vibrating material or system. For quartz itself, these losses are due to internal frictional effects in the crystal lattice associated partly with the random thermal oscillation of the silicon and oxygen atoms, and partly with the interactions of impurities or lattice defects. For a resonator unit, the losses are a combination of those within the element and external losses caused by the presence of the mounting system, damping by the surrounding atmosphere, and damage of the element surface. Although methods are available for reducing the various external losses, manufacturers use them only when absolutely necessary because of the added production costs.

Q values required of resonators range from a few million for frequency and time standards down to a few thousand for some filter applications. In the former case, every effort must be made to reduce external losses to a minimum; the Q factor of the resonator is then largely determined by that of the quartz, and natural crystal or synthetic quartz of comparable Q value must be used. In low-Q filter resonators large external losses are quite acceptable and may exceed the losses in a natural quartz element by two or three orders of magnitude; under these conditions, natural quartz can be replaced by synthetic with a Q value an order of magnitude lower without significantly affecting the Q value of the resonator. Between these extreme cases, synthetic quartz with intermediate Q values can be used.

To date, most of our output has been fast-grown material, with a room-temperature Q value of about 2×10^5 at 5 megahertz. This has been used successfully for channel filter resonators. Proving trials for higher-Q quartz are now in progress, and it is expected that synthetic quartz for all but the most exacting resonator specifications will be available in the near future.

7. Current Advantages and Future Prospects

The current advantage of using synthetic quartz for resonator manufacture is mainly that it allows resonator elements to be produced more cheaply. Natural quartz, because of the way it occurs, the way it is mined, and the necessity of trimming to remove grossly flawed material, reaches the market mainly in the form of irregular broken pieces of crystal. The combination of small size, poor shape, and frequent occurrence of twinning and other defects leads to low yields of resonator elements and high labour costs. In contrast, synthetic quartz is produced in the form of large blocks of good reproducible shape; the blocks are of known, convenient, or even ideal orientation*, are grown with dimensions to suit the particular elements to be cut, and are free from twinning. The blocks are therefore well suited to mass-production techniques for cutting and give substantially higher yields at lower material and labour costs than natural quartz. Further cost reductions may be expected as growth processes are improved, output increases, and more automated cutting techniques are introduced. Reducing resonator prices will no doubt lead to their expanded use both in established and in new applications; the position of quartz-crystal channel filters in relation to competing resonator devices and the double-modulation technique has already been strengthened in this way.

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*For fast growth, high quality, and good crystal shape, seed plates are preferentially cut perpendicular, or nearly so, to the optic (Z-) axis; the major length (Y- or Y'-dimension) extends between a pair of opposite prism faces. For −5-degree X channel filter elements, the seeds are cut at 85/95 degrees to the optic axis so that the long edge of the elements to be cut is parallel to the long seed edge and to the major growth surface.

The first work on synthetic quartz for resonator use was prompted by the difficulties of obtaining suitable natural quartz, which had to be imported from Brazil. Our present process for producing synthetic quartz uses as source material natural quartz also imported from Brazil but much more abundant and cheaper than electronic-grade material. It is anticipated that in times of emergency indigenous materials such as quartzites, vein quartz, or flints, could be substituted as nutrient material.

Considerable technical advantages may reasonably be expected to develop from the use of man-made quartz. The properties of natural quartz, although generally good enough for all existing resonator specifications, do nevertheless impose limitations on future improvements in performance. Probably the most important single trend concerns frequency-temperature behaviour, with specifications calling for even smaller frequency deviations over the same operational temperature ranges, or for wider temperature ranges for the same frequency tolerances. It has been reported [10] that addition of a germanium compound to the growth solution yields a doped synthetic quartz for which the frequency-temperature curves are flatter and broader than those for natural quartz, thereby enabling the required resonator performance to be achieved.

Quartz resonators at present are not operated at temperatures much above 105 degrees Celsius (221 degrees Fahrenheit). However, there could be circumstances in which higher operating temperatures would be necessary or advantageous—for example, if ambient temperature is higher than 105 degrees Celsius and refrigeration plant cannot be provided, or under certain conditions of irradiation when the use of a higher operating temperature can reduce radiation-induced damage and consequent frequency shift. The Q factor of natural quartz falls continuously as temperature is raised from room temperature and can become too low to meet resonator specifications. The Q factor of synthetic quartz, on the other hand, reaches a minimum somewhere in the range from 35 to 130 degrees Celsius (95 to 266 degrees Fahrenheit) and then increases before falling again at high temperatures. Over much of the high-temperature range, selected synthetic quartz has a higher Q factor than natural quartz and may find use where the latter is unsatisfactory. It must be acknowledged, however, that better Q factors at elevated temperatures can be achieved with both natural and synthetic quartz by electrolysis of the material—that is, by first subjecting it to a potential field of about 1 kilovolt per centimetre (2·5 kilovolts per inch) at a temperature of 400 to 500 degrees Celsius (750 to 930 degrees Fahrenheit) to sweep out certain impurities [11]. The doping and electrolytic techniques, separately or together, give further possible scope for modifying properties in ways not yet imagined.

It should be mentioned that high-quality quartz is also used for the manufacture of optical system components, such as prisms, lenses, windows, and specimen cells. Synthetic quartz of selected grades has been shown to have advantages here over natural quartz, particularly in improved homogeneity and better transmittancy in the far-ultraviolet and near-infrared regions of the spectrum.

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He joined the Quartz Crystal Division of Standard Telephones and Cables in September 1957 to take charge of work on synthetic quartz, and has taken the project through all stages of development and engineering to actual production.

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Transmission-Loss Measurements Made on Two Knife-Edge Diffraction Paths Over the Andes*

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1. Introduction

The present telephone cable circuits between Argentina and Chile pass over the great mountain barrier of the Andes, and since part of this route is above 10 000 feet (3000 meters) heavy snowfalls and avalanches make it difficult to maintain these circuits, particularly during the winter months. An increase in the number of circuits between the two countries is now required, and a study was therefore made of more reliable and less costly methods of communicating across this mountain barrier. The objective was a reliable, high-quality, 60-channel system not requiring the maintenance of lines or equipment in the high Andes.

A beyond-the-horizon radio circuit between sites on each side of the Andes was first considered as a possible solution, but a study of the path profile over the Andes indicated that the loss on such a path would be prohibitive. However, under certain conditions mountain ranges can act as diffracting knife-edges for radio waves, resulting in considerably less loss than would be the case for a normal beyond-the-horizon path. Map studies, plus a survey of the area, indicated that by a careful selection of sites it would be possible to establish a knife-edge diffraction path making use of a 22 000-foot (6700-meter) peak, known as Tupungato, as a diffracting edge. It was estimated that the loss on such a path would be of the order of 210 decibels.

Since the transmission loss on a knife-edge diffraction path depends critically on the sharpness of the knife-edge, it was decided to make measurements on two paths passing over Tupungato. Suitable sites were selected on each side of the Andes, and during September and October of 1962 ITT Federal Laboratories carried out transmission-loss measurements at

*Presented at the Second International Congress on Telecommunications, Madrid, Spain; 15–20 November 1965.

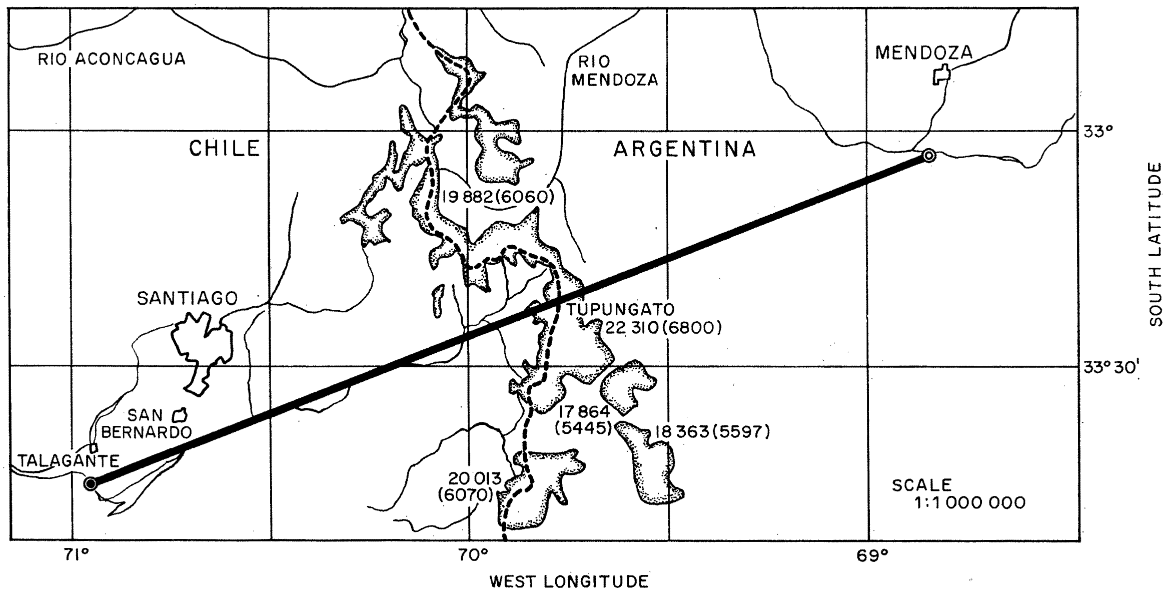


Figure 1—Map of the transmission path. Elevations are in feet (meters).

a frequency of 891 megahertz on two diffraction paths passing over different parts of Tupungato. The result of these measurements showed that the median loss on the first path tested was 210 decibels, as estimated, but that the loss on the second path was only 204 decibels, or 6 decibels less than on the first.

The recorded carrier on both paths was, for a large percentage of the time, typical of knife-edge diffraction paths. However, for a small percentage of the time (less than 1 percent) the loss was about 18 decibels above the median, and the variations in the received carrier were then more characteristic of a beyond-the-horizon path.

From the results of the path-loss measurements it is estimated that a reliable, high-quality, 60-channel system could be established across the Andes using a transmitter power of only 1 kilowatt and 30-foot (9.1-meter) antennas.

2. Path Characteristics

Transmission-loss measurements were made on two knife-edge diffraction paths in the Andes; the first passing over a point about 1 mile south of the highest part of Tupungato, and the second passing over its highest point. A map of the first path, with the location of the terminals, is shown in Figure 1; for the second path the same terminal in Chile was used, but the terminal in Argentina was about 2 miles north of that shown in Figure 1. The main characteristics of these two paths are as follows:

	Path 1	Path 2
Path length in statute miles (kilometers)	127 (204)	122 (196)
Angular distance ($K = 1.33$)	6° 42′	7° 48′
Height of knife-edge above sea level in feet (meters)	19 700 (6000)	22 000 (6700)
Height of terminals above sea level in feet (meters):		
Argentina	3120 (950)	3330 (1015)
Chile	1230 (375)	1230 (375)

The profile of path 1 is shown in Figure 2. The profiles of the two paths were very similar, the chief difference being that the height of the knife-edge on path 2 was 22 000 feet (some 2000 feet greater than on path 1).

The point of minimum clearance on the two paths was at the Lonquen Range some 8 miles (13 kilometers) from the receiving site at Naltagua Bridge near Santiago. Tupungato and the Lonquen Range, as measured with a theodolite at the receiving site, are shown in Figure 3. The Lonquen Range has a maximum elevation of 2590 feet (790 meters) on the transmission paths, and the calculated minimum clearance was 460 feet (140 meters) on path 1 and 755 feet (230 meters) on path 2. These values of clearance assume K (the ratio of the effective radius to true radius of the earth) to

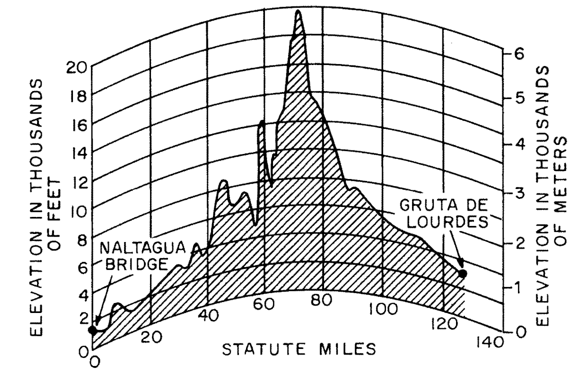


Figure 2—Profile of path 1 for $K = 1.0$.

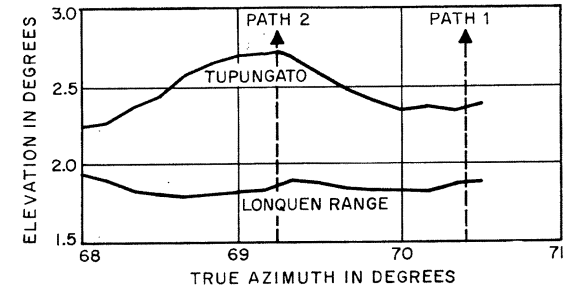


Figure 3—Azimuth and elevation of Tupungato and Lonquen Range as seen from Naltagua Bridge site.

be 1.33. It was also calculated that the line-of-sight paths from the receiving site to the knife-edge would be just grazing at the point of minimum clearance for $K = 0.47$ on path 1 and $K = 0.33$ on path 2.

Since the loss on a diffraction path depends critically on the sharpness of the knife-edge, it is of interest to examine the profile through the diffracting edge. Figure 4 shows such profiles for the two paths tested; this figure is based on the 50-meter contours shown on area maps of scale 1 in 100 000. From the profiles it is estimated that the effective radius of the knife-edge for path 1 is about four times as great as for path 2. However, since the map contours used for determining these profiles were spaced by 50 meters, no greater accuracy than this can be claimed for the profiles shown in Figure 4.

3. Equipment Employed

The equipment used for the path-loss tests consisted of a 100-watt transmitter and a narrow-band recording receiver operating on 891 megahertz. The antennas employed on path 1 were 30-foot-diameter paraboloids, and on path 2 a 30-foot antenna was used at one terminal and a 10-foot antenna at the other. An order-wire circuit, operating on 6.9 megahertz, was provided between the two terminals. Primary power was provided from engine generators at each terminal. Figure 5 shows the receiving installation at the Naltagua Bridge site some 30 miles south of Santiago in Chile.

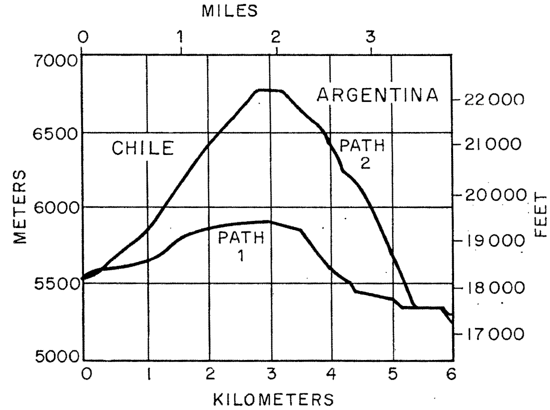


Figure 4—Profiles of Tupungato.

4. Test Procedure

Having aligned the antennas at both terminals for maximum received level, the received carrier was then recorded continuously for more than 300 hours, first on path 1 and then on path 2. The transmitter output was kept constant within about ± 1 decibel and the receiver was calibrated every 12 hours throughout the tests. The recorded level of the received carrier was divided into 15-minute intervals, and the median carrier level was determined from the distribution of the 15-minute medians. It is believed that the overall accuracy of the path-loss measurements was of the order of ± 2 decibels.

5. Results

5.1 Path 1

Transmission-loss measurements were carried out continuously on this path during September 1962 for a total of 348 hours. The median path loss was found to be 210 decibels and the standard deviation 5.5 decibels. The distribution of the 1394 fifteen-minute medians is shown in Figure 6. The daily recorder charts showed no marked diurnal change in path loss, although there was a tendency for the fading to be of greater amplitude between the hours of 10 a.m. and 2 p.m. local time.

In general, it was found that when the path loss was less than the median value the fading was of very small amplitude, but as the path loss slowly increased the fading amplitude also increased. This relationship between path loss and fading amplitude is clearly seen in the recordings shown in Figure 7. The time constant of the receiver-recorder combination used during these tests was about 2 seconds.

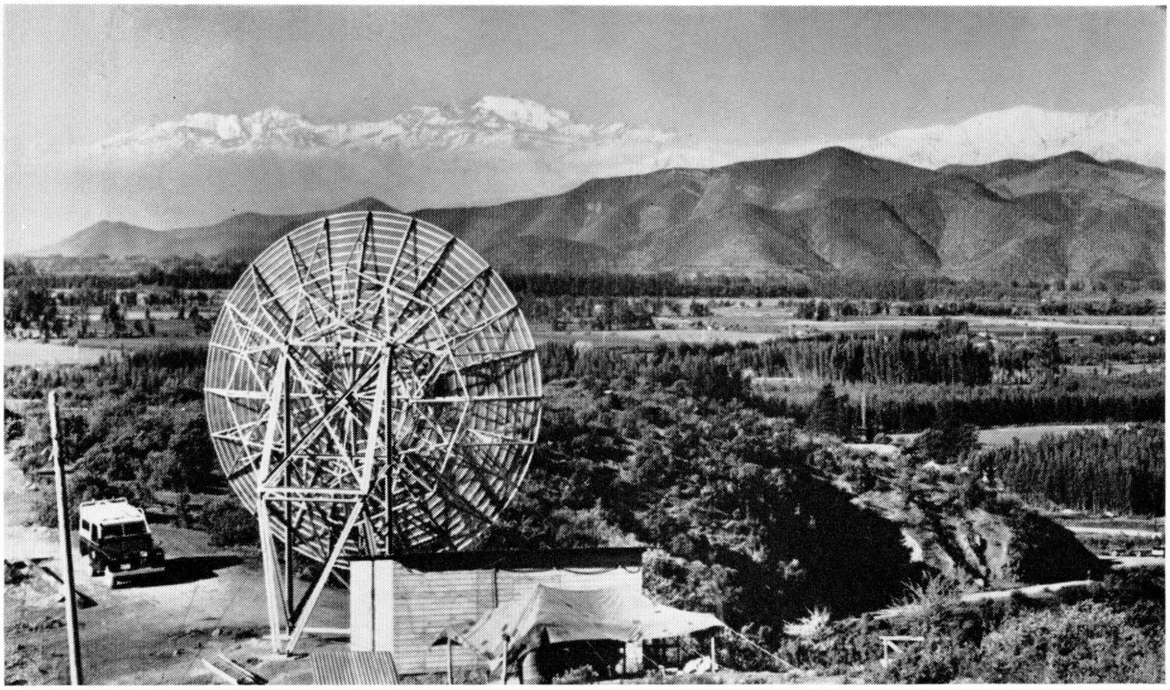


Figure 5—Receiving antenna at Naltagua Bridge site.

5.2 Path 2

Transmission-loss measurements were carried out continuously on this path during October 1962 for a total of 390 hours. The median path loss in this case was found to be 204 decibels and the standard deviation 4.0 decibels. The distribution of the 1561 fifteen-minute medians is shown in Figure 8. The daily recorder charts showed no marked diurnal change in path loss. It was found that when the loss was about at

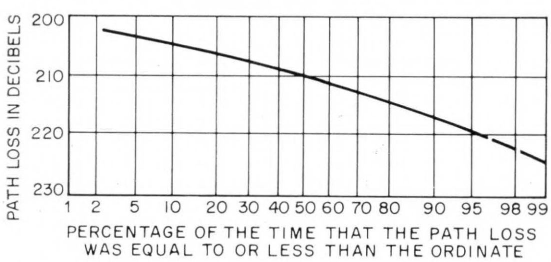


Figure 6—Distribution of 1394 fifteen-minute medians over path 1.

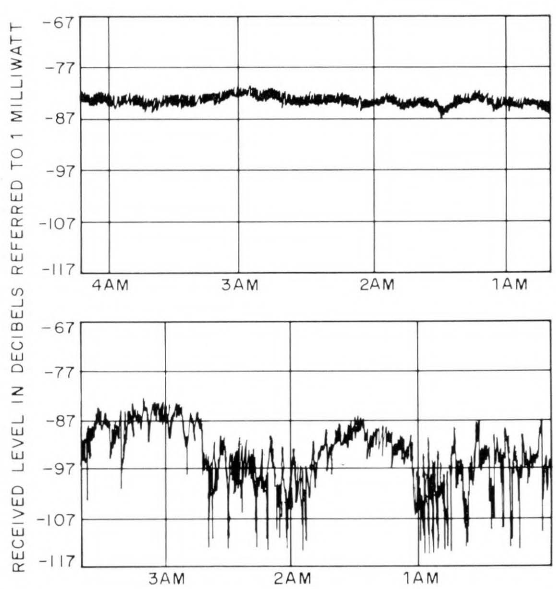


Figure 7—Typical recorder charts for path 1. The upper chart was made on 21 September and the lower chart on 13 September 1962.

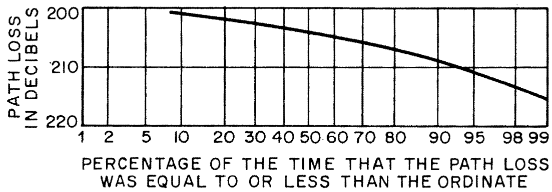


Figure 8—Distribution of 1561 fifteen-minute medians over path 2.

the median value, the fading was of very small amplitude (say ± 2 decibels), but as the path loss increased so also did the fading amplitude. This effect, though not so marked as on path 1, is clearly indicated in Figure 9.

6. Discussion of Results

The results of the transmission-loss measurements showed that considerable diffraction gain was obtained on the two paths tested. Table 1 shows the measured median loss; the loss assuming an ideal, perfectly absorbing, horizontal knife-edge; and the estimated annual median loss for beyond-the-horizon paths of the same length and angular distance.

TABLE 1
MEASURED VERSUS ESTIMATED MEDIAN LOSS

	Measured Median Loss (decibels)	Estimated Median Loss	
		Ideal Knife-Edge (decibels)	Beyond-the-Horizon Path (decibels)
Path 1	210	188	252
Path 2	204	189	258

It is interesting that path 2, although having a greater angular distance (7.8 degrees compared with about 6.7 degrees) had a median loss 6 decibels less than that of path 1. The lower loss measured on path 2 was no doubt due to the smaller effective radius of the diffracting edge on this path. Photographs of the knife-edge taken from the air, and the profiles shown in Figure 4, confirm that the knife-edge was considerably sharper on path 2 than on path 1.

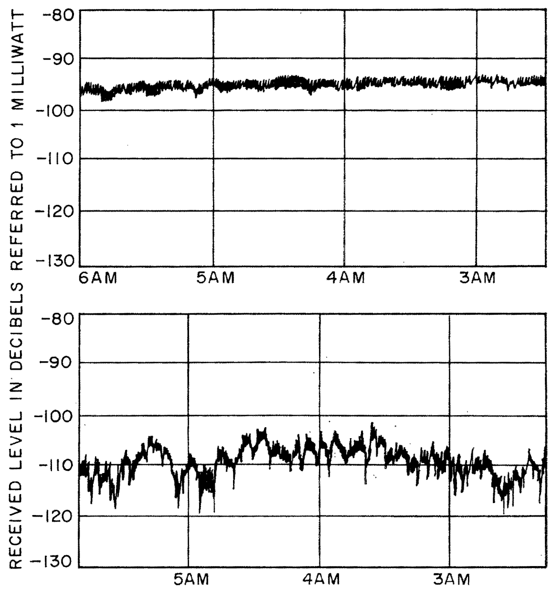


Figure 9—Typical recorder charts for path 2. The upper chart was made on 3 October and the lower chart on 1 October 1962.

The received carrier on a knife-edge diffraction path may be considered to be the result of two modes of propagation: diffraction at the knife-edge, and scatter from a common volume above the knife-edge. For a small percentage of the time (less than 1 percent) the steady diffraction component of the received carrier decreased by 15 decibels or more, and the recorded carrier then had all the characteristics normally associated with a beyond-the-horizon path. This effect is clearly shown in Figure 7, where the top trace shows the steady diffraction component and the lower trace shows what is believed to be the more-variable scatter component. The attenuation of the diffraction component relative to the scatter component may have been caused by inverse bending of the radio rays, resulting in the point of minimum clearance at the Lonquen Range becoming an obstruction between the knife-edge and the receiving site. Another possible explanation is that an interference pattern existed between the direct and a reflected ray on one of the line-of-sight paths from either the transmitter or the receiver to the knife-edge. A minimum of such a pattern occurring either at the knife-edge or at the receiving antenna would reduce the diffraction component of the received carrier.

It is seen from both Figures 7 and 9 that when the diffraction component was attenuated, and the transmission seemed to be largely by the scatter mode, the median path loss was only about 15 to 20 decibels greater than the value corresponding to the normal diffraction component. This relatively high level of the scatter component on both paths is thought to have been attributable to: First, the scattering volume was in a turbulent region of the atmosphere just above the knife-edge; and second, the altitude was about 20 000 feet and not some 45 000 feet above sea level as would be the case for a beyond-the-horizon path of the same angular distance on a smooth earth. Thus, the scatter component of the received carrier on knife-edge diffraction paths is, in general, likely to be of greater amplitude than would be estimated for a beyond-the-horizon path of the same angular distance on a smooth earth.

7. Estimated Performance

In estimating the performance of a wide-band radio link crossing the Andes, the results obtained on path 2 (a median loss of 204 decibels and a standard deviation of 4 decibels at 891 megahertz) have been assumed. Assuming a transmitter power of 1 kilowatt with 30-foot-diameter antennas and fourfold diversity, the median carrier level will be −69 decibels referred to 1 milliwatt, giving a median carrier-to-noise ratio of 32 decibels for a 60-channel system, and a propagation reliability (above receiver threshold) greater than 99.9 percent.

8. Conclusion

Transmission-loss tests were made on two knife-edge diffraction paths between sites near Santiago in Chile and Mendoza in Argentina. Considerable diffraction gain was obtained on both paths. The loss on the path passing over the highest and the sharpest part of the knife-edge was found to be 6 decibels less than that measured on the path passing about 1 mile south and 2000 feet below the highest point.

For a small percentage of the time on both paths the type of fading recorded was similar to that normally obtained on a beyond-the-horizon or scatter path. This condition occurred more frequently on the first path tested than on the second and is thought to have been caused by a reduction in the amplitude of the diffraction component, relative to the scatter component, of the received carrier. Inverse bending of the radio rays, or interference between a direct and a reflected ray, would explain this reduction.

The measurements indicated that the scatter component of the received carrier was considerably greater than would be estimated for a normal scatter path of the same angular distance. The relatively high level of the scatter component is thought to have been due to the fact that the scattering volume was just above the knife-edge, at an altitude of about 20 000 feet, and not more than 40 000 feet above the earth as would be the case on a beyond-the-horizon path of the same angular distance.

Based on the results obtained during the transmission-loss measurements, it is estimated that a system of 60 voice channels could be established on path 2 having a propagation reliability greater than 99.9 percent when using a transmitter power of 1 kilowatt, 30-foot-diameter antennas, and fourfold diversity.

9. Acknowledgments

The invaluable assistance given during these tests by the Chilean Telephone Company and by Companía Internacional de Radio of Argentina is gratefully acknowledged.

Author's biography is on following page.

R. E. Gray was born in Wynford, England, on 15 February 1902. He graduated from Faraday House, London, in 1924 with the equivalent of a bachelor's degree.

From 1924 to 1927, he was with Standard Telephones and Cables, London, and from 1927 through 1939 was with Laboratoire Central de Télécommunications, Paris. During the second World War, he was on loan to the Royal Aircraft Establishment and to the Telecommunication Research Establishment in England.

He participated in the first microwave communication link between France and England, in the introduction of the ground-controlled-approach aircraft landing system in England, and in the original commercial transatlantic radiotelephone service. He was also active in the installation of the first Spain-Argentina radiotelephone link, as well as the multichannel radio link joining Scotland and Ireland.

In 1945, Mr. Gray joined ITT Federal Laboratories, where he is presently a senior scientist. He continues his radio wave propagation studies with particular attention to forward-scatter and satellite-communication systems.

Number Analyzer, an All-Electronic Route Translator

J. VAN GOETHEM

Bell Telephone Manufacturing Company; Antwerp, Belgium

1. Introduction

The route translator described in this article has been developed to improve the adaptability of nodal and district exchanges to modifications of the national telephone network and to reduce the updating effort involved.

The translator has been designed around a newly developed semipermanent capacitor store which contains all relevant network data.

The equipment is fully electronic and its high operating speed makes it capable of handling the traffic of any size of exchange. When used in an electromechanical switching system with "relay logic," special interface circuits are provided which communicate with the translator electronically and with the exchange electromechanically. These circuits, called buffers, can handle a rather limited amount of traffic and hence their number depends on the calling rate of the exchange.

The number analyzer has been incorporated in the *7E-N* rotary system as a route translator for nodal exchanges and as a class-of-line store for local offices. The first route translator was installed in the Beverwijk Exchange of The Netherlands Posts, Telegraphs, and Telephones Administration in December 1965.

2. Network Layout

The telephone network of The Netherlands is star-shaped and organized on a decimal basis: A maximum of 10 terminal exchanges are connected to a nodal exchange and a maximum of 10 nodal exchanges to a district exchange (Figure 1).

All terminal exchanges are identified by a 4-figure prefix called *SABC,* of which *SA* identifies the district exchange, *B* identifies the nodal exchange, and *C* identifies the terminal exchange.

As an example, when subscriber 2304 of terminal exchange 1652 wants to call subscriber 841 of terminal exchange 1839, he dials *O*-1839-841.

The initial *O* indicates to terminal exchange 1652 of the calling subscriber that an outgoing call is being placed (that is, the next 4 figures must be treated as a prefix and not as a local subscriber's number).

For an outgoing call all digits (except the initial *O*) are transferred from the terminal exchange to its nodal exchange, where the route translation takes place.

3. Route Translator Data

The route translator for a nodal exchange of the telephone network of The Netherlands must provide for the following information.

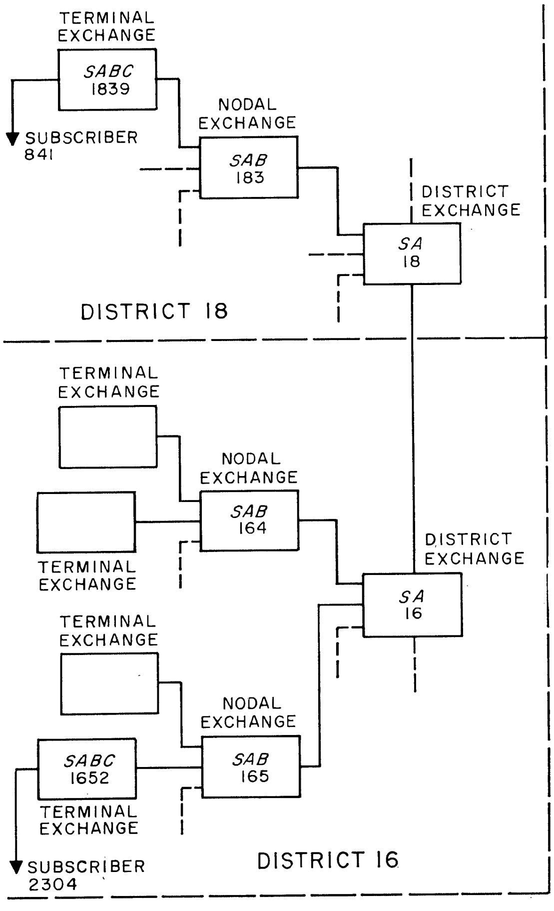


Figure 1—Star-shaped telephone network.

(A) The number of digits of the called subscriber. This number allows the digit receiving equipment (register) of the exchange to determine the last digit to be received and hence reduces the busy time of the register.

(B) Position of a second dial tone. If a second dial tone must be given, the route translator indicates after which digit this must be done.

(C) Tax rate indication.

(D) Control data to steer the subsequent switching stages and reach the wanted group of trunk lines.

(E) Type of signaling to be used on the trunk line.

(F) Number of prefix digits to be transferred to the distant exchange.

(G) Indication of an alternative route if any.

4. Overall System Organization

Means must be provided to transfer the route translator data to any of the registers of the nodal exchange. As these registers are electromechanical devices using relays for performing their functions, the time required to take out prefix data and store route data (84 milliseconds) is a large multiple of the time required by the actual route translator to supply the data associated with a given prefix (1 millisecond). Therefore an adapter circuit has been used between the central route translator and the register circuits. This device, called a buffer, operates with the registers on a relay-speed basis and with the route translator on an electronic-speed basis. Its traffic-handling capacity is obviously much smaller than that of the translator, and for large exchanges several buffers must be provided.

Figure 2 represents the basic organization.

5. Route Translator Organization

As a prefix of 4 decimal figures (S,A,B,C) must be analyzed, the straightforward solution would be to use a store with 10 000 addresses

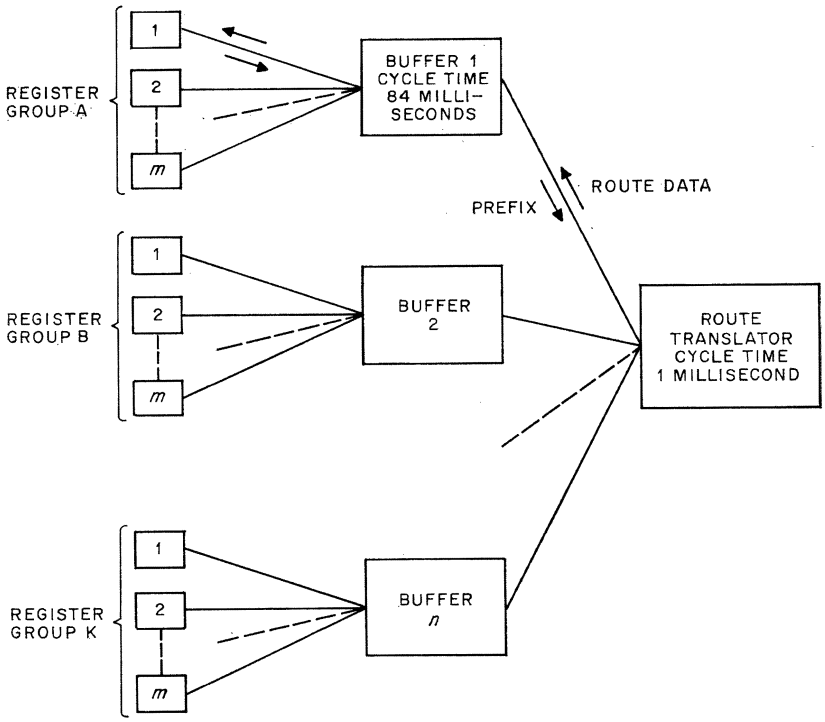


Figure 2—Basic organization of system.

for storing the call data associated with these 10 000 prefixes (Figure 3). However, in practice the 4 figures of the prefix are not always required to determine the call data. This allows the store size to be reduced substantially by using a more elaborate organization (Figures 4 and 5).

In Figure 3, all route data associated with a given prefix are stored in a single memory address. In Figure 4, on the other hand, the store is divided into 4 specialized sections, which are addressed in turn by means of the prefix to be analyzed at time intervals $T1$, $T2$, $T3$, $T4$, respectively. The data obtained in the readout circuits are transferred consecutively via gates to recorders a through g during the same time intervals $T1$, $T2$, $T3$, T4, and hence after T4 all route data are available in the recorders and can be transmitted to the interrogating equipment.

The arrangement of Figure 4 avoids interdependence of the access circuits for the different data a through g and allows for optimizing the design in each section. This is explained as follows.

Let us consider the first store section in Figure 4, storing a, the number of digits of the called subscriber (Figure 5).

According to the customer's specification, among the 100 possible SA combinations in the national telephone network, there are a maximum of 16 combinations for which the figures B and/or C are required for determining a. Therefore store section 1 with 100 addresses

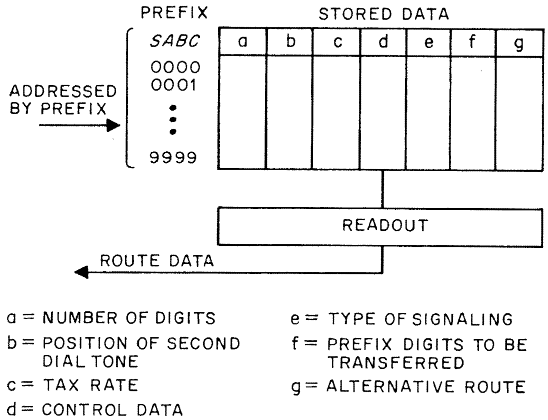


Figure 3—Route translator design.

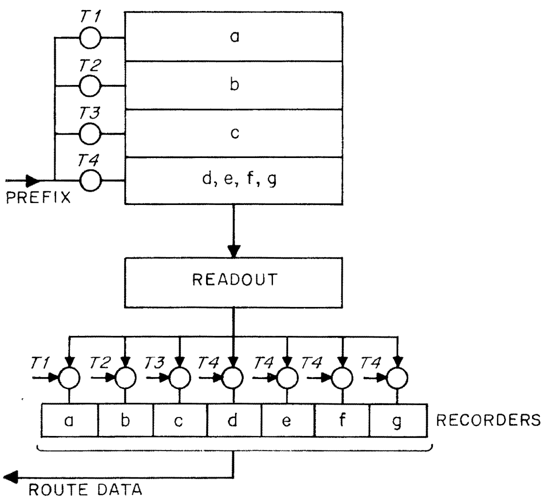


Figure 4—Address sectors of route translator.

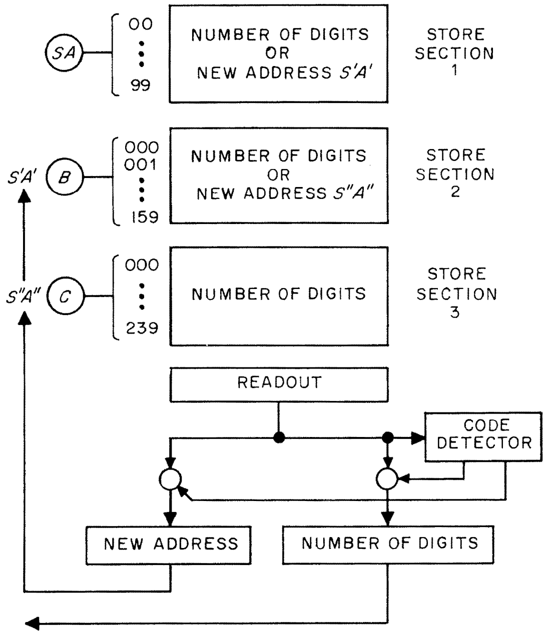


Figure 5—Number-of-digits section.

provides answer a in all but a maximum of 16 addresses. For these 16, which may be randomly distributed among the 100, the store gives an intermediate answer called "new address," which is denoted $S'A'$. The numbers $S'A'$ have the numerical values 00 through 15 and are used to interrogate store section 2 in combination with prefix digit B. This section has 160 addresses. The customer specifies that of these 160 possible combinations a maximum of 24 will require the last digit C for determining a. Here again 24 randomly distributed addresses store a new address $S''A''$ (numerical values 00 through 23), which are combined with digit C for addressing store section 3. The latter has 240 addresses all of which store an a value.

Discrimination between a and a new address is made possible by using a different code for both data. A code detector tests the store output and directs the answer either to the new address or to the number-of-digits recorder.

The program of Figure 5 is repeated for the data b, c, and the route data $d+e+f+g$ of Figure 3, which yields the overall arrangement of Table 1.

TABLE 1
PROGRAM OF STORE

Store Section	Read Time Slot	Address	Number of Addresses	Matrix	
				Bits 1–5	Bits 6–10
Number of digits	$t4$	SA	100	a 4/5; S' 2/5	a 4/5; A' 2/5
	$t8$	$S'A'B$	160	a 4/5; S'' 2/5	a 4/5; A'' 2/5
	$t12$	$S''A''C$	240	a 4/5	a 4/5
Position of second dial tone	$t16$	SA	100	b 2/5	
Tax rate	$t20$	SA	100	c 4/5; S' 2/5	c 4/5
	$t24$	$S'B$	40	c 4/5	c 4/5
Route data	$t28$	SA	100	e 2/5; 4/5	f 2/5
	$t32$	SA	100	V 2/5–4/5	W 2/5–4/5
	$t36$	SA	100	Z 2/5–4/5; S' 2/5	U 2/5–4/5
	$t40$	$S'B$	60	e 2/5	f 2/5
	$t44$	$S'B$	60	V 2/5–4/5	W 2/5–4/5
	$t48$	$S'B$	60	Z 2/5–4/5; S'' 2/5	U 2/5–4/5
	$t52$	$S''C$	20	e 2/5	f 2/5
	$t56$	$S''C$	20	V 2/5–4/5	W 2/5–4/5
	$t60$	$S''C$	20	Z 2/5–4/5	U 2/5–4/5
	$t64$	Z	10	e 2/5	f 2/5
	$t68$	Z	10	V 2/5	W 2/5–4/5
	$t72$	Z	10		U 2/5–4/5

Key:
S', S'', A', A'': New addresses
a: Number of digits
b: Position of second dial tone
c: Tax rate
U, V, W: Selection control data
V: 2/5 code: First selection
4/5 code: Skip first selection
W: 2/5 code: Second selection
4/5 code: Skip second selection
U: 2/5 code: Third selection
4/5 code: Skip third selection
e: Type of signaling
f: Prefix digits to be transferred
Z: 2/5 code: Address of alternative route
4/5 code: No alternative route exists

Reading of the store is under control of clock pulses in time slots $t4$, $t8, \ldots, t72$, of Figure 6, which sequentially actuate the different address sectors.

Each store address has 10 bits that are coded in twice 2-out-of-5 or 4-out-of-5 as shown in the Matrix column. For example, for the number-of-digits section the final answer a is given by twice a 4-out-of-5 code (maximum of 25 combinations) and a new address by twice a 2-out-of-5 code.

The route data require more than 10 bits for storing all information. These data are spread over 3 addresses which are read in turn (for example, when addressed with SA, respectively, on time positions $t28$, $t32$, $t36$) and stored on readout bistables.

Time slot $t28$ gives the type of signaling e and the prefix digits to be transferred f, both in a 2-out-of-5 code.

Slot $t32$ gives two decimal figures V and W for controlling the selection to the wanted trunk group. They are given in a 2-out-of-5 code except when no actual selection stage is provided. In this case a figure *11* is given (4-out-of-5 code) indicating to the register that this selection is to be skipped.

Slot $t36$ gives a third decimal figure U for selection control and a figure Z. When Z is given in a 2-out-of-5 code, this indicates that an alternative route is available for which all data can be found in address Z of the alternative route section (time slots $t64$, $t68$, $t72$). When Z is given in a 4-out-of-5 code, no alternative route is available.

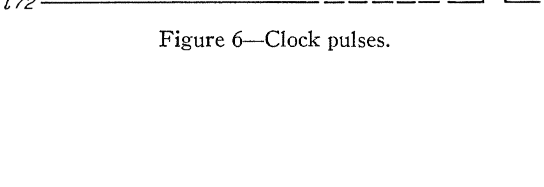


Figure 6—Clock pulses.

When S and A are not sufficient to define the route data, a 4-out-of-5 code is given instead of e in time slot $t28$, indicating that the content of the first 5 bits of time slot $t36$ is to be interpreted as a new address S' and not as a Z.

As explained before, this S' is then combined with B for addressing the store in time slots $t40$, $t44$, $t48$, which eventually delivers a second new address S'' for addressing the store in combination with C (time slots $t52$, $t56$, $t60$). Finally, the store is addressed with Z if available and if the alternative route is required by the register to give all the particulars of this route.

6. The Store Proper

The actual translator store is a matrix-type semipermanent memory with 800 addresses of 20 bits each, as shown in Figure 7. Each crosspoint of the store may or may not have a crosspoint capacitor for determining the binary crosspoint value *1* or *0*, respectively.

The data associated with each address are determined by the capacitor pattern on the corresponding row of the store.

Physically the store is built up of 40 submatrices (2 stacks of 20) having 20 addresses of 20 bits.

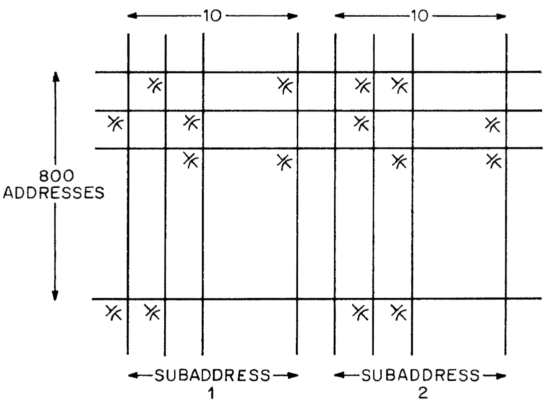


Figure 7—Capacitor matrix. The absence of a capacitor at a crosspoint gives a *0* output.

One of them is shown in Figure 8 (top view) and Figure 9 (bottom view); it is a printed-wiring board carrying 20 column conductors on the top. Close to them are square electrodes which are through-connected to the row conductors at the bottom. The actual crosspoint area consists of half a square and the corresponding part of the column conductor next to it, as indicated by the dark square in row 7 from top and column 7 from left in Figure 8. The top of the submatrix is covered by an insulating layer of lacquer. A capacitor crosspoint coupling is made by placing an isolated electrode in the position of the dark square; this constitutes a capacitor between row and electrode on one side and between electrode and column on the other side. The effective coupling be-

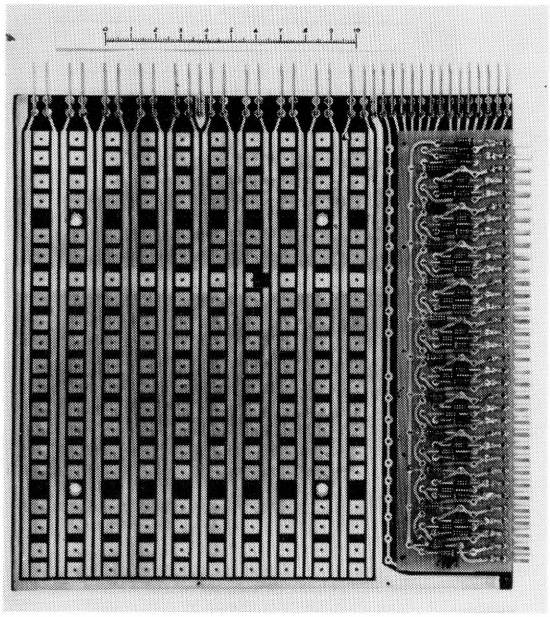


Figure 8—Top view of submatrix.

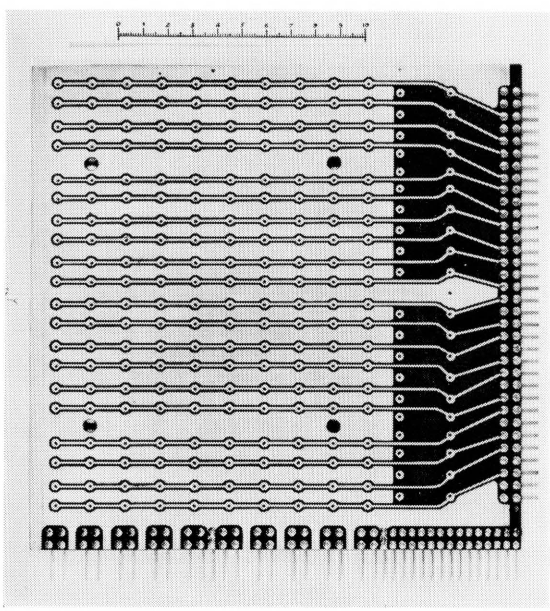


Figure 9—Bottom view of submatrix.

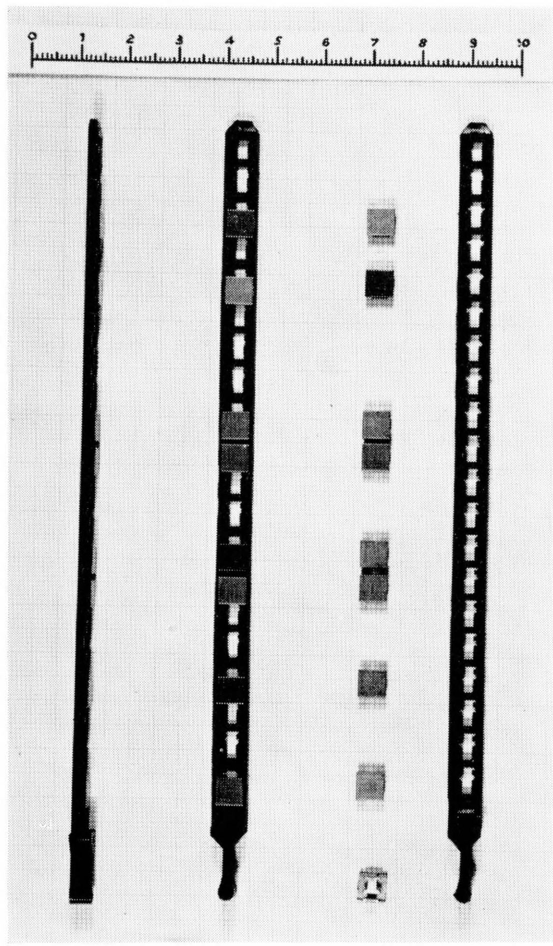


Figure 10—Code strips and coupling electrodes.

tween row and column is 3.5 picofarads mean value.

The coupling electrodes are mounted in plastic code strips according to the code to be stored (Figure 10). They can be easily removed and inserted when data must be changed. After coding, the code strips are slipped into channels on top of the submatrix boards. Figure 11 shows the complete store with all 800 strips inserted.

Words of 10 bits were chosen for the number analyzer. Therefore each row of the store contains 2 addresses of 10 bits, called subaddresses 1 and 2, respectively, and one of which is chosen under control of the address information.

7. Address and Readout Arrangement

For reading the capacitor code on a given address, the read signal of Figure 12*B* is applied

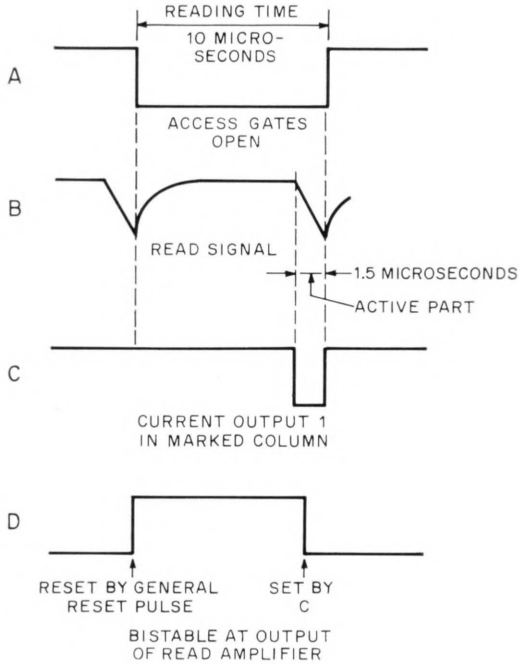
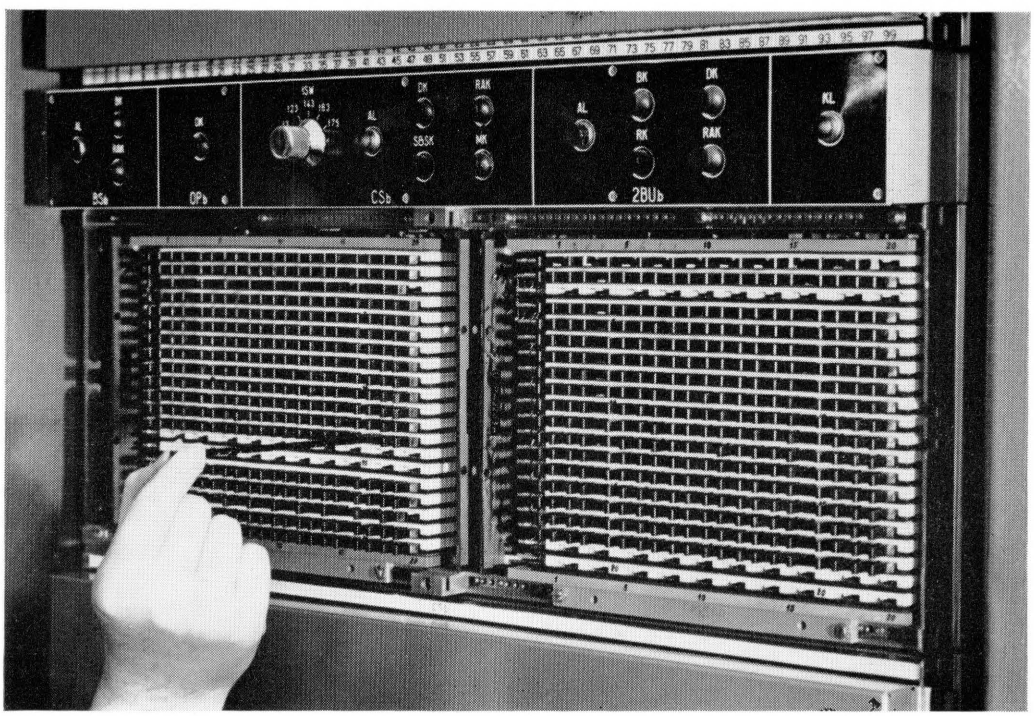


Figure 12—Read cycle of capacitor store.

Figure 11—Front view of complete store.



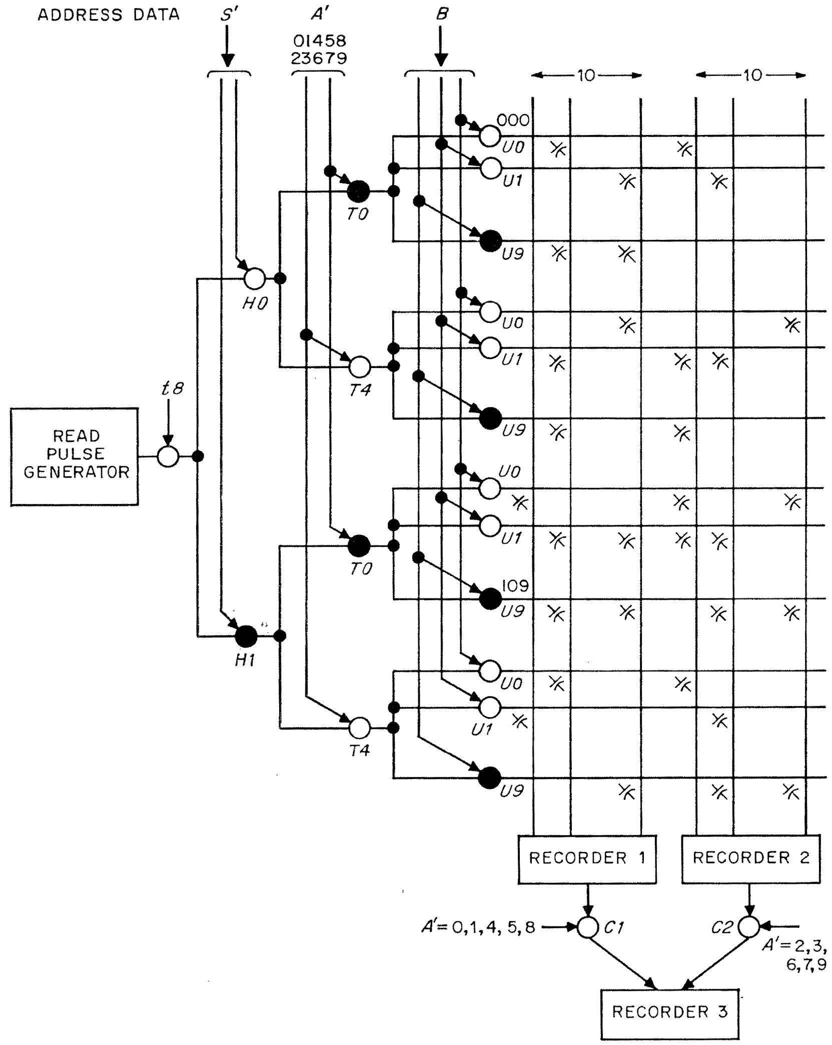


Figure 13—Principle of access gating for 160 $S'A'B$ combinations of the number-of-digits section.

to the wanted row by means of an access gating network which is opened during 10 microseconds (Figure 12*A*).

The active part of this read waveform is the linearly falling section at the end of the 10-microsecond access time. It produces a constant current in all columns which are coupled to the interrogated row and leaves the others substantially currentless (Figure 12*C*). Hence the capacitor code is converted into a current code in the column wires.

The access gating network is a diode-resistor arrangement mounted on the submatrices as illustrated by Figure 8.

The gating principle is shown in Figure 13.

The access to the 160 $S'A'B$ addresses of the number-of-digits section of the matrix is represented. For instance, when the row corresponding to $S' = 1$, $A' = 0$, and $B = 9$ is to be addressed, access gates $H1$, $T0$, and $U9$ are opened together with column selection gate $C1$. Hence the read pulse gets to row 109 during time

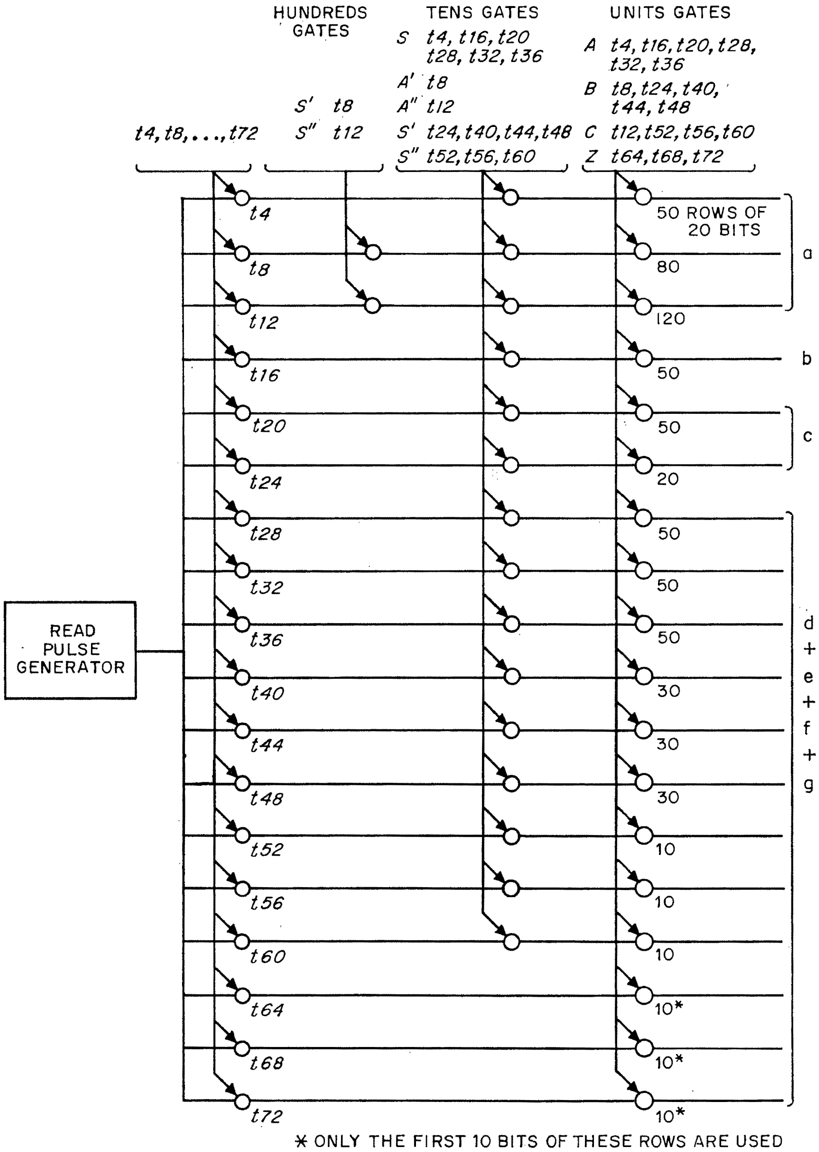


Figure 14—Access to the route translator.

interval $t8$. All 20 bits of this row are interrogated but only the first 10 are sent to recorder 3, where the answer is made available. As indicated, the 10 figures A' are rearranged into 5 groups of 2 for driving the five T gates and in 2 groups of 5 for driving gates $C1$ and $C2$, respectively.

The overall addressing network is given by Figure 14.

The addressing data S,A,B,C,S',A',S'',A'',Z are conditioned with the timing pulses written behind them. For example, at the first interrogation time slot ($t4$), A is connected to the units gates and S to the tens gates for interrogating one of the 100 SA addresses of the number-of-digits section of Figure 6.

In a further stage (for example, at time slot $t52$) the address data S'',C are connected to the

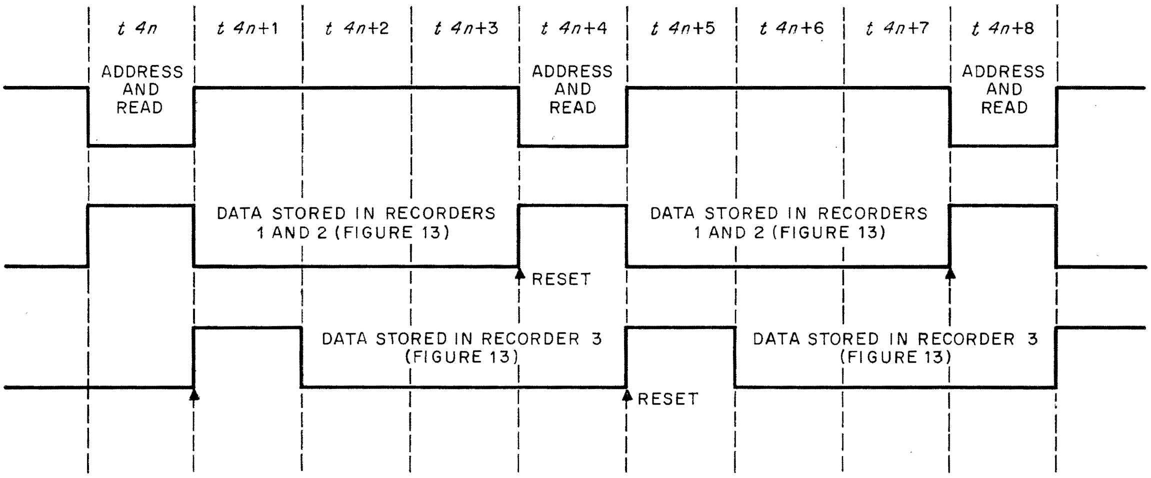


Figure 15—Timing of route translator.

tens and units gates, respectively, for interrogating one of the 20 $S''C$ addresses of the route-data section of Figure 6.

The readout equipment of the capacitor store consists of a sensitive current amplifier per column wire for detecting the *1* current in the columns which are capacitively coupled to the interrogated row. The main characteristics of this amplifier are (A) a low input impedance to permit short transient times, and (B) a stabilized gain to permit the elimination of noise by a fixed threshold after amplification.

A resistance-capacitance-coupled amplifier is used with a common-base input stage and negative feedback.

The read data are stored on bistables which are triggered by the signals exceeding the threshold of the amplifiers. These bistables are reset to *0* before each successive reading by means of a general reset pulse (Figure 12D).

The actual timing of the read operations is shown in Figure 15. Each time the route translator is engaged, a pulse generator is started which generates a series of 96 timing pulses of 10-microsecond width. The store is addressed at each fourth time slot ($t4, t8, t12, \ldots, t72$). The data read out are displayed by recorder 3 (Figure 13) during the 3 time slots ($t4n+2$, $t4n+3$, $t4n+4$ following the readout time slot $t4n$.

8. Transcoding and Display of Read Data

For uniformity and ease of code checking, 2-out-of-5 and 4-out-of-5 codes are used throughout the store. However, the information to be delivered to the telephone registers must be adapted to the requirements of these circuits. Therefore transcoding is required before the data can be sent out. This is achieved by the "answer processing unit," part of which is shown in Figure 16.

The data delivered by recorder 3 (10 bits) are first analyzed by the code detector, which finds out the code used (2-out-of-5 or 4-out-of-5). Combining the result with the time slot of occurrence determines whether the data are a "new address" or a final answer. For example (referring to Figure 6), in time slots $t6$ and $t10$ a 2/5 code means a "new address" whereas in time slot $t30$ (e and f) it means a final answer. Gate $G2$ represents also the transcoding of the answer into a code adapted to the telephone register. The data a,b,c,d,e,f,g are sent to the buffer circuit in time slot $t89$.

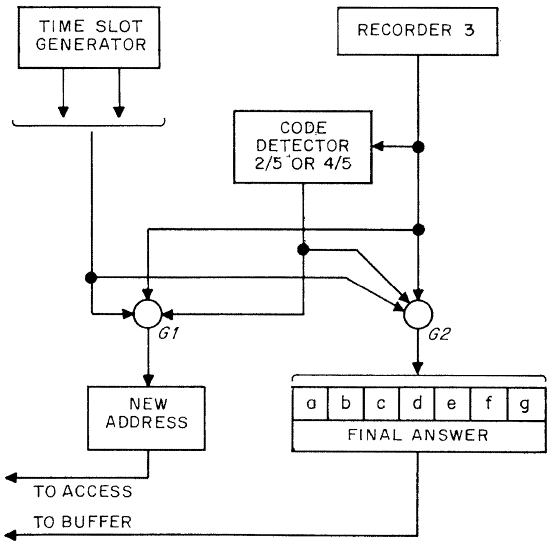


Figure 16—Transcoding and display.

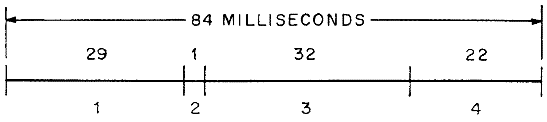


Figure 17—Timing in buffer circuit in milliseconds.

1. Connection of telephone register to buffer by operation of connecting relay in register.
2. Interrogation of route translator and storage of answer.
3. Sending of answer to telephone register where it is stored on relays.
4. Release of connecting relay in telephone register.

9. Start of the Route Translator—The Buffer Scanner

As shown in Figure 2, the route translator is common for all buffer circuits. Each buffer has a test point to which a calling potential is applied whenever the buffer needs the route translator. A buffer scanner in the answer processing unit scans these test points continuously at a rate of 1 per 10 microseconds until it finds a "calling potential." It then stops, connects the addressing and answering wires of the calling buffer to the route translator, and starts the route translator operation by triggering the time slot generator. After one complete cycle (96 time slots of 10 microseconds) the route translator is restored to rest and the buffer scanner continues searching for a calling buffer.

10. Buffer Circuit

As explained previously, the buffer circuit is used to adapt the "low" operation speed of the electromechanical telephone registers to the "high" speed of the route translator to use it efficiently. The buffer circuit performs the following functions.

(A) It scans the test points of the telephone registers and detects and identifies those waiting for prefix translation. This function is performed by the register scanner of each buffer.

(B) It establishes a signaling path to such a "calling" register (by operating a connecting relay in the register circuit) and receives the prefix to be analyzed.

(C) It calls for route translation service, addresses the route translator by the received prefix, and stores the answer at the end of the translator cycle.

(D) It sends the answer to the telephone register during a time sufficient to operate a set of recorder relays.

(E) It releases the signaling path to the telephone register.

The timing scheme of the buffer is given by Figure 17.

11. Reliability

To ensure service continuity in case of a component failure, duplicate equipment is used in accordance with Figure 18.

The telephone registers are arranged in groups *A, B, . . . , N,* each comprising 60 circuits. Each group is served by 2 buffers. For example, each of the *A* registers has access to buffer *a*1 and buffer *a*2 by having a scanning point in register scanner *a*1 and register scanner *a*2. The actual central equipment consisting of the route translator and the address and answer processing unit is duplicated. Each buffer circuit has access to both of them by having a scanning point in both buffer scanners.

The register scanners serving the same register group are mutually exclusive, which avoids double testing of a calling telephone register. For the same purpose, electronic suppression of the calling potential is used in the buffer scanner as soon as it has been detected.

11.1 Codes and Code Checks

Redundant codes are used throughout the equipment to enable fault detection and localization.

The following checks are provided (see Figure 18).

(A) Address data sent to route translator (*Ca1*, *Cb1*).

(B) Answer delivered by route translator (*Ca2*, *Cb2*).

(C) Answer after transcoding in answer processing unit (*Ca3*, *Cb3*).

(D) Answer as sent to telephone register (*Ca4*, *Cb4*).

The results of the first 3 checks are transferred to the buffer together with the actual answer. The buffer then compares the check results to determine whether a fault is due to its own equipment or to the central part. In the first case it blocks itself, while in the second no action is taken. With one of two associated buffers out of order, the grade of service of the 60 telephone registers involved is decreased but can be accepted during the time required to

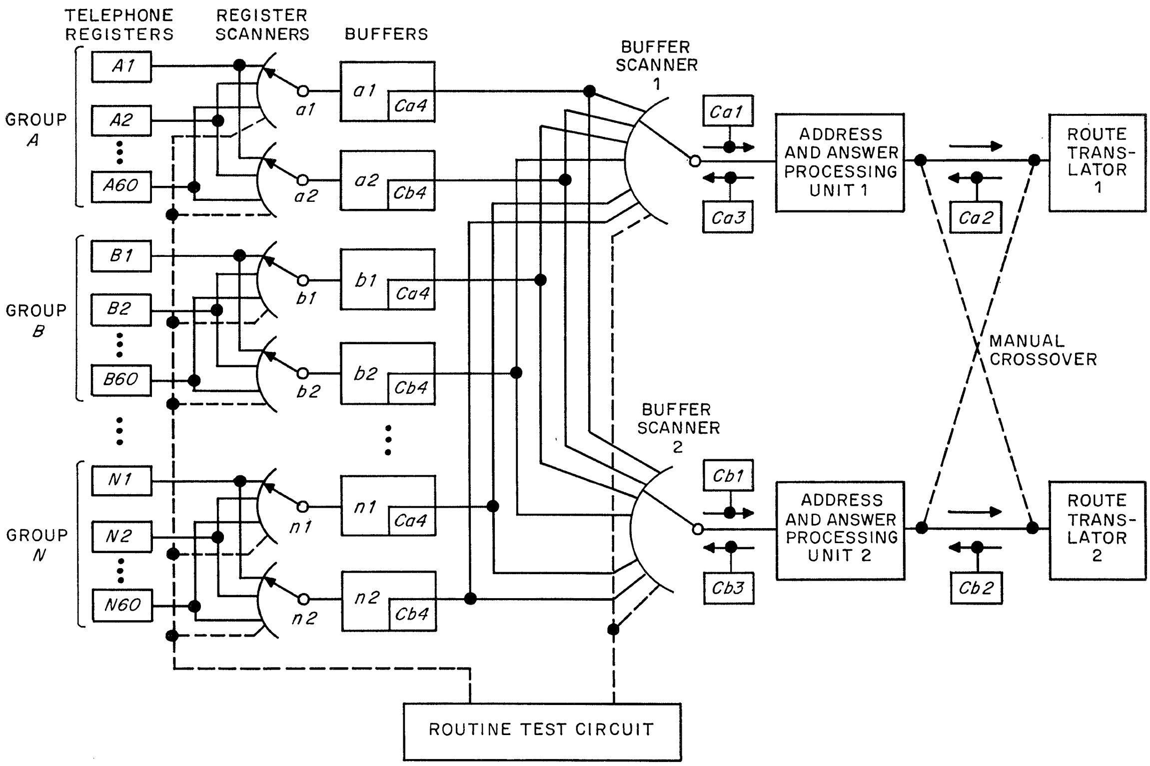


Figure 18—Block diagram of number analyzer.

clear the fault. A fault in the central part is treated by the routine test circuit.

11.2 Routine Tests

The central part of the number analyzer is permanently supervised by an automatic electronic routine test circuit, which acts as a buffer circuit and therefore has a scanning point in buffer scanners 1 and 2. As it runs continuously, any fault in the central equipment is almost immediately detected and the faulty unit taken out of service. With half of the central part out of order, the grade of service is not affected because the remaining part is capable of handling all the traffic.

The routine test circuit also has a scanning point in the register scanners for completing the tests on the buffer circuit. When in the buffer testing phase, it simulates a telephone register and checks those parts not covered by check *Ca*4 or *Cb*4.

11.3 Maintenance Facilities

To ease fault tracing, the more significant bistables are provided with a visual indicator enabling their position to be read and deductions to be made without requiring measuring equipment.

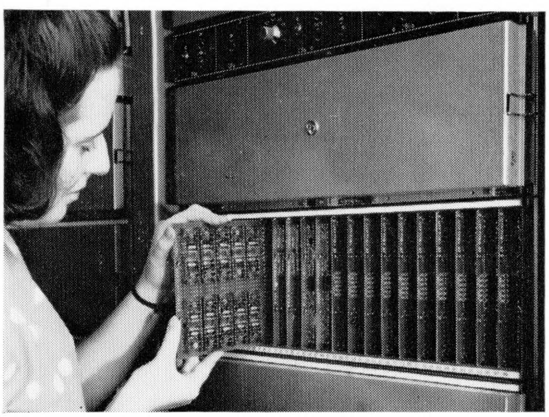


Figure 19—All parts are mounted on plug-in cards, and Minibell type paraplate modules are used.

A manual crossover may be arranged between the route translators and the address and answer processing units to increase equipment flexibility during servicing.

12. Equipment Practice

The International Standard Equipment Practice * has been used throughout. All parts are

* F. Beerbaum, J. Evans, and F. Leyssens, "Standard Equipment Practice for ITT Europe," *Electrical Communication,* volume 39, number 2, pages 199–211; 1964.

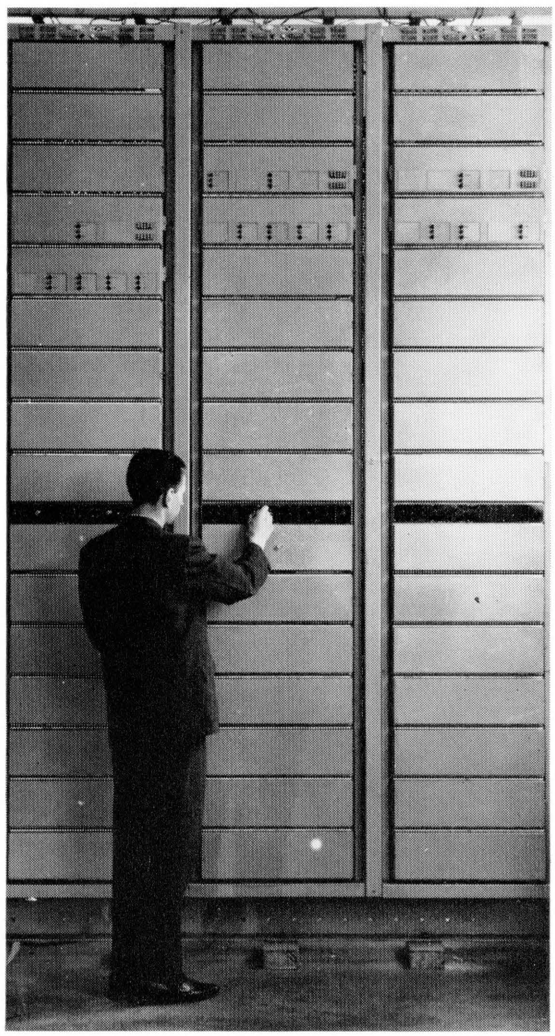


Figure 20—Front view of complete route translator.

mounted on plug-in cards of the standard-practice size, 176.5 × 160 millimeters (7.0 × 6.3 inches). For the logic building blocks, paraplate modules of the Minibell * type are used as can be seen in Figure 19.

* Standard of Bell Telephone Manufacturing Company.

Figure 20 is a front view of a route translator capable of serving 120 telephone registers. It contains 3 bays and is 3105 × 1800 × 265 millimeters (122 × 71 × 10.4 inches) in overall size. For each additional 60 registers, half a bay is required.

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Portable 7-Gigahertz Radio System for Multichannel Telephony

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1. Introduction

The use of transistors and the modular construction of radio- and intermediate-frequency circuits has led to a new generation of all-solid-state small-capacity radio link equipments, first introduced in the 6-gigahertz auxiliary radio link [1]. This earlier equipment met somewhat less severe requirements than the 7-gigahertz independent radio link described here.

Although both equipments offer high reliability, low power consumption, and carry the same message loads, the 7-gigahertz system has a higher output power so that it can use smaller antennas, has better suppression of spurious signals for a tighter frequency plan, better noise performance, and its own service channel.

The *BFM24-7000* is intended to provide short-haul facilities (*A*) in difficult geographic situations, (*B*) where wire line facilities would prove uneconomical, (*C*) where open wire requires replacement or is difficult to maintain, (*D*) where existing cable routes are being exhausted, and (*E*) as spurs leading from heavy-traffic microwave systems.

Both systems are designed to transmit up to 24 channels while meeting noise performance of −59 decibels relative 1 milliwatt referred to a point of zero relative level, psophometrically weighted, over 6 hops covering approximately 300 kilometers (180 miles).

Reliability is obtained by using highly derated silicon planar epitaxial transistors and diodes, tantalum capacitors, and carbon film resistors.

Only 30 watts are necessary for a receiver-transmitter combination. A standby battery will normally operate the system for more than 24 hours in the event of failure of mains power. Mains and battery are connected in parallel, so that automatic switching occurs and there is no interruption of service. Operation on battery alone is also possible. The supplementary order wire or service channel has a power consumption of 5 watts.

Simplicity and compactness have been emphasized in the design. Maintenance procedures as well as installation cost have been held to a minimum consistent with equipment requirements. Antennas for this band together with supporting structures are commercially available at low cost.

The equipment can be used at temperatures from −20 to +55 degrees Celsius. Various applications are possible, such as on unattended stations in mountains or as relays in a pole-line system.

2. General Description

2.1 Radio Equipment

The radio-frequency equipment uses direct modulation (without translation to an intermediate frequency), and the signal is demodulated at each repeater to provide access to the baseband.

Direct phase modulation is used to satisfy the stringent requirements of frequency stability obtained with quartz-crystal-controlled oscillators.

The high order of successive frequency multiplication also allows for noncritical tuning of the linear modulator, as deviation at the modulating frequency is only 1/256 of final deviation.

2.2 Technical Characteristics

Frequency Range: 7125–7425 megahertz with extension to 8400 megahertz.

Frequency Plan: Depends on country or per Recommendation 385 of the International Radio Consultative Committee. Channel spacing = 7 megahertz.

Frequency Spacing: 161- or 175-megahertz spacing between transmitter and receiver of same channel.

Adjacent Channels: 14-megahertz spacing between channels on the same antenna.

Transmitted Power: Minimum transmitted power is +17 decibels referred to 1 milliwatt.

Transmitter Frequency Stability: $\pm 5 \times 10^{-6}$ with an accuracy of $\pm 2 \times 10^{-5}$ or $\pm 1 \times 10^{-5}$ (for all causes including tolerances).

Minimum Receiver Input (Threshold):* −90 decibels referred to 1 milliwatt.

Receive Noise Figure: 12 decibels maximum.

Fading Margin: 35 decibels.

Intermediate-Frequency Center Frequency: 35 megahertz.

Number of Channels: Up to 24 channels are available.

Baseband Width: 6–108 kilohertz.

Baseband Level Input: −45 (+0, −3) decibels referred to the level at the 2-wire point of origin.

Baseband Level Output: −15 (−0, +3) decibels referred to the level at the 2-wire point of origin.

Baseband Impedance: 75 ohms unbalanced or 150 ohms balanced.

Pre-emphasis and De-emphasis: 3 decibels per octave.

Maximum Hops in Tandem: 10.

Ambient Temperature: −20 to +55 degrees Celsius for full performance.

System Figure†: 145.5 decibels.

* Threshold is defined as the super-high-frequency receiver input level at which the baseband output varies by 0.5 decibel.

†The system figure is defined as the sum (in decibels) of (*A*) the weighted signal-to-noise ratio in a telephone channel and (*B*) the attenuation between transmitter output and receiver input.

3. Design of Typical Hop

The expected performance of a hop may be computed for the equipment on the following assumptions.

Path loss for 50 kilometers at center of frequency band (decibels)	144
Loss at antenna connections (4 decibels), both sides (decibels)	8
Total loss (decibels)	152
Minimum transmitter power (50 milliwatts) (decibels referred to 1 milliwatt)	+17
Gain of antenna (40 decibels) for 6-foot diameter, both sides (decibels)	80
Overall planning net loss (decibels)	72
Receiver carrier power (decibels referred to 1 milliwatt)	−55
Fading margin (decibels)	35

Figure 1 represents these values and shows the equivalent repeater gain of 72 decibels.

4. Transmitter Chain (Figure 2)

4.1 Oscillator and Modulator Circuits

The basic frequency of the crystal oscillator is between 28 and 29 megahertz. The crystal is mounted in a temperature-controlled oven to maintain the required stability of $\pm 5 \times 10^{-6}$. A series-tuned circuit, in series with the crystal, allows an adjustment of the frequency with a tolerance of $\pm 1 \times 10^{-5}$ [2]. The oscillator consists of a transistor connected in common-base configuration, with the crystal in the feedback circuit between collector and emitter.

The collector circuit of the oscillator is directly modulated with the order-wire signals (300 to 3400 hertz), giving accessibility in this way independently of the multiplex equipment.

The baseband signal, amplified by the transmitter baseband amplifier mounted on the modulator board, is given a pre-emphasis characteristic of 3 decibels per octave.

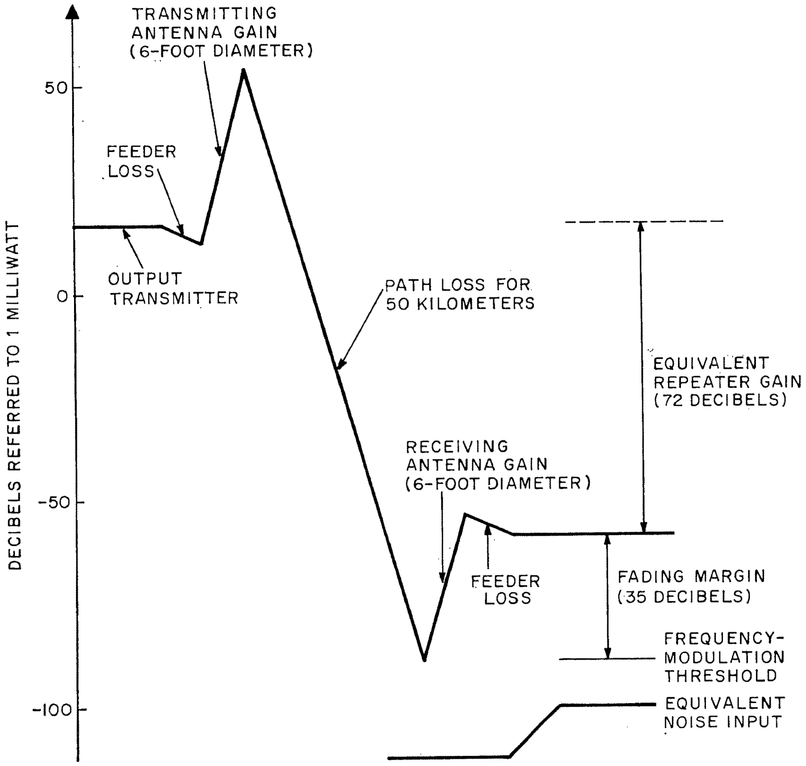

Figure 1 — Performance characteristics for an intermediate-frequency bandwidth $B_{if} = 1.5$ megahertz and a noise figure of 12 decibels. The equivalent noise input $= KTB_{if}$.

The oscillator is separated from the modulator circuit by a common-emitter common-base cascode isolating amplifier.

Phase modulation by the baseband signal occurs at the carrier fundamental frequency (28–29 megahertz). This direct phase modulation is obtained in a tuned circuit with a Q of about 20, the center frequency of which is varied by applying the modulating signal to a semiconductor diode, acting as a voltage-controlled capacitor.

The deviation is 1/256 radian root-mean-square at a baseband of 100 kilohertz. The frequency of the phase-modulated signal is then multiplied by 2, and finally the signal is amplified and limited to a nominal level of 50 milliwatts at the output of the modulator.

4.2 Multiplier Chain

4.2.1 *Active or Transistor Part*

The modulated carrier is multiplied by 4 and amplified to an output level of approximately 2 watts at 225 megahertz. This amplifier uses three *2N3137* and one *2N3553* transistors for the final output stage. Heat sinks are used.

4.2.2 *Passive or Varactor Part*

The first varactor frequency changer multiplies the input frequency by 4 with a typical conversion loss of 3 decibels. This circuit is built on stripline and uses one idler circuit at the second harmonic of the input frequency.

About 1 watt at approximately 900 megahertz is delivered to the final multiplier or octupler, using a coaxial input and a waveguide output.

The coaxial band-pass input filter and the matching circuits, as well as the idler circuits at the second and fourth harmonics, have a conversion loss of typically 7 to 8 decibels (loss of output filter not included). The output power variation of the whole chain for the extreme temperature range is typically less than 2 decibels.

4.3 Transmitter Waveguide Filter and Antenna Connection

The 3-section direct-coupled waveguide filter is of the minimum-insertion-loss type. The 3-decibel bandwidth of the transmitter filter is 20 megahertz (see Figure 3). Special care in manufacturing permits low insertion loss to be achieved.

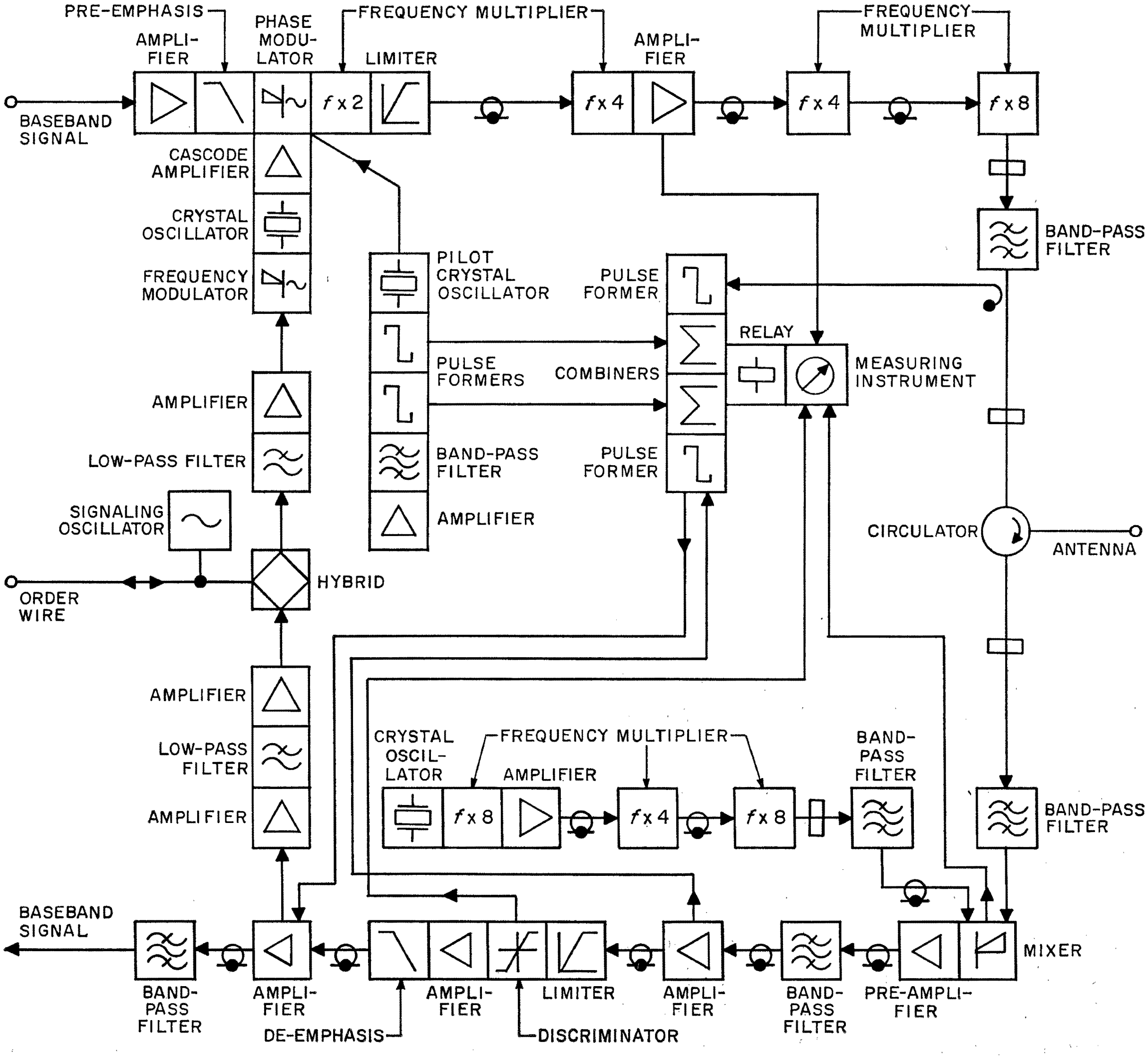

Figure 2—Block diagram of transmitter and receiver.

As direct-coupled filters have spurious pass bands, any need for better spurious suppression can be met with a broad-band interdigital filter [3]. A broad-band waveguide-to-coaxial connector transition is available for simple direct connection to the antenna structure.

A circulator can also be mounted on the equipment, permitting common antenna operation for both transmitter and receiver.

5. Receiver Chain (Figure 2)

5.1 General

The selectivity of the receiver and its noise figure determine the threshold. The selectivity is a compromise between the minimum bandwidth of the spectrum to be transmitted and the super-high-frequency channel spacing. To keep the distortion within limits with a 4-pole filter, the 3-decibel intermediate-frequency bandwidth must be at least 1.32 megahertz. However, in some countries (for example Germany) the frequency plan is specified with a 0.5-megahertz channel spacing. The perturbing signal 0.5 megahertz from the wanted signal must be attenuated by 30 decibels, 1 megahertz away by 10 decibels, and 2 megahertz away may be at the same level.

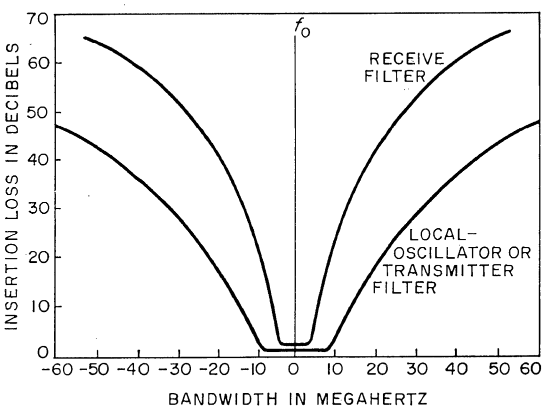

Figure 3—Insertion loss of waveguide filters as a function of bandwidth.

5.2 Super-High-Frequency Parts (Figure 4)

The preselector is a 3-cavity direct-coupled fixed-tuned band-pass filter. It prevents local-oscillator radiation and provides an image-frequency attenuation of at least 60 decibels.

Since the 3-decibel bandwidth is half that of the transmitter (typically 8 to 9 megahertz), this highly selective filter is made of invar to reduce detuning effects with temperature.

The balanced mixer, using the local-oscillator frequency, converts the super-high-frequency input signal to an intermediate frequency of 35 megahertz. Matched-pair diodes realize a noise figure of 8 to 9 decibels. The balanced structure of the waveguide mixer reduces the amplitude-modulated noise contribution of the local-oscillator chain in the noise figure and provides a 30-decibel-minimum isolation of the local-oscillator frequency into the waveguide. Local-oscillator radiation at the antenna connector is further reduced by at least 30 decibels in the preselector.

A low-noise intermediate-frequency preamplifier that has a broad-band (6-megahertz) gain of 20 decibels is part of the structure of the mixer unit.

5.3 Local-Oscillator Chain

The local-oscillator chain is similar to the transmitter chain, except for the omission of modulation and for the levels encountered. The 500-milliwatt output of the transistor stages gives about 5 milliwatts at the local-oscillator input to the mixer. A fixed attenuator of 6 decibels is inserted at the output of the final octupler to provide isolation between the multiplier chain and the mixer.

5.4 Intermediate-Frequency Chain

The intermediate-frequency main amplifier is preceded by a filter which substantially determines the selectivity of the receiver.

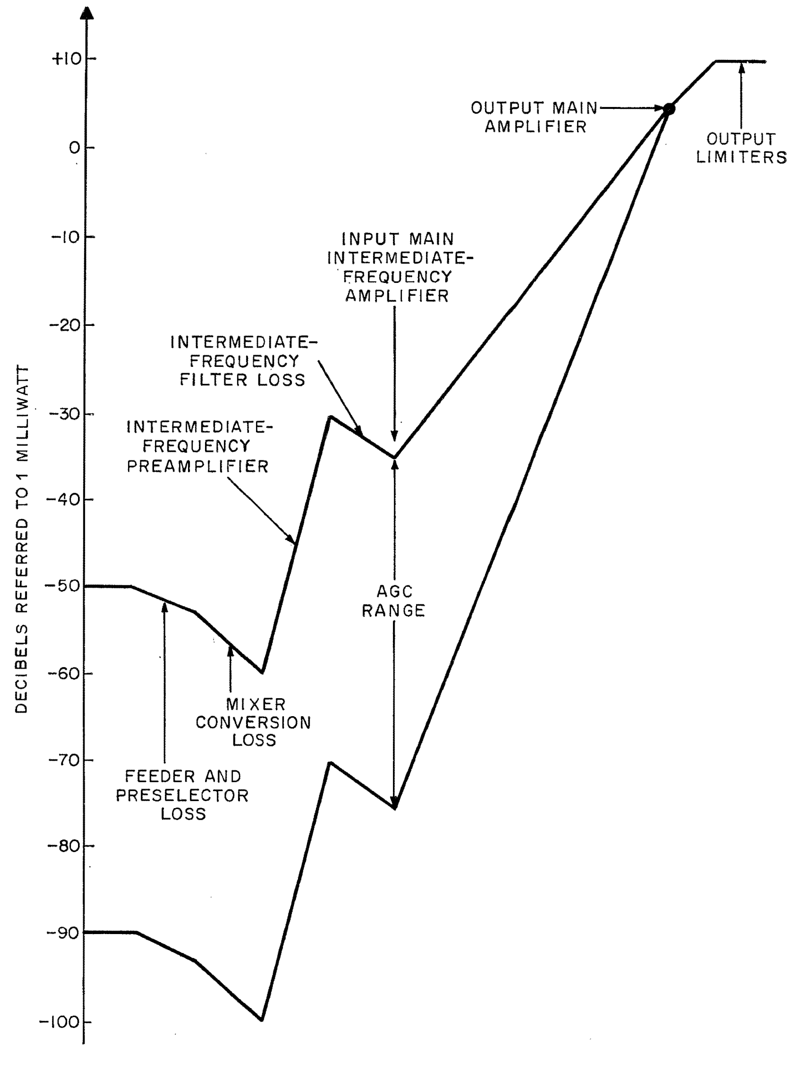

Figure 4—Receiver levels.

This filter consists of 4 synchronously tuned capacitively coupled circuits with a 3-decibel bandwidth of 1.8 megahertz, with a typical insertion loss of 4 decibels. The total intermediate-frequency bandwidth at 3 decibels down is reduced to 1.5 megahertz by the selectivity of the main intermediate-frequency amplifier.

This amplifier is realized with 5 cascode circuits, synchronously tuned (common-emitter common-base configuration). Since this configuration has the property of good isolation between output and input, it permits easy tuning and good stability [4].

An automatic-gain-control circuit varies the gain of the amplifier and also delivers a voltage for alarm indication.

5.5 Demodulator and Baseband Amplifier

The demodulator board includes two amplifier-limiter stages, the discriminator, and the de-emphasis circuit.

The limiting is realized with 2 tuned amplifier stages, the output collector circuit being shunted by two diodes. These silicon diodes are mounted with opposite polarity, so that limiting is at ± 0.7 volt approximately.

For linearity, the balanced discriminator has a peak separation deviation of 8 megahertz.

The demodulated signal is passed through a de-emphasis network with a characteristic identical to the pre-emphasis 3-decibel-per-octave curve. The two 3-decibel-per-octave characteristics compensate for the 6 decibels per octave resulting from the demodulation of a phase-modulated signal by a frequency discriminator.

The baseband signal is then amplified to obtain the nominal level at interconnection point with the multiplex equipment. This baseband-amplifier board consists of a series of attenuator pads to permit adjustment of the output level in steps of 0.5 decibel, and a 3-stage resistance-capacitance-coupled amplifier with resistance feedback.

6. Auxiliary Circuits

6.1 Service Channel

The service channel arrangement allows conversation between stations on a party-line basis. A 2-wire connection is available for a remote telephone set or a 4-wire connection for measuring transmission. In-band signaling is used at 1600 hertz.

The speech channel can be limited to 2400 hertz, so that remote-control and signaling information can be transmitted. If one hop happens to be interrupted, the service channel is kept operative on the intact hops.

6.2 Power Supply and Metering Circuits

The power supply can be connected to mains, to battery, or to both. For mains connection, voltage variations of -15 to $+10$ percent are acceptable within the frequency range of 47 to 63 hertz. For battery applications, inputs between 21.5 and 29 volts can be tolerated by the series regulator.

A selector knob, associated with a built-in meter, allows the operation of the most important stages of the transmitter and the receiver to be checked, thus simplifying maintenance.

6.3 Alarm Circuits

Visual indications of transmitter or receiver failure are monitored with alarm lamps mounted on the front panel of the power supply. The transmitter alarm is actuated when the super-high-frequency output power falls 3 decibels below normal level. The receiver alarm is actuated when the super-high-frequency input level falls below a predetermined level above the threshold.

This alarm may also be combined with pilot oscillator or detector alarm, if necessary. External contacts for local or remote indication are provided.

6.4 Pilot

A continuity pilot at 116 or 119 kilohertz is optional. Baseband filters with pilot band-stop or band-pass characteristics are available for various system applications.

7. Mechanical Considerations

The modular approach has led to complete standardization of circuit boards in plug-in shielded molded boxes. These boxes have the following features.

(A) Radio-frequency shielding is greater than 80 decibels.

(B) Both sides of the printed-circuit board are easily accessible without special tools.

(C) They follow the standard equipment practice for ITT Europe [5].

Interchangeable plug-in units and built-in meter and metering circuits simplify maintenance. Repairs can be done in a central work shop.

Two versions of the equipment are available.

(A) Figure 5 shows the subrack version for bay mounting. A complete transmitter-receiver with standby, order wire, and changeover equipment can be mounted with its multiplex equipment for 24 channels in a bay 2000 millimeters (79 inches) high, 220 millimeters (8.6 inches) deep, and 600 millimeters (23.6 inches) wide.

(B) Figure 6 shows the portable version in a hermetic waterproof box with a total weight of 20 kilograms (45 pounds). It has external super-high-frequency coaxial connections as well as alarm and order-wire extensions. This version can be used, for example, when the radio equipment can be mounted near the antenna structure while the multiplex equipment is installed some distance away.

8. Typical Performance and Measured Data

Figure 7 shows a typical result of a system performance measurement, the signal-to-noise ratio in a telephone channel as a function of the super-high-frequency path attenuation. The system figure at the highest modulating channel (108-kilohertz slot) is 145 decibels. This value is 147 decibels at 70 kilohertz and 153 decibels at 15 kilohertz. The increase of the system figure with decreasing modulating frequency is due to the modulation improvement factor.

Figure 8 shows the influence of a perturbing super-high-frequency signal, modulated with white noise in the baseband 6–108 kilohertz, on the signal-to-noise ratio in a telephone channel at the normal received super-high-frequency signal. Measurements have been made at normal path attenuation of 60 decibels. A signal-to-noise ratio of less than 50 decibels, psophometrically weighted, was considered to be a perturbation.

9. Conclusion

A compact all-solid-state small-capacity radio link in the 7-gigahertz range has been demonstrated to satisfy very stringent requirements for independent use by public or private networks.

This equipment also satisfies the national requirements in Germany of January 1966 (FTZ 529-R1-2925) and makes it possible to achieve parallel hops with a frequency separation of 2 megahertz. An attenuation of 10 decibels, obtained with different polarizations, permits operation at a separation of 1 megahertz.

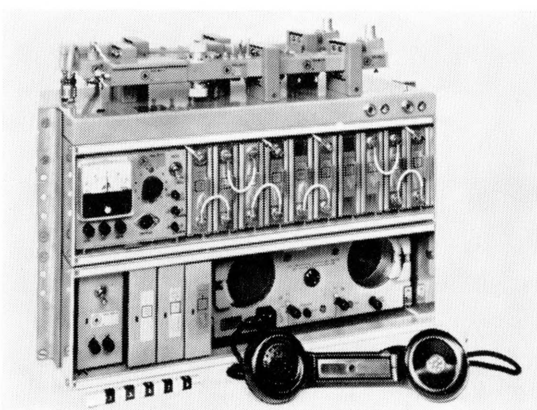

Figure 5—Subrack version of the *BFM24-7000*.

Figure 6—The *BFM24-7000* mounted in a portable cabinet.

10. References

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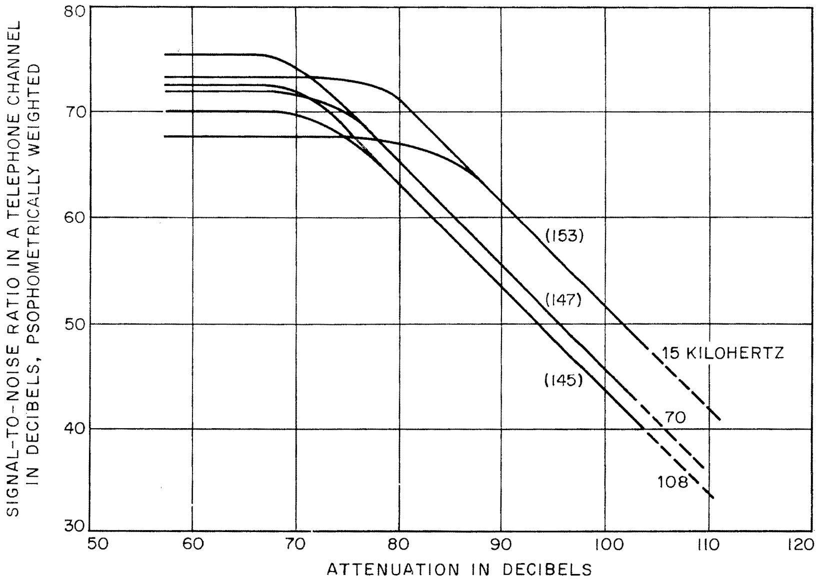

Figure 7—System performance measurements for 3 representative channels. System noise figures in decibels are shown in parentheses.

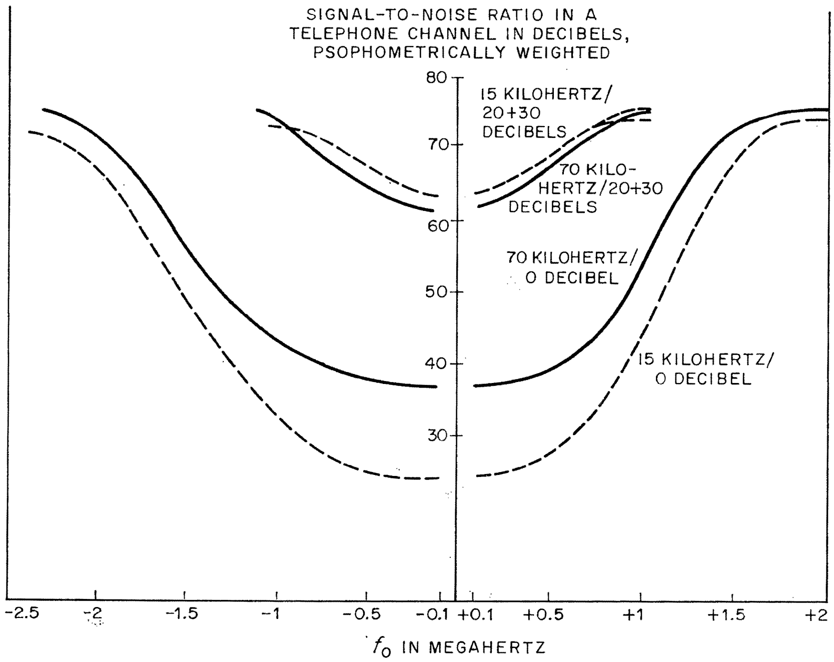

Figure 8—Influence on 15- and 70-kilohertz channels of a perturbing super-high-frequency signal modulated by white noise over the baseband from 6 to 108 kilohertz.

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In 1961 he joined the Bell Telephone Manufacturing Company and in 1963 took charge of a development group. Since June 1966 he has been in charge of the radio-link department.

Railway Cable with High Screening Properties

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1. Introduction

Whenever an alternating current runs in an elongated loop parallel with ground, a voltage is induced in parallel metallic structures such as buried cables. The greater the distance between the go and return currents of the primary loop, the greater the induced voltage. Dangerous voltages can occur in buried telephone cables when an electrical earth fault develops in a nearby power transmission line. If the power transmission system operates with an earthed neutral, the short-circuit current can become high enough to damage the telephone cables. If in addition the earth conductivity is low, dangerous voltages can be induced even in cables buried at considerable distances from the power line.

In Norway, where long power transmission lines run along the valleys from remote hydroelectric stations and the ground conductivity is very low, voltages induced in telecommunication cables presented a problem that could be solved economically only by the use of aluminum-sheathed steel-tape armored telephone cables.

A similar problem arises when railways are electrified by single-phase alternating current with return through the rails and the ground. In this case the induced voltage is rarely high enough to endanger the cable or the operators. On the other hand, harmonics in the traction current may cause unacceptable interference on parallel telephone cables.

To reduce this effect the Norwegian State Railways (*NSB*) normally installs booster transformers. These reduce the spread of the return current and increase the rail current from 50 to 60 percent of the current in the catenary to 95 to 99 percent. This considerably reduces the voltage induced in cables installed some distance from the railway track, but does not have so great an effect on cables laid directly along the track. The railway-owned telephone and signaling cables are normally placed on the right-of-way because the railway must serve way stations along the line. Using normal lead-covered steel-tape-armored cables having virtually no screening effect at these low induced voltages, the described installation practice involving booster transformers gave induced voltages of the order of 1.4 to 2.3 volts per 100 ampere-kilometers of catenary current. The induced voltage was found to be in accordance with the following equation, which is valid for distances between 2 and 5 meters (6.5 and 16.4 feet).

$$e = 3.6/D \qquad (1)$$

where

e = induced voltage per 100 ampere-kilometers
D = horizontal distance between the middle of the track and the cable in meters.

This was considered acceptable for the then relatively short cable systems belonging to Norwegian State Railways.

When the Norwegian Telecommunication Administration (*NTA*) in one instance in 1949 had to share the trench with Norwegian State Railways along the railway track, the induced voltages caused some operational difficulties for the former. The matter was then investigated more thoroughly, and it was found both by theoretical calculations and by experiments that the induced voltage would fall steeply with increasing horizontal distance for the first 12 meters (40 feet). Beyond 12 meters the induced voltage would remain practically constant, as shown in Figure 1. Hence it was agreed that whenever these two administrations had to share a trench, the distance between the middle of the rails and the cable would be 12 meters if possible. After this technique was adopted, the induced voltage was reduced to the order of 0.2 volt per 100 ampere-kilometers. This value was approximately halved when ordinary aluminum-sheathed steel-tape-armored cables were introduced.

2. Electrification of Oslo-Bergen Railway

The Oslo-Bergen railway is one of the main lines connecting the two largest cities in Norway. It runs for a total of 492 kilometers (306 miles) through valleys in the eastern part, across the mountain plateau at altitudes up to 1301 meters (4269 feet), and then along the fjords in the western part. It is well known for beautiful scenery. For 15 percent of the distance it runs through tunnels or snow screens as shown in Figure 2. A map of the line is shown in Figure 3.

When this line was about to be electrified, the following problems arose.

(A) The terrain was very rugged, making it impossible on many stretches to dig a trench at least 12 meters from the center of the track.

(B) The highest part of the route (Haugastøl to Myrdal) had to be electrified without booster transformers. Regular inspection and repair of tunnels and snow screens are necessary on this stretch. To do this without danger the voltage must be switched off. To reduce the influence on traffic, a bypass feeder line had to be built some distance from the track and this precluded the use of booster transformers.

(C) The ground conductivity was extremely low, as shown in Table 1.

TABLE 1

GROUND CONDUCTIVITY ALONG THE OSLO-BERGEN RAILWAY

	Conductivity in Electromagnetic Units	Resistivity in Ohm-Meters
Typical rocky country	2×10^{-14}	500
Hønefoss-Gulsvik	2×10^{-15}	5 000
Gulsvik-Nesbyen	1×10^{-15}	10 000
Gol-Ustaoset	4×10^{-15}	2 500

On the sections Oslo-Roa and Hønefoss-Nesbyen-Gol, ordinary aluminum-sheathed steel-tape-armored cables were installed where possible 12 meters from the center of the track. Measured induced voltages on these sections are given in Table 2.

TABLE 2

INDUCED VOLTAGES, OSLO-GOL*

Section	Cable Length in Kilometers (Miles)	Distance Between Cable and Center of Track in Meters (Feet)	Induced Voltage per 100 Ampere-Kilometers of Catenary Current
Oslo-Roa	58.5 (36.4)	12 (40)	0.065
Hønefoss-Nesbyen	89.4 (55.6)	12 (40)†	0.184
Nesbyen-Gol	14.4 (8.9)	12 (40)	0.128

* With booster transformers.
† Long portions have cable only 2.5 meters (8.2 feet) from center of track.

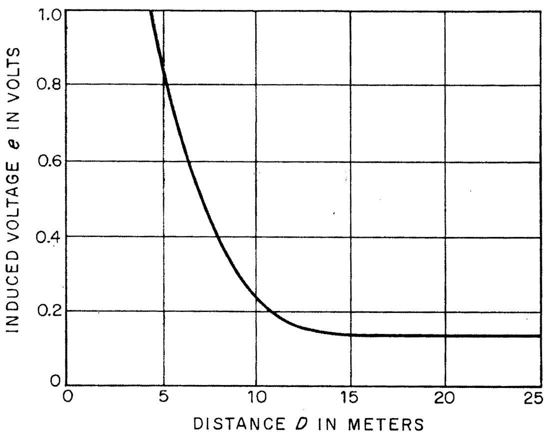

Figure 1—Induced voltage e per 100 ampere-kilometers as a function of distance D from middle of track (experimental results from southwest Norway on a stretch with booster transformers).

From Gol westward to Uppsete the cable had to be installed directly alongside the track for reasons already explained. It was necessary to develop a special cable for this section that had considerably improved screening properties at

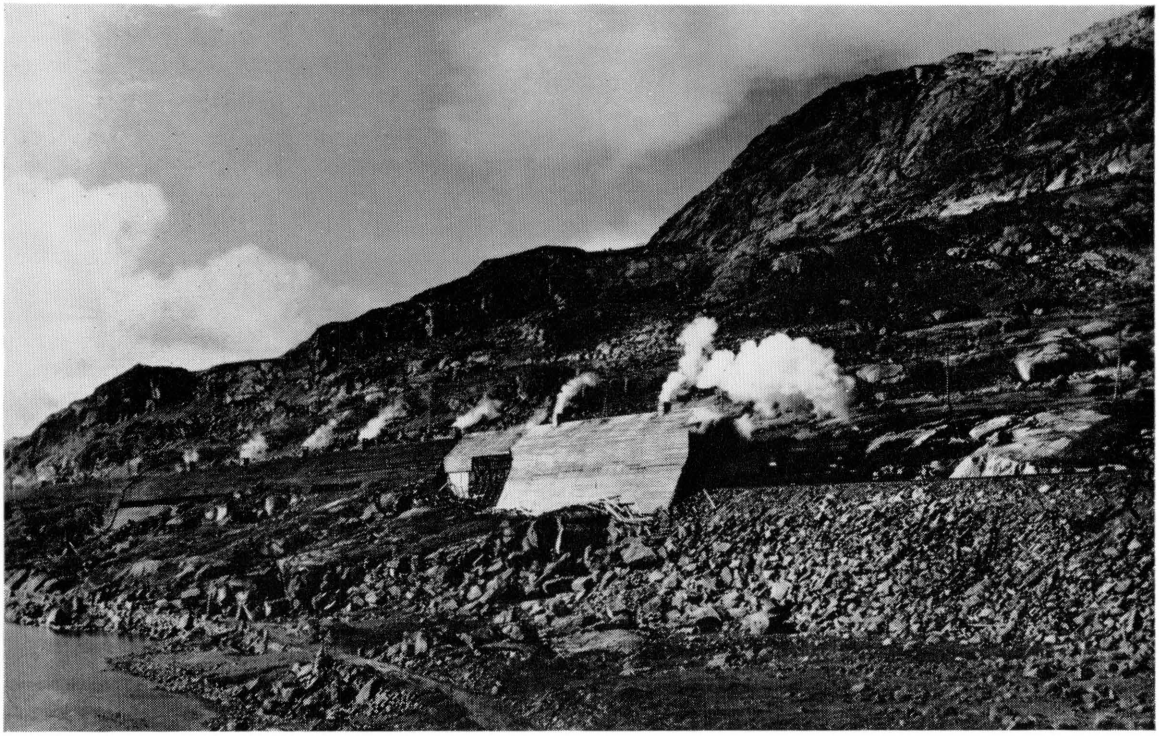

Figure 2—Train emerging from snow screen.

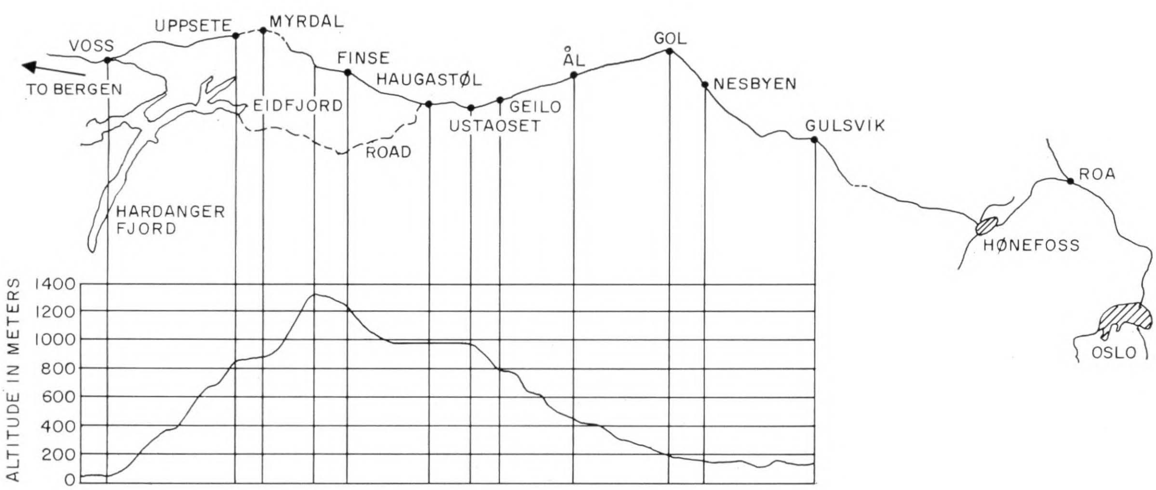

Figure 3—Map of Oslo-Bergen railway between Oslo and Voss.
Altitude is shown for the part between Gulsvik and Voss.

very low induced voltages. This article describes the development of this cable and the results obtained.

On the section from Uppsete to Voss, where booster transformers are installed and the cable could be placed approximately 12 meters from the track, ordinary aluminum-sheathed cables with soft-steel armor are used. The induced voltage on this stretch is 0.184 volt per 100 ampere-kilometers. From Voss to Bergen a 30-year-old heavily sheathed lead-covered cable is used and is located close to the track. The induced voltage here is tolerable (1.29 volts per 100 ampere-kilometers).

3. Development of Cable

3.1 Theoretical Studies

The Norwegian State Railways asked Standard Telefon og Kabelfabrik to study the problem of designing a cable that at $16\frac{2}{3}$ hertz had a screening factor better than 0.3 with induced voltage of only 2 volts per kilometer. The company had no aluminum press available at that time and only theoretical studies could be carried out.

Four alternative solutions were studied.

Alternative 1 used no armor. The idea was to provide the cable with an aluminum sheath thick enough to reduce the direct-current resistance R_0 to a level that gives the required screening factor.

Alternative 2 used ordinary steel-tape armor, and the aluminum sheath was made just thick enough to meet the screening requirement.

Alternative 3 used an ordinary lead sheath of standard thickness and an armor of ARMCO type *M-6W* oriented electrical steel tape 12 mils thick.

Alternative 4 was made the same way as alternative 3, except the lead sheath was replaced by an aluminum sheath of standard thickness.

Two different cable sizes (27-quad and 37-quad trunk cables with 1.2-millimeter (0.05-inch) conductors) were designed in accordance with the 4 alternatives. Table 3 compares the dimensions for the 27-quad cable with a normal lead-sheathed steel-tape-armored cable (alternative 0). Alternative 4 offers the smallest and lightest cable, which is also the most economical with regard to the cost of the protective material.

Screening-factor curves for alternatives 1 and 2 are relatively easy to calculate, as the magnetic properties of the soft-steel tape used on these cables are known. These two alternatives have been tailored to just meet the specified screening requirements. The screening-factor curves for these two alternatives (as well as for alternative 0) are shown in Figure 4. For the special steel tapes used in alternatives 3 and 4, it was extremely difficult to obtain information of the kind necessary to calculate screening-factor curves. However, from the information available it appeared that for both of these alternatives the screening factors should be substantially better than those for alternatives 1 and 2. Even more important in this case was that the minima of the screening-factor curves would appear at a lower induced voltage.

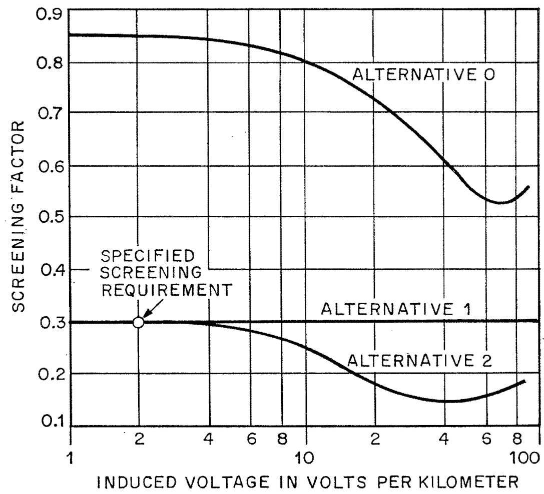

Figure 4—Calculated screening-factor curves of alternatives 0, 1, and 2 for 1.2-millimeter 27-quad cable at $16\frac{2}{3}$ hertz. Refer to Table 3.

3.2 Production of Samples

As soon as a sample delivery of steel tape type *M-6W* arrived, a length of cable corresponding to alternative 3 was armored and the screening factor measured. At this time aluminum-sheathed cables were not yet available. The steel tape received had a width of 50.8 millimeters (2 inches) and was applied to a cable having an average diameter of 37 millimeters (1.46 inches). The gap was approximately 50 percent and the lay angle approximately 40 degrees.

It is seen from Figure 5 that the measured screening factor did not meet the required value at the induced voltage of 2 volts per kilometer.

The following samples were armored by hand as soon as aluminum-sheathed cables became available.

(A) 2 × 37 × 0.8-millimeter (0.08 × 1.46 × 0.03-inch) soft-steel tape, gap 40 percent.

(B) 2 × 50.8 ×0.305-millimeter (0.08 × 2 × 0.012-inch) *M-6W* steel tape, gap 40 percent.

(C) 1 × 37 × 0.8-millimeter (0.04 × 1.46 × 0.03-inch) soft-steel tape, gap 40 percent, plus 1 × 50.8 × 0.305-millimeter (0.04 × 2 × 0.012-inch) *M-6W* steel tape, gap 4 percent.

Measured screening-factor curves on these samples are shown in Figure 6. The screening factors on samples **(B)** and **(C)** satisfy the

TABLE 3
Comparison of 27-Quad Cables

	Alternative				
	0	1	2	3	4
Sheath:					
Material	Lead	Aluminum	Aluminum	Lead	Aluminum
Thickness in millimeters (inches)	2.3 (0.09)	3.9 (0.15)	2.35 (0.09)	2.3 (0.09)	1.2 (0.05)
Inner corrosion protection:					
Material	Crepe paper	Polyvinyl chloride	Polyvinyl chloride plus crepe paper	Crepe paper	Polyvinyl chloride plus crepe paper
Dimensions in millimeters (inches)	4×0.4 (0.16×0.016)	1.3 (0.05)	0.9 (0.035) plus 2×0.4 (0.08×0.016)	4×0.4 (0.16×0.016)	Same as for alternative 2
Armor:					
Material	Normal steel tape	—	Normal steel tape	Special steel tape	Special steel tape
Dimensions in millimeters (inches)	2×37×0.8 (0.08×1.46 ×0.03)	—	2×37×0.5 (0.08×1.46 ×0.02)	2×37×0.3 (0.08×1.46 ×0.01)	Same as for alternative 3
Outer corrosion protection:					
Material	Jute	—	Jute	Jute	Jute
Thickness in millimeters (inches)	2.0 (0.08)	—	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)
Outside diameter in millimeters (inches)	43.8 (1.72)	38.4 (1.51)	42.5 (1.67)	41.8 (1.65)	39.4 (1.55)
Conductor diameter in millimeters (inches)	1.2 (0.05)	1.2 (0.05)	1.2 (0.05)	1.2 (0.05)	1.2 (0.05)
Core diameter in millimeters (inches)	28.0 (1.10)	28.0 (1.10)	28.0 (1.10)	28.0 (1.10)	28.0 (1.10)

customer's requirement with sufficient margin. By the middle of 1959, we therefore felt that development had progressed far enough to enable us to offer cables with the required screening factor to the customer.

3.3 Corrosion Protection and Earthing Problems

In this section, the screening factor has been measured under the assumption that the installed cable is earthed either continuously or at both ends with negligible earthing resistance. This is normally the case when lead-covered steel-tape-armored cable is buried in reasonably moist ground, because the compound jute layers are soaked with moisture after a short while. In the case of an aluminum-sheathed cable, the aluminum sheath itself is insulated from earth by a plastic sheath to protect it against corrosion. The normal practice in Norway is to connect the aluminum sheath to the steel-tape armor at every cable joint and use the armor as an earthing electrode.

In some cases, as in this one, it was deemed necessary to give the armor improved corrosion protection. The special steel tape (only 0.3 millimeter thick) was of vital importance to the functioning of the cable, and tests in the laboratory showed that the insulating layer of Carlite already on the tape gave very little protection against corrosion. It was therefore decided to cover the steel-tape armor with a double lapping of plastic tape in addition to the compound jute layers. The problem then arose of how to obtain a sufficiently low earthing resistance of the cable without reducing its screening properties too much.

When the earthing resistance becomes large compared with the impedance per unit length of the cable protection, the screening factor is increased (screening effect reduced) by an amount called the "earthing penalty."

This is given by

$$\Delta r_k = (l - r_k)\,\frac{l - e^{-\gamma l}}{\gamma l} \qquad (2)$$

where

Δr_k = earthing penalty
r_k = nominal screening factor as measured on cable samples
l = length of exposed cable
γ = propagation constant for the circuit cable sheath and earth.

For values of $\gamma l > 3$, equation (2) can be simplified to

$$\Delta r_k = (l - r_k)\,\frac{l}{\gamma l}\,. \qquad (3)$$

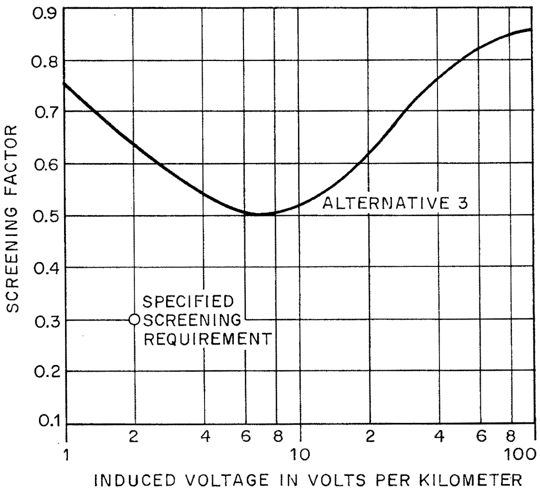

Figure 5—Measured screening-factor curve of alternative 3 for 1.2-millimeter 27-quad cable at 16⅔ hertz.

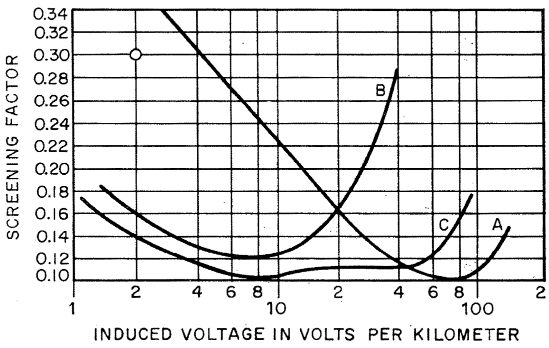

Figure 6—Measured screening-factor curves on handmade samples of 1.2-millimeter 27-quad cable at 16⅔ hertz. Refer to Section 3.2.

As in this kind of circuit the susceptance ωC normally is small compared with the conductance G, the propagation constant γ can be simplified to

$$\gamma = (G)^{1/2} \cdot (R + j\omega L)^{1/2}. \qquad (4)$$

As the screening factor r_k is given by

$$r_k = \frac{R_0}{R + j\omega L} \qquad (5)$$

(R_0 being the direct-current resistance of the cable sheath), (3) can be further simplified to

$$\Delta r_k = (l - r_k)\frac{1}{l}\left(\frac{r_k}{R_0 G}\right)^{1/2}. \qquad (6)$$

In Figure 7 the earthing penalty Δr_k is shown as a function of r_k for different values of the conductance G per kilometer between cable protection and earth. The scale for Δr_k is drawn as a function of the length of exposure.

If, for instance, an exposure length of 40 kilometers (25 miles) permits an earthing penalty of 0.1 on a nominal screening factor of 0.15, we find from Figure 7 that the conductance G must not be much lower than 0.03 mho per kilometer. The problem then was how to obtain this conductance when the cable was buried alongside the rails.

If the cable was earthed at every joint (cable length = 434 meters (1424 feet)) the necessary conductance would be obtained if the earthing resistance was less than approximately 77 ohms. We found that this would be obtained if a 3.0-millimeter (0.12-inch) copper wire was run along the cable in the trench and connected to the cable sheath and armor at every cable joint. This arrangement would be satisfactory even if the earth resistivity was as high as 10 000 ohm-meters.

4. Production of Cable

To improve the protection against induced 50-hertz voltages from nearby overhead power

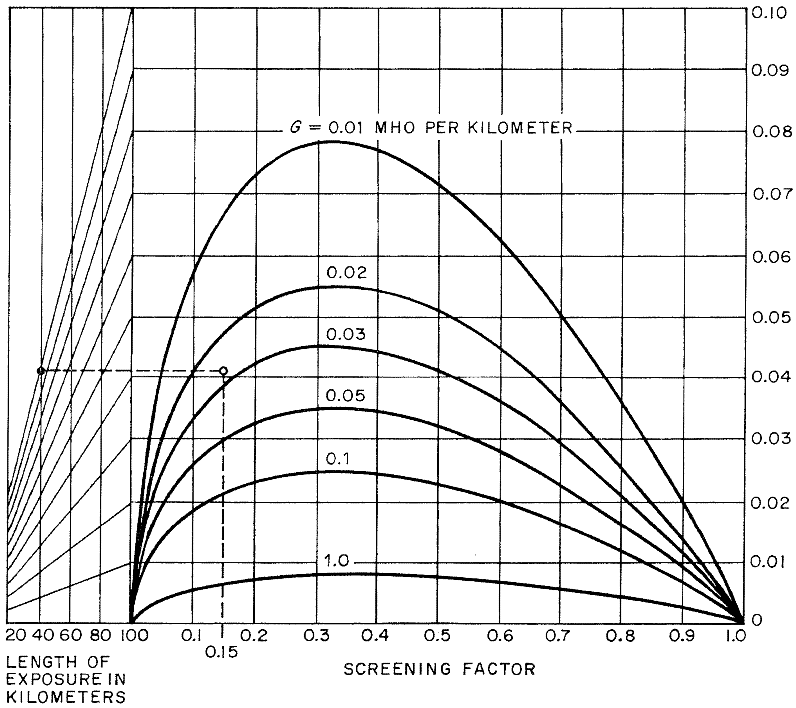

Figure 7—Earthing penalty Δr_k as a function of screening factor r_k, with average conductance G and exposure length l as parameters. See equation (6). ($R_0 = 0.24$ ohm per kilometer.)

transmission lines, sample (C) in Figure 6 was chosen. This introduced the problem of running the steel-tape head in the armoring machine with one heavy pad of 0.8-millimeter soft steel tape and a much lighter pad of 0.305-millimeter tape of *M-6W* steel. This was solved by adding an average counterweight to the light tape.

The corrosion protection for the steel tapes consisted of: a layer of impregnated crepe paper, two separate layers of polyethylene tape, a layer of jute yarn, and finally whitewash. Asphalt compound was used between all layers. This required in the beginning that the armoring be done in two operations. Later, the armoring machine was modified to carry out the whole process in one operation.

The special steel tape was rather brittle and subject to cracks along its edges. Some was so brittle that it could not be used. Jointing by spot welding could easily be done after the insulating layer was removed.

The screening factor was measured on a number of cables from each order to make sure that requirements were met. Variations from sample to sample could be caused by uneven aluminum thickness, varying gap width in the armor, and inconsistent quality of the steel tapes. Varying the gap width, which also implies varying the angle between the tape and the axis of the cable, had a marked effect on the screening factor.

Table 4 summarizes the executed orders of this special type of cable. Figures 8 through 10 show the spread of screening-factor curves measured as production control.

5. Installation and Test

In 1960–61 the electrification of the line continued from Hønefoss to Ål, and tests were carried out in October 1962 in mild and humid weather. Results of these tests for the sections

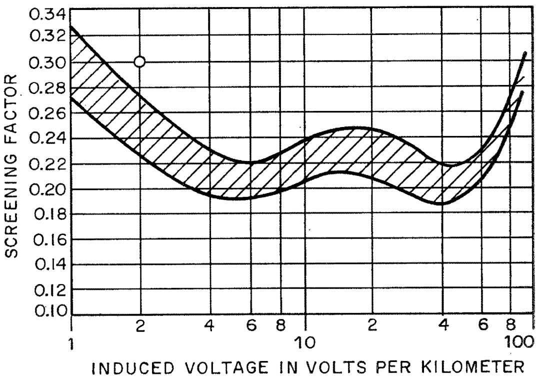

Figure 8—Production-control screening-factor curves for 1.2-millimeter 19-quad cables at $16\frac{2}{3}$ hertz (1.1-millimeter aluminum sheath). Normal variations (gap approximately 45 percent). Refer to Table 4.

TABLE 4
EXECUTED ORDERS

Production Year	Total Length in Kilometers (Miles)	Number of Cable Lengths	Length of Each Cable in Meters (Feet)	Number of Quads	Conductor Diameter in Millimeters (Inches)	Railway Section	Screening-Factor Curves
1960	51.0 (31.7)	118	434 (1424)	19	1.2 (0.05)	Gol-Geilo	Figure 8
1960–61	51.5 (32.0)	237	218 (715)	27	1.2 (0.05)	Geilo-Finse	Figure 9
1962	34.4 (21.4)	158	218 (715)	27	1.2 (0.05)	Finse-Myrdal	Figure 9
1963	7.0 (4.3)	32	218 (715)	27	1.2 (0.05)	Myrdal-Uppsete	Figure 9
1963	8.9 (5.5)	21	434 (1424)	12	1.2 (0.05)	Myrdal-Voss	Figure 10
1963	2.5 (1.6)	5	500 (1641)	4	1.2 (0.05)	Power Station*	Figure 10
Total	155.3 (96.5)	571					

* Supplied to the Power Board for installation at a nearby power station.

Hønefoss-Nesbyen-Gol are given in Table 2. On these stretches, ordinary aluminum-sheathed steel-tape armored cables were installed 12 meters from the middle of the track where possible. On the last 29.9-kilometer (18.6-mile) section Gol-Ål, however, the specially armored cable was installed only 2.3 meters (7.5 feet) from the center of the track. Tests on this section gave 0.419 volt induced in the cable core per 100 ampere-kilometers of catenary current with the booster transformers in operation.

In December 1963 the electrification was extended (with booster transformers) from Ål to Geilo and Ustaoset. On this 36.46-kilometer (22.66-mile) section, the special cable was laid 2.3 meters (7.5 feet) from the middle of the track. (About $\frac{2}{3}$ was of 19-quad cable and the remainder of 27-quad cable.) Results of the field tests are shown in Table 5.

Figure 11 shows that the effective screening factor for this section lies well between the measured screening-factor curves for 19-quad and 27-quad cables. The earthing penalty on this section has not been significant.

The last section (Haugastøl-Voss) of the railway was completed in November 1964. When the final tests and measurements took place at

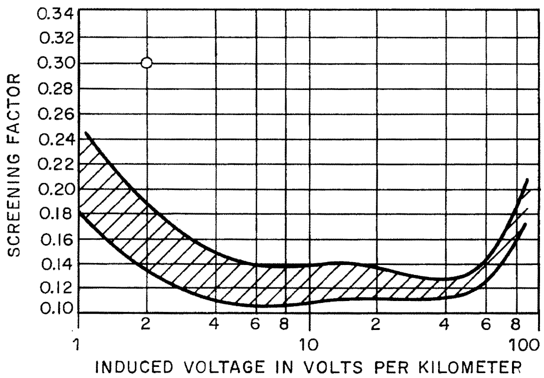

Figure 9—Production-control screening-factor curves for 1.2-millimeter 27-quad cables at $16\frac{2}{3}$ hertz (1.3-millimeter aluminum sheath). Refer to Table 4.

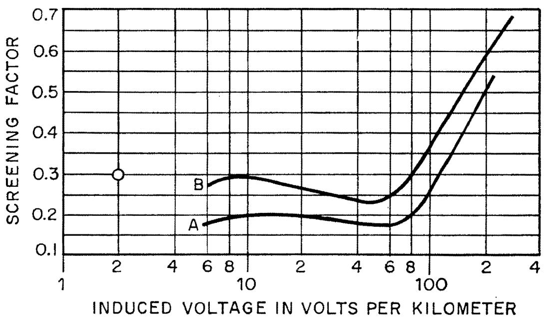

Figure 10—Production-control screening-factor curves at $16\frac{2}{3}$ hertz. A = 1.2-millimeter 12-quad cable with 1.0-millimeter aluminum sheath. B = 1.2-millimeter 4-quad cable with 0.9-millimeter aluminum sheath. Refer to Table 4.

TABLE 5
INDUCED VOLTAGES, ÅL-USTAOSET

Catenary Current in Amperes	Theoretical Induced Voltage in Volts per Kilometer*	Measured Induced Voltage in Volts	Measured Induced Voltage per 100 Ampere-Kilometers of Catenary Current	Effective Screening Factor
60	1.27	9.5	0.326	0.205
100	2.11	14.0	0.385	0.182
150	3.16	19.5	0.358	0.169
200	4.22	24.5	0.336	0.159
250	5.27	30.0	0.329	0.154
300	6.33	35.0	0.320	0.152

* Calculated on the basis of (A) 7.25 meters (23.79 feet) between catenary and cable, (B) 2.47 meters (8.10 feet) between middle of track and cable, (C) soil resistivity of 5000 ohm-meters ascertained by measurement, and (D) rail return current of 98.9 percent of the catenary current.

the end of November 1964, it was found practical to measure the section Geilo-Haugastøl, which includes a part (Geilo-Ustaoset) of the section Ål-Ustaoset measured earlier. On this 22.13-kilometer (13.75-mile) section, as shown in Table 6, values deviating less than 5 percent from the earlier measured values were found. On this section, a 27-quad cable and booster transformers were installed.

The 60.3-kilometer (37.5-mile) section Haugastøl-Myrdal is of special interest, as booster transformers on this section had to be omitted. The inducing current was in this case supplied to the catenary or the bypass line at Haugastøl and a connection to the rails arranged at Myrdal.

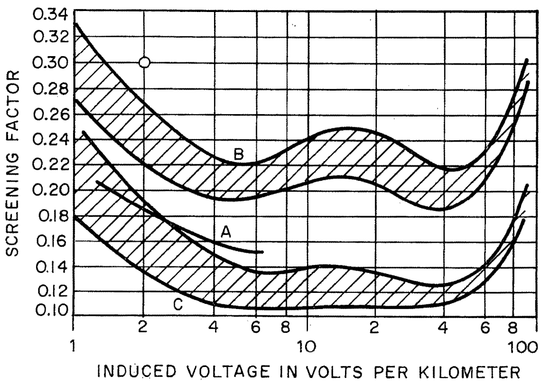

Figure 11—Curve *A* is the effective screening factor between Ål and Ustaoset. *B* and *C* are the factory measured screening-factor curves for 19-quad and 27-quad cables, respectively.

A measuring circuit was arranged between Geilo and Uppsete (see Figure 3). This means that the measuring circuit extended 23 kilometers to the east and 6 kilometers to the west of the exposed section. A 27-quad cable was installed on this section. Results obtained when feeding through the catenary are given in Table 7.

It had been estimated that in this case (without booster transformers) the rail current would be 63 percent of the catenary current. Measurements during the test showed that it was actually 65 percent of catenary current. The induced voltage had been estimated to be

TABLE 7
INDUCED VOLTAGES, HAUGASTØL-MYRDAL

Catenary Current in Amperes	Inducing Current in Ampere-Kilometers	Measured Induced Voltage in Volts	Measured Induced Voltage per 100 Ampere-Kilometers of Catenary Current
46.4	2 800	15.8	0.564
64.4	3 880	20.0	0.515
94.4	5 690	26.8	0.471
102.5	6 180	29.4	0.475
149	8 990	42.0	0.467
185	11 180	54.0	0.484
198.5	11 990	59.0	0.493
243	14 670	76.0	0.518
254	15 320	82.0	0.535
298	17 980	99.5	0.553
302	18 220	99.5	0.545
355	21 400	120.0	0.560

TABLE 6
INDUCED VOLTAGES, GEILO-HAUGASTØL

Catenary Current in Amperes	Theoretical Induced Voltage in Volts per Kilometer*	Measured Induced Voltage in Volts	Measured Induced Voltage per 100 Ampere-Kilometers of Catenary Current	Effective Screening Factor
46	0.962	4.8	0.462	0.225
92	1.920	8.3	0.407	0.194
144	3.010	12.0	0.376	0.180
198	4.140	15.7	0.358	0.171
246	5.150	19.0	0.350	0.167
301	6.300	22.2	0.334	0.159

* Calculated on the same basis as in Table 5.

0.62 volt per 100 ampere-kilometers. The measured values were therefore well below the expected values.

Results of the measurement when the current was sent through the bypass line are of minor interest and will not be given in detail. In this case the measured rail current was 29 percent against the estimated 23 percent and the induced voltage varied between 0.353 volt and 0.25 volt per 100 ampere-kilometers, against the estimated value of 0.28 volt per 100 ampere-kilometers.

The last section (Myrdal-Voss) is of minor interest, as the cable here lies 12 meters from the center of the track with the exception of the 5.3-kilometer (3.3-mile) Gravahalsen tunnel near Myrdal.

6. Summary and Conclusion

As a rough idea of the induced voltages to be expected for the different installation techniques, the average figures obtained on the Oslo-Bergen railway and other electrified lines in Norway are given in Table 8.

On the Oslo-Bergen railway line, the Norwegian State Railways required that the induced voltage on the 60.3-kilometer (37.5-mile) section between Haugastøl and Myrdal (without booster transformers) should be less than 100 volts when 300 amperes were supplied either through the catenary or through the bypass line. As can be seen from Table 7, this requirement was just met. As the screening factor of the special cable in the relevant range is nearly 3 times better than the screening factor of normal cable (cable having an ordinary steel-tape armor and an aluminum sheath), the requirement could not have been met with an ordinary cable. If it had been possible to install booster transformers on this section, normal cable installed 12 meters from the center of the track would have met the requirement. The extra cost in this case would have been approximately $5000 per kilometer, against a moderate increase in cable price due to the special armor used.

There was insufficient time to carry out a short-circuit test on this line, but it was estimated that under short-circuit conditions the voltages induced in the cable would not exceed 500 volts.

TABLE 8

INDUCED VOLTAGES IN VOLTS PER 100 AMPERE-KILOMETERS

Type of Cable	With Booster Transformers		Without Booster Transformers	
	12 Meters from Track	In the Ballast	12 Meters from Track	In the Ballast
Lead-covered steel-tape armored	0.2	2.0	3.3	2.8
Aluminum-sheathed steel-tape armored	0.1	1.0	1.6	1.4
Special		0.35		0.5

Figure 12—Plowing the cable into the ballast of the railway line.

As these cables are tested with 2000 volts between the conductors and the sheath for 2 minutes, no cable breakdown need be feared because of induced voltages. On the 73-kilometer (45-mile) section between Gol and Haugastøl (where booster transformers were installed), the alternative solution would have been to install an ordinary cable 12 meters from the center of the track at an extra cost of approximately $4000 per kilometer. The laying of the cable close to the track was very economical, as a plow was available that dug the trench and laid and covered the cable in one operation. This equipment is shown in Figure 12. The development of this cable, therefore, on these two sections reduced the electrification cost by approximately $600 000.

However, the solution using a specially armored cable in the ballast is not acceptable where the Norwegian Telecommunication Administration and the Norwegian State Railways share the trench, as on the stretch Hønefoss-Gol. The degree of screening would not be sufficient to meet requirements of the International Telegraph and Telephone Consultative Committee for long-distance trunk cable systems. From Gol westward, however, the Norwegian Telecommunication Administration cable system was already completed when the electrification started. The cables run on the opposite side of the valley, or at any rate at some distance from the railway between Gol and Haugastøl. At Haugastøl the two routes part completely, the telecommunication cables following the road to Eidfjord in Hardanger (see Figure 3).

7. Bibliography

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Arve Rambøl was born in Eidskog, Norway, in 1919. He graduated from the Technical University of Norway in Trondheim in 1945. After a short period of study in England he joined the Norwegian Defence Research Establishment in 1946. Except for one year of study in the United States he worked in this establishment until 1954, mainly on antennas and radio wave propagation.

Mr. Rambøl joined Standard Telefon og Kabelfabrik in 1954 as head of the technical department for telephone cables. In 1964 he was promoted to Chief Engineer, Telephone Cables.

Leif Saxegaard was born in Tynset, Norway, in 1893. After graduating from the Technical University of Norway in Trondheim he joined the telecommunication department of the Norwegian State Railways in 1920, was promoted to chief telecommunication engineer in 1953, and retired in August 1963. He is at present a consulting engineer specializing in interference problems.

Magnetic Thin-Film Memory Having Low Access Currents

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1. Introduction

The evolution of digital circuit techniques is conditioned by the ever-increasing need for high-speed systems. In the competition between the different techniques of random-access memories, magnetic thin-film memories have easily won first place in speed performance. At present their access time is limited only by the associated electronic circuits, whereas for the other types (except perhaps the semiconductor memories, which are limited at present to systems having very low capacity) the work cycle is lengthened by the response time of the memory element itself. Even though the speed differences are tending to diminish, the other processes could, at most, approach but not surpass the speed of the magnetic thin-film memory.

If we consider the economic aspect of the problem, the cost of a memory unit can be broken down into two main elements: the cost of the storing medium itself, and the cost of the associated electronics.

The magnetic thin-film memory planes are potentially the least expensive type of memory element. They are produced by a few simple technological operations carried out with high efficiency. Their production and test permit a high degree of automation.

The electronic circuits for a coordinate-access memory are generally less costly than those for a linear-selection memory. However, if the power necessary to control the memory can be reduced to be compatible with the use of monolithic integrated circuits, the economy of these circuits should more than make up for the increased cost of linear selection. This is why work has been undertaken to reduce input power sufficiently to ensure this compatibility. Note, however, that the access currents have not been reduced to the extreme limit of the possibilities. Two experimental models of medium capacity (10^4 to 10^5 bits), developed during this study, are described.

2. Technical Description of the Models

2.1 General

Our development program has been marked by three successive models of planar magnetic thin-film memories. The first one, of small capacity, (10^3 bits in 64 words of 16 digits), has been described previously [1]. It used planes evaporated on glass substrates.

The second and third models took advantage of the great progress in evaporation of films on metal substrates. The second model, which had about 10^4 bits (256 words of 36 digits), was initially intended to test, on a reduced scale, the elements of the third model (1024 words of 36 digits), and is now used as a test apparatus for the planes. The two memories, actually electrically identical, have been constructed on different mechanical frames.

2.2 Memory Planes

The two newer models use the same type of memory planes. Their mechanical and magnetic characteristics follow.

Substrate is of oxygen-free high-conductivity copper. Its dimensions are 50 by 50 by 4 millimeters (2 by 2 by 0.16 inches).

Magnetic film is a continuous Permalloy film evaporated on an underlayer of silicon monoxide and protected by silicon monoxide. It is 380 angstrom units thick.

Anisotropy field H_K is 2.2 $\pm$0.2 oersteds.

Coercive field H_C is typically 3 oersteds.

Magnetostriction is practically zero, as the composition of the deposited alloy is controlled to better than $\pm$0.1 percent.

Skew of the easy axis with respect to the edge of the plate $-2° \leqq \beta \leqq 2°$.

Dispersion $\alpha_{90} \leqq 2$ degrees.

The metal substrate provides excellent mechanical precision; tighter coupling between the magnetic film and the access conductors, leading to a saving in access current; reduction in the alternating-current components of the leakage fields of the conductors, which permits an increase in the density; and reduction in the characteristic impedance of the lines and hence of the power requirements.

2.3 Access Conductors

The access to the elementary memory cells is obtained by means of two printed-circuit conductor networks at right angles to each other. The study of the distribution of the magnetic fields and the necessity of bringing the word current to a level compatible with the use of integrated driving circuits has led to the following characteristics of both networks.

The word (control) network of conductors is parallel to the easy magnetizing axis of the film. The conductors are 0.25 millimeter (0.01 inch) wide and 0.017 millimeter (0.0007 inch) thick. The pitch is 0.6 millimeter (0.02 inch). The distance to the magnetic film is 0.006 millimeter (0.0002 inch). There are 72 lines (64 plus 8 spares) per memory plane.

The digit (information and sensing) network of conductors is perpendicular to the easy magnetizing axis of the film. The conductors are 0.75 millimeter (0.03 inch) wide and 0.035 millimeter (0.0014 inch) thick. The pitch is 1.25 millimeters (0.05 inch). The distance to the magnetic film is 0.05 millimeter (0.002 inch). There are 36 lines per memory plane.

Since the magnetic film is continuous, a memory cell is bounded only by the access conductors. It corresponds, in a first approximation, to their crossing surface. The density is of 133 crosspoints per square centimeter (858 per square inch), and 2 crosspoints per bit are used to eliminate the stray signal of the readout induced by the capacitance coupling with the word conductor.

The access conductors are held by a rigid mechanical frame pierced with holes in which the memory planes are placed. Figure 1 shows the network of access conductors which appears at the bottom of each hole. The planes are electrically connected to the framework by peripheral contacts and pressed against the conductors by a pressure spring. The metal substrate serves as a common ground return, and the access conductors thus form transmission lines of the microstrip type.

The propagation speed along these lines is greater than 10^{10} centimeters per second, which, for the density adopted, gives a delay in the direction of the digit lines of about 5×10^{-12} second per word.

2.4 Access Electronics

Figure 2 shows the general organization of the access circuits of the two models [1].

The same conductors are used to send the information to the memory and to receive the sense

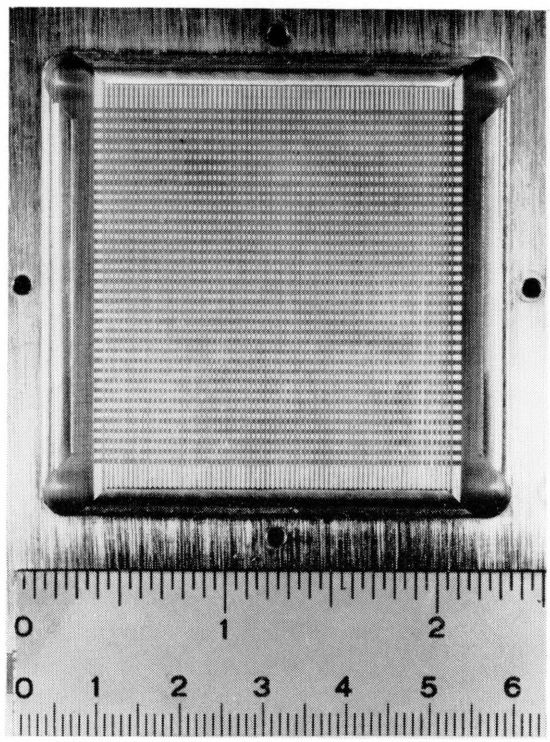

Figure 1—Network of access conductors.

signals. Therefore a 6-winding balanced transformer is used to separate these two functions, and the memory is divided into two subassemblies driven in parallel. The rejection of the stray signal induced by the information current is higher than 50 decibels without any adjustment of the elements.

Three groups of circuits are shown.

(A) A clock supplying 4 elementary timing signals, each corresponding to the execution of 1 operation of the work cycle.

(B) An address decoding system composed of a register, two predecoders, and a final matrix that contains as many transistors as there are word lines. The final matrix is placed right on the framework of the memory matrix.

(C) Information loops made up of a linear sense amplifier, a gate isolating the actual sense signal from the stray writing signals, one of the bistables of the output register, logic circuits, and a generator supplying the bipolar information current.

All the digital circuits use discrete components in ultra-fast diode-transistor logic (*DTL*).

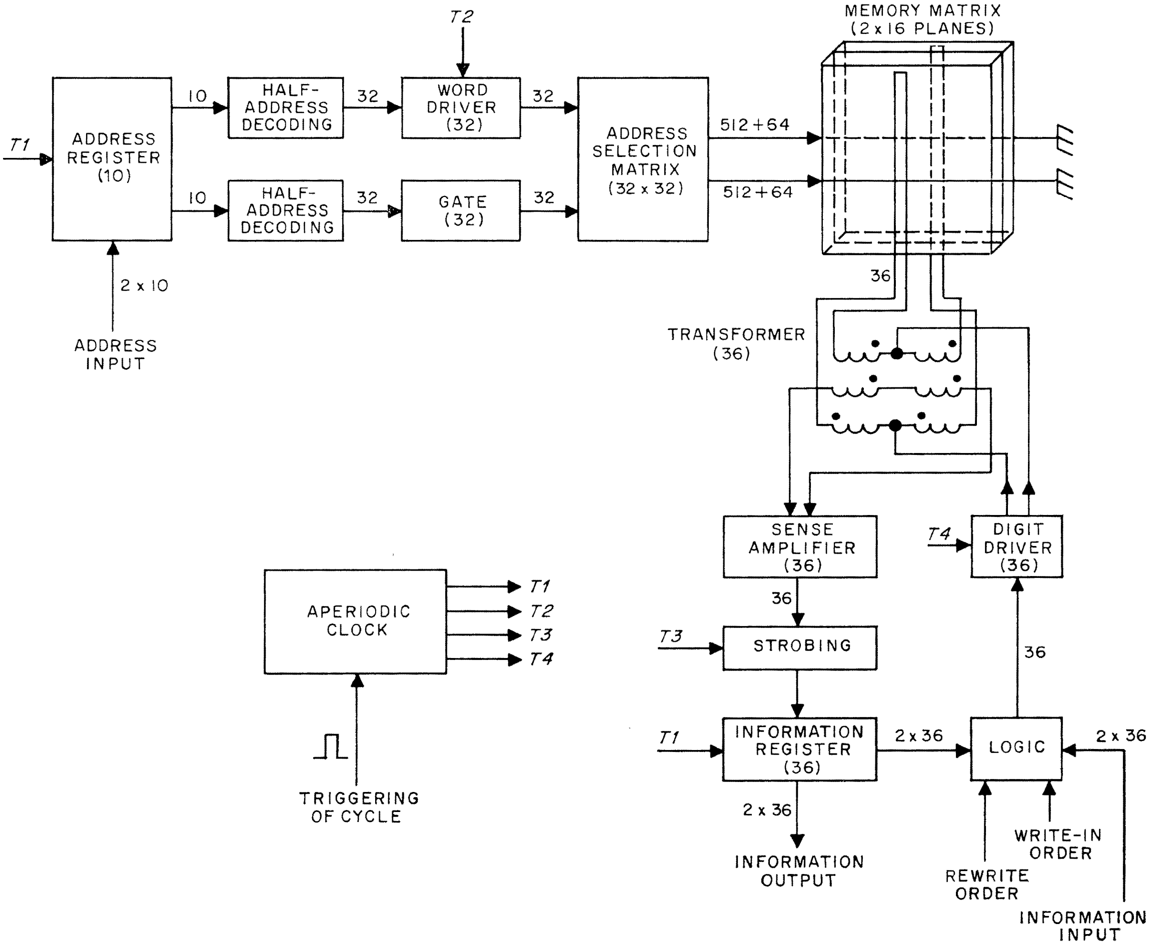

Figure 2—Organization of memory.

2.5 Output Characteristics

For the structure described, Figure 3*A* shows a typical output characteristic of the memory cell

$$e_o = f(I_c)$$

and Figure 3*B* shows

$$e_o = f(I_i)$$

where

e_o = amplitude of the output signal
I_c = control (word) current
I_i = information (digit) current.

The latter characteristic is measured without disturbances and also after 10^6 disturbances by the simultaneous action of inverted digit current and neighboring word current.

It is seen that fully satisfactory operation is obtained with $I_c = 200$ milliamperes and $I_i = 40$ milliamperes, which represent the values adopted for the models.

Figure 3 also shows that even for $I_i = 120$ milliamperes and $I_c = 250$ milliamperes, no serious creeping phenomenon occurs. The use of low-impedance transmission lines further decreases the power required. The word lines are grounded at the ends, and the induced voltage on the inductance of the line during the rising edge of the current has a low amplitude and duration (30 microvolts per centimeter for a current of 200 milliamperes with a rise time of 15 nanoseconds).

The power values are now low enough to be compatible with monolithic integrated circuits for all access circuits. The standard circuits now available are capable of fulfilling most of the functions, and only two special types of integrated circuits would be necessary: the address selection elements (multiple transistors), and the digit generators.

Since the ratio of input power to output power is comparable to that of the ferrite core memories, the desired reduction of input power requirements must be accompanied by a correspondingly low output level from the thin magnetic films. Thus it is indispensable to take major precautions against disturbances of any type. In this context, it is interesting to mention that the sense amplifier, which is the element of the memory most sensitive to disturbance, using two standard monolithic integrated circuits, has given completely satisfactory service.

2.6 Model for 256 Words of 36 Digits

Figure 4 shows the memory matrix of model 2.

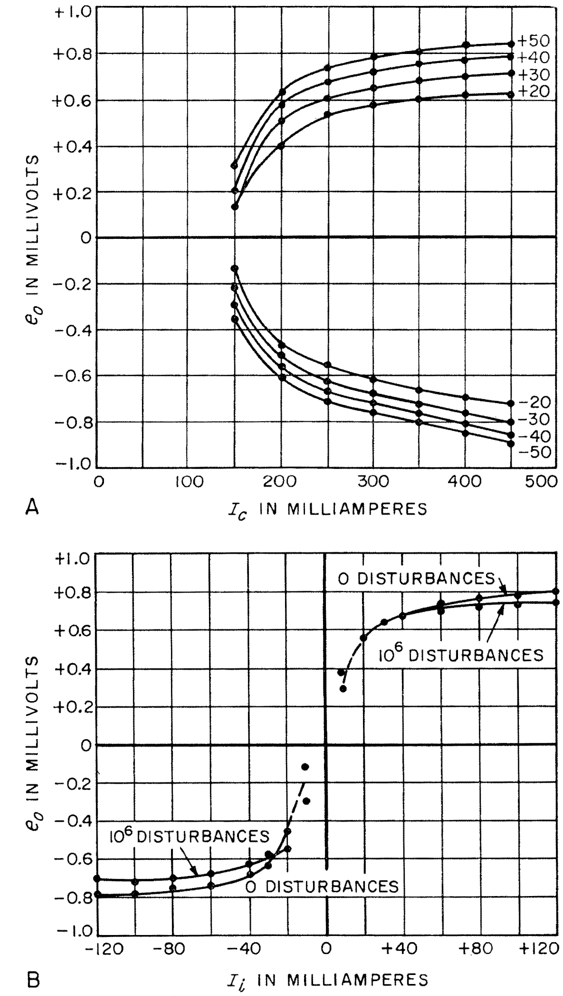

Figure 3—Typical output characteristics of the memory cell. *A* shows e_o as a function of I_c for the indicated values of I_i in milliamperes. *B* shows e_o as a function of I_i for $I_c = 250$ milliamperes.

The decoding transistors have been distributed on V-shaped mechanical structures. Figure 5 shows the complete model surrounded by test equipment for the automatic sequential control of its operation. The details of the tests are given in Section 3.

For this model, the access time for readout is 75 nanoseconds, and the read-write cycle time is 150 nanoseconds. The address and information codes are introduced with logic levels of 0 volts and +6 volts. The clock cycle can be triggered periodically or aperiodically by a pulse of 6 volts and a duration of 10 nanoseconds.

2.7 Model for 1024 Words of 36 Digits

Figure 6 shows the memory matrix of model 3 during assembly. The main difference from

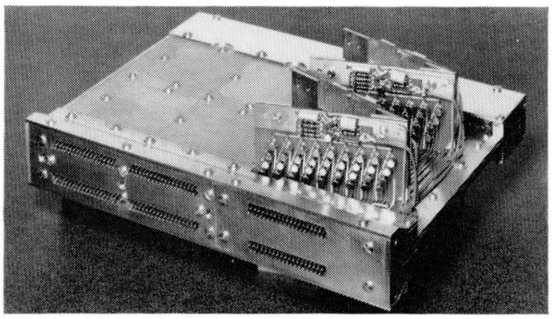

Figure 4—Memory matrix of model 2.

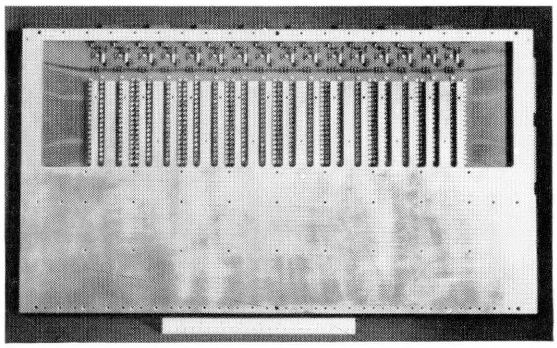

Figure 6—Memory matrix of model 3 during assembly.

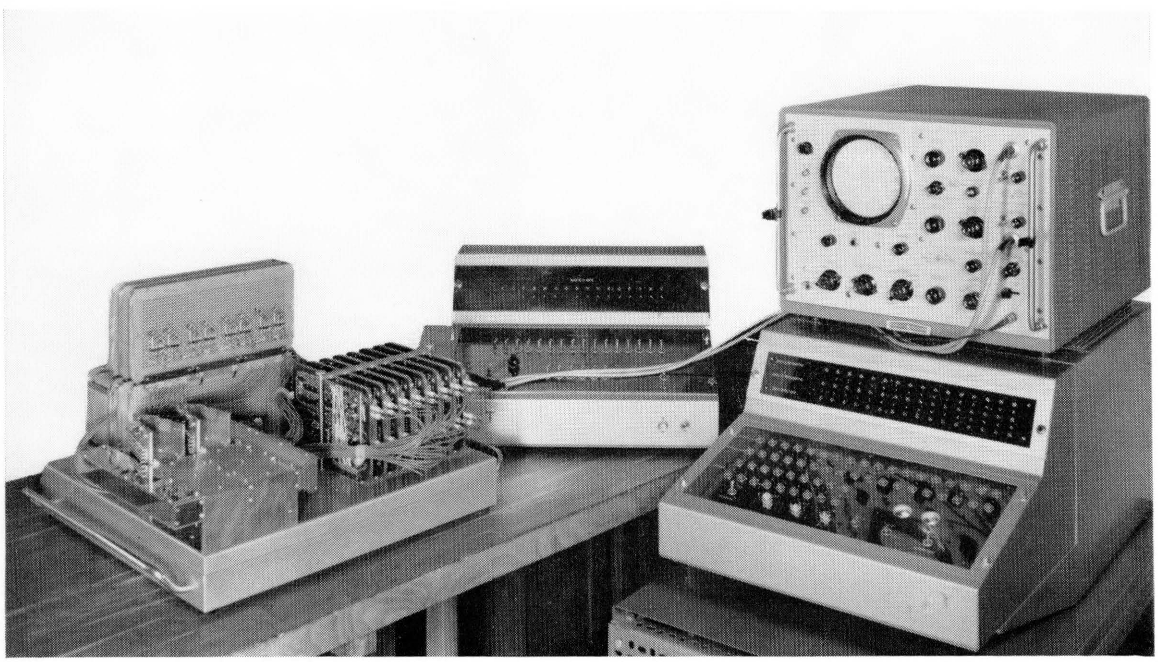

Figure 5—Test setup for automatic control of model 2.

model 2 is in the plane configuration of the address decoding matrix. The access circuits are distributed in 3 drawers as shown in Figure 7. The bottom drawer has all the clock elements and the address decoding, while the other two drawers (shown at top back to back) contain 18 digit chains each.

The memory has been tested in sections of 64 words with the same apparatus used for model 2. The access time for readout is 85 nanoseconds, and the read-write cycle time is 170 nanoseconds.

3. Tests

Models 2 and 3 have been tested by means of a special memory exerciser for a systematic sequential control of the operation. The memory exerciser supplies the memory with address and information codes and triggers the operation cycles. On a particular chosen address J, the sequence of the programmed operations is the following.

(A) Writing a control code C_0 constituted of a sequence of *0*'s at address J, interrogation of the contents of address J, and comparison with C_0. If no error is detected, the system proceeds to the next test.

(B) Writing a control code C_1 constituted of a sequence of *1*'s at address J, interrogation, and comparison with C_1. If no error is detected, the system proceeds to the next test.

(C) Writing a control code C_0 at address J. To disturb this, a code D_{10} (an alternate sequence of *1*'s and of *0*'s) is written 10^6 times at address $J-1$ and then at $J+1$ at the maximum repetition frequency. Finally, there are interrogation and comparison with C_0. If no error is detected, the system proceeds to the next test.

(D) Identical to **(C)** but the disturbance is made by the code D_{01} (an alternate sequence of *0*'s and of *1*'s).

(E) Identical to **(C)** but the code written at J is C_1 disturbed by D_{10}.

(F) Identical to **(C)** but the code written at J is C_1 disturbed by D_{01}.

If no error is detected during this entire sequence, the simulator submits $J+1$ to the same program, et cetera. If an error is detected, the program stops and the location of the faulty element and the nature of the fault are indicated by a display system.

The entirely automatic test is limited to one memory plane (64 addresses), its total duration being 2 minutes. In the case of a memory with a larger capacity, it is obviously possible to manually switch as many more planes as desired. Using more-elaborate measurement equipment, it is possible to test several planes in parallel at the same time.

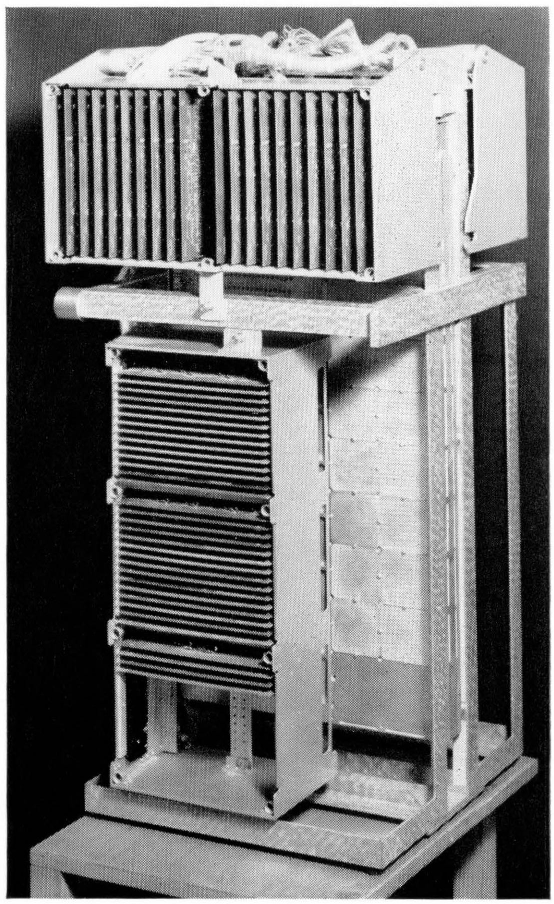

Figure 7—Model 3 memory with access electronics.

The tests have been expanded to 10^{11} (100-billion) disturbances without showing any further deterioration.

On a large number of samples, we have obtained a very good manufacturing yield, which is effectively further increased by the redundancy system (additional word lines).

4. Conclusions

These developments indicate the following possibilities for magnetic thin-film memories.

(A) Very fast memories. Cycles of the order of 100 nanoseconds are possible for medium capacities. This increases the information-processing capability for a given memory capacity.

(B) Integrated manufacture and control of the memory medium. It is possible to manufacture and control, automatically, entire memory planes having several thousand cells each, instead of making and checking individual elements, and this must lead to a very favorable reduction in cost. In addition, the level of the access power can be reduced sufficiently to permit the total integration of the associated electronics in a linear-access memory.

5. Acknowledgments

We wish to express our thanks to Mr. Pauthier, who was in charge of the technical coordination of the studies, to Messieurs Cagnard and Le Saec, who developed the thin-film techniques, and to all the engineers and technicians of the team, who constructed and tested the models.

6. References

1. J. M. Tyszka, "Memory for Test and Evaluation of Magnetic Thin Films," *Electrical Communication,* volume 41, number 2, pages 167–176; 1966.

André Judeinstein was born in Paris, France, on 2 January 1931. In 1955, he received his engineering degree from the École de Physique et Chimie Industrielles de la Ville de Paris.

In 1958, he joined Compagnie Française Thomson Houston to work on microwave tubes. In 1959, he entered the switching research department of Laboratoire Central de Télécommunications, where he is now the head of the department on ultra-fast electronics.

J. M. Tyszka was born in Lodz, Poland, on 23 May 1931. He received a bachelor of science degree in electrical engineering in 1954 and a master of science degree in 1957 from Politechnika Warszawska, where he had served as a faculty assistant since 1952. In 1962, he received his Doctorate of Engineering from the Faculty of Sciences of the University of Paris.

In 1960, Dr. Tyszka joined Laboratoire Central de Télécommunications, where he worked on tunnel-diode ultra-fast memories, pulse circuits in the nanosecond region, and magnetic thin films.

Paris Inaugurates New Vaugirard Pentaconta Exchange—The old Vaugirard 10 000-line rotary *7A* telephone exchange opened 36 years ago has been replaced by a 16 000-line Pentaconta switching system shown in part in Figure 1. The additional 6000-line expansion constitutes the first part of the new Paris *533* exchange, which will later have 10 000 lines. To reduce the number of incoming trunk groups, the new equipment will serve as a tandem center for the Lecourbe rotary exchange in the same building.

The new installation required 2150 frames of equipment, making it the largest Pentaconta *1000* exchange in the world. The trunk groups were transferred first, followed by the old and then the new subscribers' lines. Traffic of about 1500 erlangs was involved and its transfer without incident indicates the great cooperation between the technical personnel operating the old and those installing the new equipment.

A week later the Bossuet Pentaconta exchange was expanded by 3000 lines. Mr. Billotte, Overseas Territory Minister, attended the opening ceremonies. This Paris exchange is the first of a series for which the manufacturing time has been reduced to 18 months.

Le Matériel Téléphonique
France

Multiplexing of Pulse-Code-Modulation Systems—Pulse code modulation is at present used mainly for 24-channel telephone systems. Such systems, used as basic groups and assembled by time-division multiplex, can give the larger capacity that will soon be needed for both long- and short-haul transmission. A family of compatible multiplexers has been planned with capacities of 4, 16, and 64 groups, respectively. Although the primary use will be for pulse-code-modulation telephony, arbitrary digit streams can be accepted at any stage.

The first experimental equipment combines 16 groups each of 1.536 megabits per second to form a single stream of about 25 megabits per second. The groups need not be synchronous with the multiplex equipment or with each other. The line bit rate is 0.5 percent higher than the sum of the group bit rates, which allows synchronizing and control channels to be added. It also ensures that, despite any fluctuations in relative timing, there are sufficient time slots on the line to take all the incoming information; any excess is filled with redundant digits known as "stuffing." To allow these extra

Figure 1—Mr. J. Marette, French Minister of Post and Telecommunications (left), and Mr. M. Jambenoire, Director of the Paris Area Telecommunications, passing by the distributing frame when the new Vaugirard exchange was cut over.

digits to be inserted, each group is passed through a 4-bit buffer store at the multiplexer. The timing irregularities so introduced are smoothed out at the demultiplexer by means of a complementary buffer store, whose output is timed by a phase-locked oscillator. The stuffed digits are identified and the oscillator frequency determined by the control channels, which use error-correcting codes to give protection against random and burst interference.

The equipment makes extensive use of semiconductor integrated circuits.

Standard Telecommunication Laboratories
United Kingdom

Aircraft Carrier Control Approach Radar—The AN/SPN-35 is a precision approach radar with search capability out to 40 nautical miles (74 kilometers) designed for use aboard aircraft carriers of the United States Navy. It is mounted on a stabilized platform that compensates for the pitch and roll of the ship. It is suitable for all aircraft having landing speeds up to 180 knots (330 kilometers per hour). Delivery of 14 units has resulted in a contract for additional equipments.

ITT Gilfillan
United States of America

Console for Composing and Altering Displays—Electronically generated symbols may be displayed on the 12-inch (30-centimeter) square screen of a cathode-ray tube and be combined with up to 128 stored color or black-and-white slides projected through an optical port in the rear of the tube. Slides can be changed in 2 seconds and will accommodate 48 lines of 64 typewritten characters each. In addition, an internal core memory will store three complete typewritten pages of 3072 characters each for display at any time.

Characters or symbols may be placed at the intersection of any of 1024 vertical and 1024 horizontal positions, and straight-line vectors may be drawn between any such pair of positions. The data are refreshed at 40 frames per second for full typewriter coverage of 3072 characters. The rate is adjusted automatically if writing demands require this.

Displayed data may be composed, altered, or erased through use of a keyboard, roll ball, and light pen. An independently controlled cursor symbol is also available.

Developed for military command including control, data review, and editing, the console is easily interfaced to high-speed computers for either off-line data processing or on-line man-machine communication. The console is 51 by 26 by 67 inches (130 by 66 by 170 centimeters).

ITT Federal Laboratories
United States of America

Mexico Telephone Expansion—Since 1963, a series of contracts with Teléfonos de México has resulted in the installation of 29 Pentaconta telephone exchanges serving 50 750 lines. A fifth contract provides for the extension of four exchanges (Bandera, Celaya, Irapuato, and Coatzacoalcos) by a total of 6400 lines and 72 trunks, and two new Pentaconta exchanges in Ciudad Guzman and Piedras Negras with capacities of 1000 and 1500 lines, respectively.

Compagnie Générale de Constructions Téléphoniques
France

Television Color Signal Generator—Signal generator type *MF-04* produces 8 color bars that can be arranged in three different orders by plugging in appropriate printed-wiring boards. In descending order of luminance the colors are: white, yellow, cyan, green, magenta, red, blue, and black. In the newton series they are: white, yellow, green, cyan, blue, magenta, red, and black. For greatest color change they are:

white, yellow, blue, green, magenta, cyan, red, and black.

A grid of 19 vertical and 14 horizontal lines may also be produced, corresponding to the test pattern of the Study Organization of the German Broadcasting Corporation.

The color generator may be used for studio or laboratory purposes and has provision for accepting an external color subcarrier and for use with a very- or ultra-high-frequency signal generator.

Standard Elektrik Lorenz
Germany

Multiplex Telephone Equipment—The single bay side of the multiplex equipment shown in Figure 2 provides 120 telephone channels with outband signalling and with carriers supplied from either an internal master oscillator or an external control frequency. Each of the two larger cabinets houses 60 channels with channel and group translation, thus forming a basic supergroup in the frequency band 312–552 kilohertz. The outband signalling, included in each channel modem, provides for either high- or low-level signalling. With low-level signalling and constant tone during idle periods, a type of signalling used in Sweden, the equipment can be supplied with a service interruption control unit.

The design is fully approved by the Swedish Telecommunications Administration and is in series production. It uses a supergroup as the smallest unit group for routing in the carrier network. The bay shown conforms to International Standard Equipment Practice and is 2600 by 600 by 225 millimeters (102 by 23.6 by 8.9 inches).

Standard Radio & Telefon
Sweden

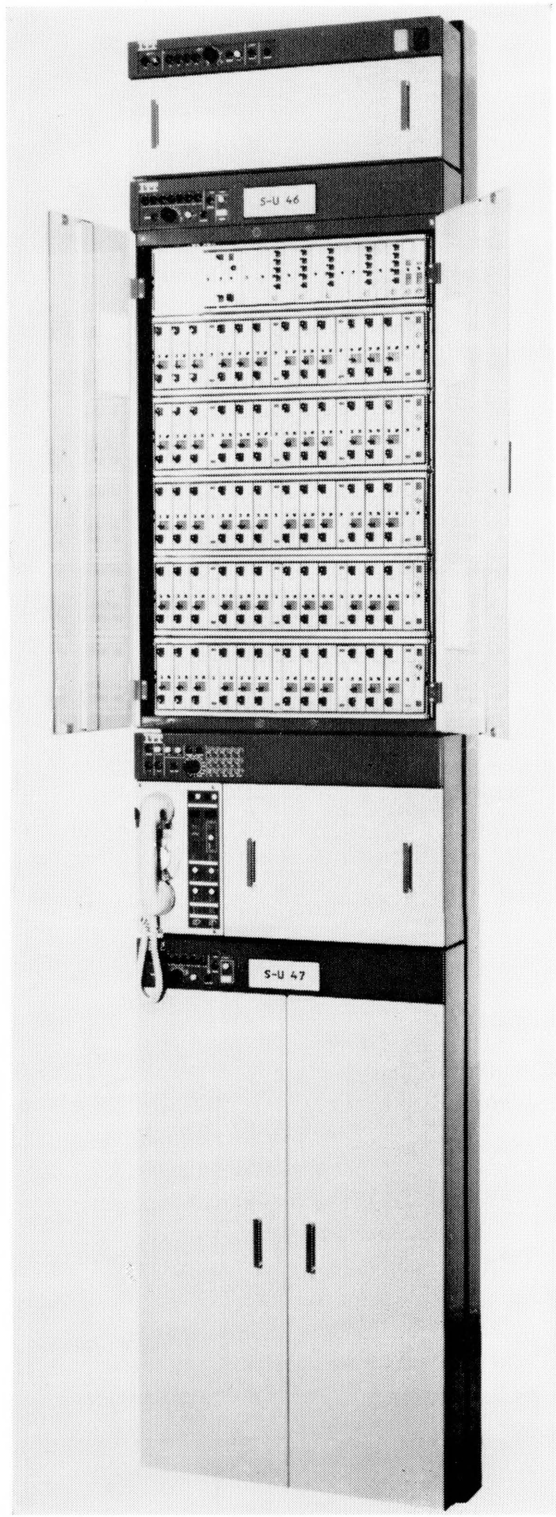

Figure 2—Multiplex telephone equipment for a 120-channel supergroup.

Mobile Television Transmitter for Temporary Service—A complete television transmitter has been built in mobile form for use during major overhaul or other construction work in a permanent installation.

The entire transmitter and forced-air-cooling equipment is accommodated in three trailers. As may be seen in Figure 3, two trailers are arranged side by side and joined by hinged side walls to form a completely enclosed transmitter room of approximately 34 square meters (366 square feet). The 10-kilowatt picture transmitter and monitor rack in one trailer and the 2-kilowatt sound transmitter in the other trailer than face each other. Suitable for color television, the transmitters meet the specifications of the Deutsche Bundespost, of the German broadcasting system, and the recommendations of the International Radio Consultative Committee (CCIR).

A third trailer houses the rectifier and voltage regulator as well as the cooling equipment. Well spaced from the transmitter trailers, it is connected to them by cables and by air hoses of 450-millimeter (17.7-inch) diameter, which are equipped with sound absorbers.

Special roofs are available to protect against ice falling from the antenna. The complete installation may be set up on firm ground in less than 24 hours. The first installation at Bergalingen, near Wehr in Baden, uses an existing antenna to provide the Second German Television Program while the permanent transmitter building is being constructed. The gain of the antenna produces a radiated power of 250 kilowatts for the picture and 50 kilowatts for the sound.

Standard Elektrik Lorenz
Germany

GH201 Data Link—A *GH201* data link has been installed between the head office of Messrs. Stokvis in Rotterdam and its warehouse in Alphen about 35 kilometers (22 miles) away. Operating at 1200 bauds, equivalent to 150 characters per second, traffic will average 1.2 million characters per day.

Each day about 3000 incoming orders to this wholesaler of motor cars, spare parts, electrical goods, and sanitary appliances are processed by computer in Rotterdam. The necessary information for preparing invoices and packing slips

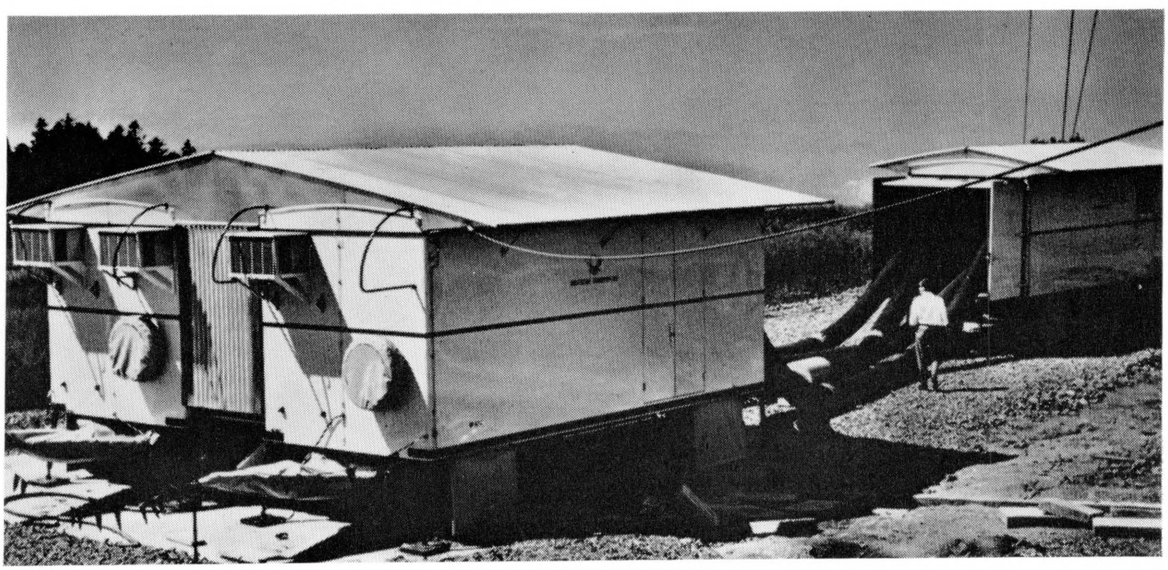

Figure 3—Mobile television transmitter.

is sent via the data link to Alphen for reproduction on a Holley page printer. Error detection facilities are included.

Nederlandsche Standard Electric Maatschappij
The Netherlands

Telegraph Message Switching Assured by Synchronous Operation of Duplicate Equipment—A new electronic telegraph message center for Air-France in Paris will handle 1400 messages during the peak half hour. This *DS.3* automatic electronic relaying center accepts and registers telegraph messages appearing on its incoming lines, recognizes routing data in the preamble of each message and arranges for retransmission toward the address according to operating procedure for the network, stores messages that are not retransmitted immediately, records messages that pass through the center when such is required, and reports on conditions within the center and on lines connected to it.

Operation is under control of a stored program and changing input and output information is supplied by wired program units. This provides for a large processing capability. Modular construction permits expansion where necessary to meet new traffic conditions. Speeds of 50, 75, 200, and 1200 bauds are determined by the characteristics of the lines being served.

Reports to a supervisory desk on conditions in the center and of the lines connected to it permit the supervisor to reroute traffic around congested lines and report faulty lines for repair. Messages with improper format are automatically routed to an operator for correction and retransmission.

Two identical equipments operate synchronously in parallel and if the one handling the traffic becomes faulty it triggers the standby equipment into active operation without loss or mutilation of the character that is being received or transmitted. The operators cannot tell except from the control signals which equipment is on line and which is standby.

To the absolute reliability of operation is added great flexibility, a smaller staff for both operating and maintaining the system, and a reduction in space requirements over earlier installations.

Compagnie Générale de Constructions Téléphoniques
France

Radio Network for Mexico—Anticipating the 1968 summer Olympic Games, Mexico has ordered substantial extension of its radio relay network for telegraphy, telephony, and monochrome and color television.

As shown in Figure 4, a new 1800-channel 6-gigahertz system will go from Ciudad Juarez at the north border, through Mexico City, to the south boundary at Tapachula, a distance of about 2000 kilometers (1250 miles). The earlier 960-channel 4-gigahertz system * inaugurated in 1962 will be extended by 6-gigahertz equipment from Cordoba to Merida, about 1000 kilometers (625 miles).

Both 6-gigahertz networks will be equipped with *FM 1800/TV-6000* and *BFM 24/6000* systems,† the latter being provided by Bell Telephone Manufacturing Company. One operating and one standby system are available for telephony and two operating and one standby system for television including sound, all with automatic switchover.

Standard Elektrik Lorenz
Germany

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* H. Carl, "Microwave Telephone Relay Network in Mexico," *Electrical Communication,* volume 39, number 3, pages 379–382; 1964.

† "Microwave Radio System for Multichannel Telephony and Television in the 6-Gigahertz Range," *Electrical Communication,* volume 40, number 2, pages 173–214; 1965.

Pneumatic Tube System for Cyclotron—The Gesellschaft für Kernforschung (Society for Nuclear Research) at Karlsruhe has ordered a pneumatic tube system to carry specimens into the irradiation chamber of its cyclotron, hold them in a defined position, and then transport them quickly to the measuring station. This latter is important for radiations having short half-lives.

An extensive control and indication system is required for the operational supervision of both the pneumatic tube system and the various irradiating and measuring devices of the cyclotron installation.

The pneumatic tube has a diameter of 65 millimeters (2.6 inches) and a special turbo blower provides for a carrier speed of 25 meters (82 feet) per second.

Standard Elektrik Lorenz
Germany

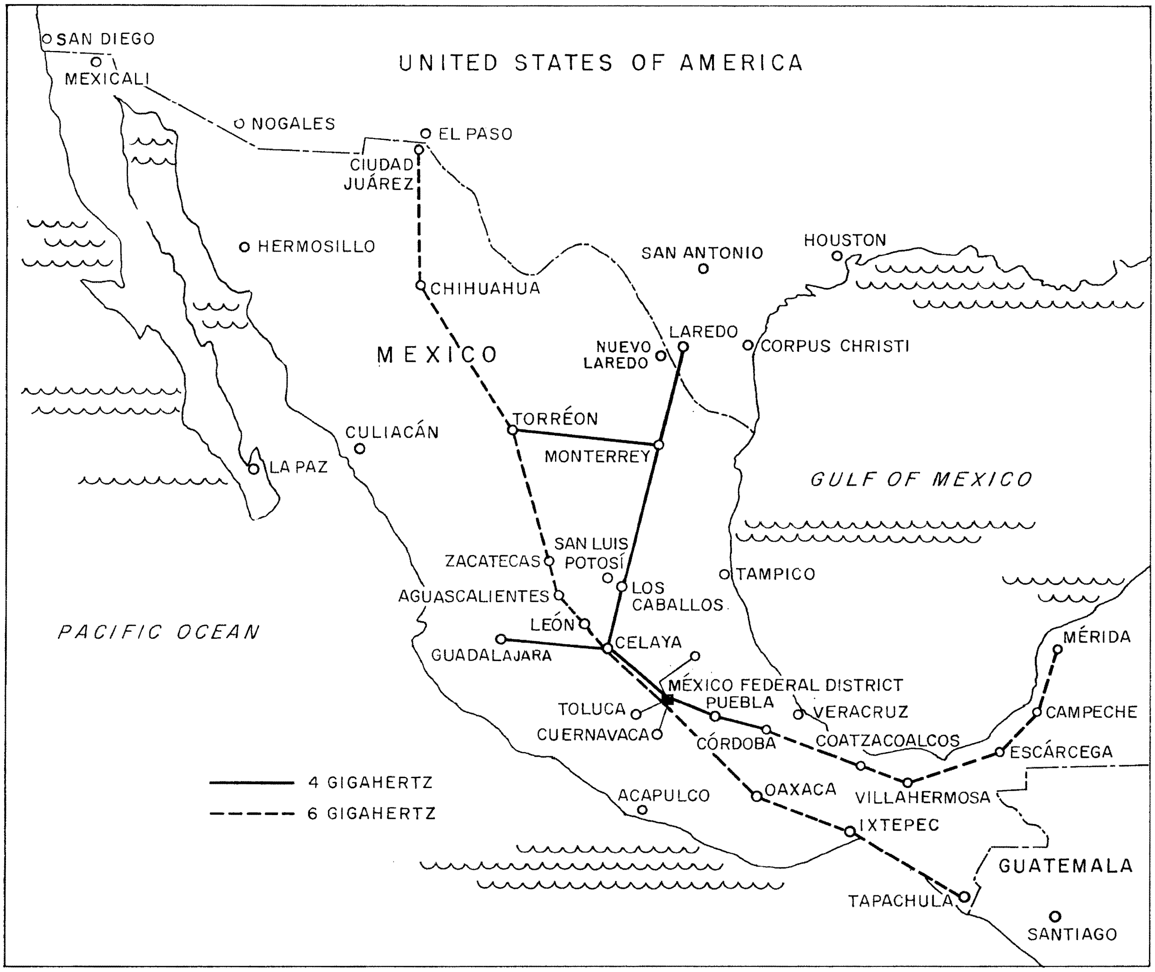

Figure 4—The original 960-channel 4-gigahertz radio network for Mexico will be extended with 1800-channel 6-gigahertz equipment as shown.

Letter Sorting Machine *Mark 5*—The *Mark 5* letter sorting machines are assembled in modules of 36 or 48 destination bins to meet the needs of each sorting station.

The manual design shown in Figure 5 has between 1 and 8 keyboards and up to 330 destination bins. An automatic sorter reads precoded addresses on letters at a nominal speed of 8 letters per second with distribution to 144 bins in 3 modules of 48 each.

Bell Telephone Manufacturing Company
Belgium

Multimeter Type *462F*—A small lightweight multimeter suitable for use in electronics has been developed. The *462F* instrument, mounted on printed-circuit board, is provided with a direct-reading scale and a knife-edge pointer with antiparallax mirror. It is protected against electrical overload and mechanical shock.

Its 20 000-ohm-per-volt movement provides high sensitivity with full-scale ranges of 1.5 direct volts and 3, 10, 30, 100, 300, and 1000 direct and alternating volts. Current ranges are of 100 microamperes direct current and of 1, 10, and 100 milliamperes, and 1 and 5 amperes direct and alternating current. Power level calibrations are from −10 to +52 decibels. Accessories are available to extend the maximum ranges. Resistance values from 1 ohm to 10 megohms may be measured.

Fabbrica Apparecchiature per
Comunicazioni Elettriche Standard
Italy

Figure 5—*Mark 5* modular letter sorting machine.

Category Scanning for Pentaconta Equipment—Each subscriber connected to a Pentaconta telephone exchange can be assigned to 1 of 10 categories by insertion of plug-in resistors at the main distributing frame. These categories determine whether the automatic equipment will provide for call deviation or for other special switching functions to that subscriber.

The category scanner tests these resistors by direct-current Wheatstone bridge measurements and transmits the results in a 2-out-of-5 code to the control circuits. The infinity value identifies the normal subscriber, the other values being between 3600 and 39 000 ohms. Figure 6 shows the switching elements of the scanner mounted on two printed-circuit boards.

Standard Téléphone et Radio
Switzerland

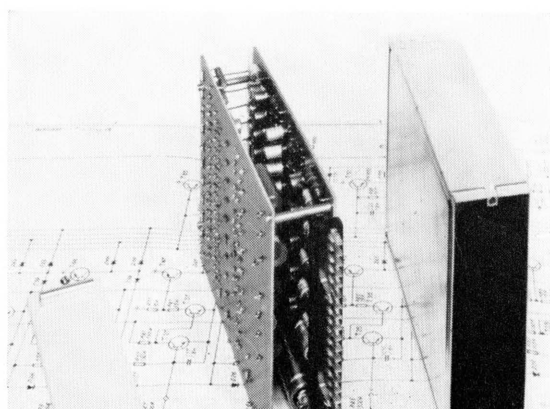

Figure 6—Electronic scanner for category identification in a Pentaconta exchange.

Gunn Effect at High Pressures—Single-crystal n-type gallium arsenide, when subjected to electrical fields $\geqq$3000 volts per centimeter, shows current oscillations owing to the transfer of the conduction electrons from their normal high-mobility state to a higher energy state with a much-lower mobility. These oscillations, which were first demonstrated by Gunn, provide a simple source of microwave energy, and devices of this type may well have considerable industrial potential.

By using extremely high pressures, of the order of 50 000 bars or 750 000 pounds per square inch, in the apparatus shown in Figure 7, it is possible to control the energy separation between the two electron states in gallium arsenide. This has now been successfully accomplished in a series of experiments. The work has shown that the mechanism for electron transfer between states is undoubtedly responsible for the Gunn oscillations. Furthermore, it has permitted the first direct determination of some of the basic parameters (such as the electron mobility) associated with the higher energy state. These are essential to any proper understanding of the effect.

Standard Telecommunication Laboratories
United Kingdom

Ultrafast Multiplier Phototube—The F4034 phototube has a 10-stage multiplier for medium gain, an end-window photocathode, and a focusable image section. It was designed to detect light pulses of very short duration and light beams, such as from a laser, modulated at very high frequencies.

The tube exhibits a rise time of 0.8 nanosecond with a 2-nanosecond pulse. The quantum efficiency of the cathode can be increased by the multiple-bounce technique that substitutes a prismatic faceplate for the regular faceplate.

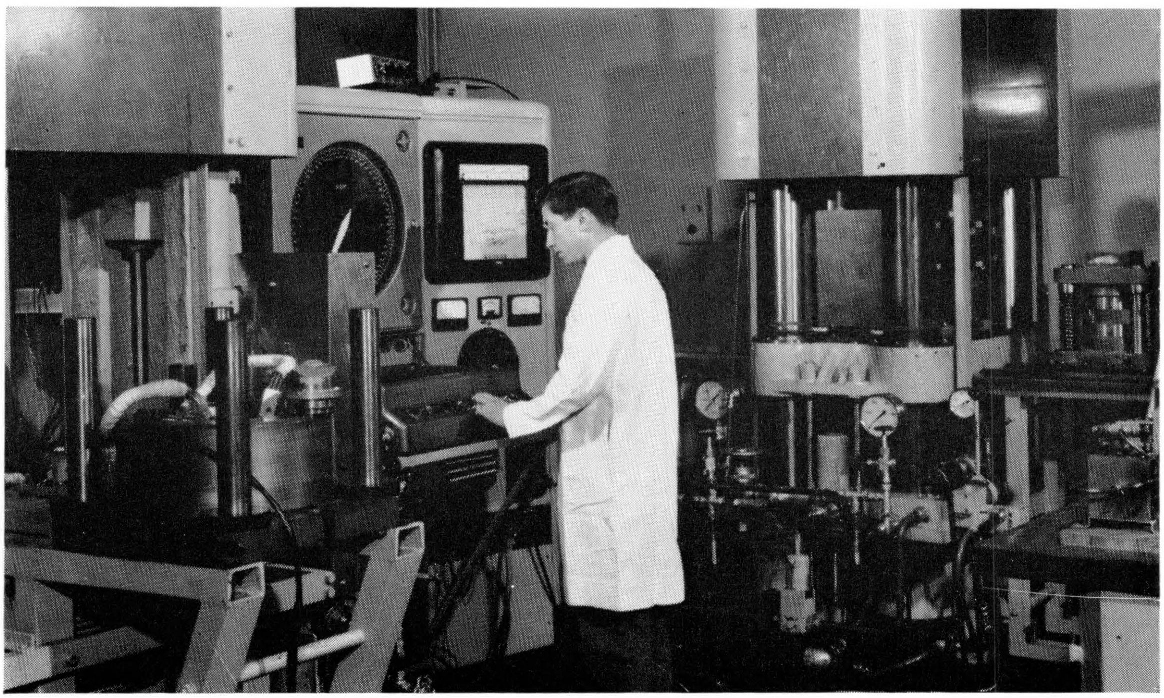

Figure 7—Tetrahedral anvil apparatus used in measurements of the Gunn effect at pressures up to 50 000 bars.

An electrostatically focused electron lens system having a definite aperture in the electron-image plane is incorporated between the photocathode and the first dynode to limit the effective photocathode area. This reduces the equivalent noise input by minimizing collected thermionic emission current and ion feedback. It also maintains high collection efficiency in the effective photocathode area. If this area is made small it can be deflected for alignment, search, and track operation. High linear output currents are delivered to a 50-ohm coaxial transmission line.

ITT Industrial Laboratories
United States of America

Portable and Car Radio Combined—A transistor radio, the Rambler, exhibited at this year's Radio Show in London, was designed for use either as a portable radio or as a car radio. The aeral input can be changed from an internal ferrite rod to the external car aerial by pushing a button. The receiver also uses expanded tuning from 540 to 1620 kilohertz—the tuning scale covers 1070 to 1620 kilohertz and 540 to 1090 kilohertz by push-button selection. A 5-to-1 reduction of the tuning drive improves station searching technique.

Standard Telephones and Cables
United Kingdom

CS2 Computer—The construction and preliminary tests of the laboratory model of the *CS2* computer have been completed. It is a digital, general-purpose, microminiature, small-capacity, low-price computer.

Its characteristics include serial operation, a 16-bit word, and single-address instructions. Integrated circuits are used together with a coincident magnetic core memory having a capacity of 1024 words of 16 bits to store both program instructions and data. Various applications are foreseen, notably, rho-theta navigation and coordinate transformation problems.

The *CS2* computer belongs to a family of large-capacity high-speed computers, notably the *825P* computer with parallel operation, a 24-bit word, and a memory of 4096 words. This computer performs real-time computations and is primarily designed for aircraft applications.

Laboratoire Central de Télécommunications
France

High-Brightness Display Storage Tube—The F-3019 is a 5-inch (127-millimeter) storage cathode-ray tube suitable for high-brightness displays for fire-control radar, airborne radar for weather and navigation, airport surveillance, television at standard frame rates, and the study of transients.

Shown in Figure 8, the high-resolution display may be erased with extreme rapidity. An on-axis writing gun minimizes distortion and facilitates equipment packaging. It uses electrostatic

Figure 8—High-brightness cathode-ray storage tube.

focusing and magnetic deflection. The tube is mounted in a shield to eliminate adverse effects of stray magnetic fields. It will withstand vibration up to 8 gravity units.

ITT Electron Tube Division
United States of America

Pulse-Code-Modulation Telephone Equipment for England—Pulse-code-modulation equipment has been ordered by the British Post Office to increase the capacity of the existing public telephone network.

Repeaters will be installed at 2000-yard (1800-meter) intervals in manholes now used to house loading coils. Two pairs of wires, each now handling a single 2-way conversation, will be operated as a 4-wire pulse-code-modulation circuit for 24 two-way conversations, a 12-fold increase in traffic capacity.

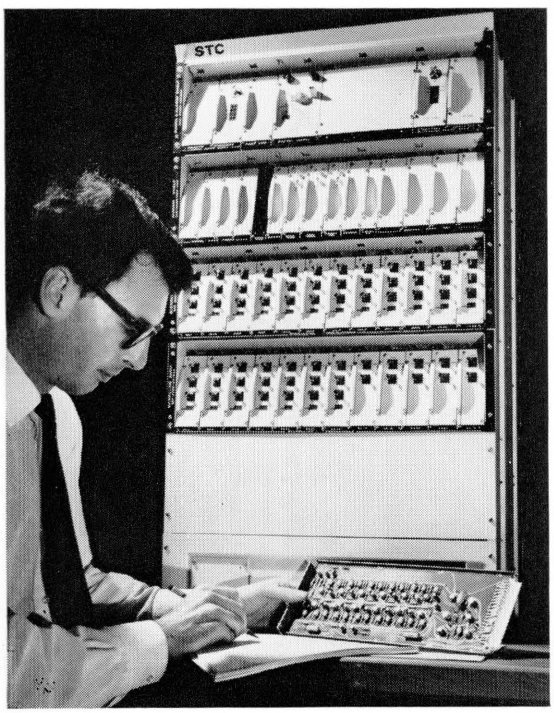

Figure 9—Pulse-code-modulation terminal equipment for a 24-channel public telephone system.

A terminal equipment is shown in Figure 9. Microcircuits are used extensively in the repeaters. Industrial resistor-transistor micrologic monolithic integrated circuits are used extensively.

Standard Telephones and Cables
United Kingdom

Electrodynamic Telephone Receiver—Production has been started on a new dynamic receiver capsule to replace the conventional electromagnetic type. It has high sensitivity and flat response over the speech band. Its electrical impedance of 200 ohms at 1000 hertz is nearly constant over the speech band, whereas that of the present design rises considerably with frequency.

A circular permanent magnet produces a radial magnetic field across an annular air gap in which the actuating coil is placed. A separator establishes the position of the diaphragm, and holes provide acoustic resistance for damping. The unit is mounted in a thermoplastic housing protected by a steel cover plate.

The ratio of weight to receiver sensitivity is important in view of the trend to lightweight handsets. The receiver must not exceed 90 grams (3.2 ounces). It has a maximum diameter of 48 millimeters (1.8 inches) and a height of 24.5 millimeters (1 inch).

Bell Telephone Manufacturing Company
Belgium

Data Link for Nuclear Power Control—The *GH205* is now being used by the British Central Electricity Generating Board to tighten the control between its headquarters in London and three nuclear power stations at Sizewell, Dungeness, and Trawsfynydd. Other connections are made to major control centers at Bramshall and Southwark. The computer system at headquarters determines how a particular area can be served economically according to demand, weather, and other factors. Depending on the origin, information is transmitted in the British 5-track shift code, International Telegraph Alphabet 2, or Pegasus code to the computer at 94 characters per second.

Standard Telephones and Cables
United Kingdom

Format Translator for International Telegraphy—For international telegraph services the International Telegraph and Telephone Consultative Committee (CCITT) recommends the application of General Telegraph Exchange (Gentex) techniques. This requires that regardless of origin telegrams be transmitted using the techniques and message format of the country of destination.

An automatic translator to go from tape to page format has been developed. It initiates carriage return and line feed signals after any specified number of characters per line have been transmitted.

For correcting errors, signals are held in a buffer store until a decision is made as to their correctness. Each character is checked for code correctness and whether it begins or ends a word. At the end of a word the store is unblocked and serial transmission starts. If an error code is sent to the store, all of the characters in the store are erased.

Construction is in International Standard Equipment Practice using plug-in printed-wiring boards. Epitaxial planar transistors and diodes are used extensively. A ferrite core memory of 1024 characters serves as the buffer store, which is shared on a time basis by four translators.

Standard Elektrik Lorenz
Germany

Spark-Gap Protectors—The ceramic-and-metal *F-2709* spark gaps shown in Figure 10 present a very high impedance until breakdown when the impedance drops to a few ohms. They may be used for high-voltage energy transfer with minimum switch dissipation as well as for the protection of other equipment against overvoltage.

A series of 12 sizes provides for breakdown between 400 and 8000 volts. Surge currents range to 3000 amperes and energy to 40 joules.

For protection against high energy transients, such as lightning, the *F-2719* gap has a standard breakdown voltage of 400 and handles a peak current from 25 000 amperes at 2.5 coulombs to 200 amperes at 200 coulombs.

ITT Electron Tube Division
United States of America

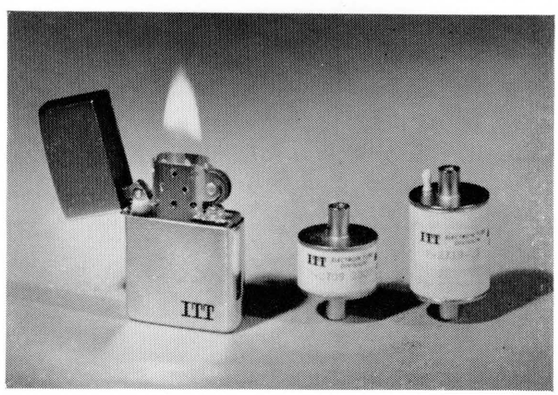

Figure 10—Spark gaps for overvoltage protection.

Pentaconta Exchange Inaugurated in Switzerland—In 1917 the first rotary telephone central office in Switzerland, which included the then new register control of switching and central drive for rotary switches, was cut over. Nearly half a century later, Pentaconta switching was introduced with the cutover of the Regensdorf exchange. A view of the switchroom is given in Figure 11.

Initially equipped with 6000 subscriber lines and having a final capacity of 10 000 lines, Regensdorf replaces a *7D* rotary center exchange. The junctions to and from the rural main exchange are for alternating-current selection, *C-5* carrier, and radio link operation. There are 70 trunks in both directions over wire, carrier, and radio, about a third being of the latter type.

Among facilities specially developed for this installation were the power supply, call deviators, and control circuits for pay stations and 2-party lines. Pulse metering is used for charging for calls.

Standard Téléphone et Radio
Switzerland

Alarm System For Mersey Tunnel—Shown in Figure 12 is a control console for an alarm system for fires and accidents being installed in the 3-mile-long Mersey tunnel near Liverpool, England. We will provide 94 break-glass alarm boxes complete with telephone instruments, 13 Sentrycall automatic fire detectors, the control console equipment, and a telephone exchange.

Control room facilities include a map display of the tunnel showing the location of alarm boxes, those that have been operated, and the state of various illuminated signs. There is also a 42-line telephone exchange and cordless switchboard.

In the various plant rooms associated with the tunnel, Sentrycall automatic smoke detectors will be installed; the operation of these is also indicated on the control room site plan.

The Mersey tunnel alarm system is a radial one; that is, a pair of wires is connected from each alarm location to the console. An electronic module on the console for each location not only detects the operated alarm but is also capable of detecting open-circuit and short-circuit faults. Comprehensive system test facilities are also included.

Standard Telephones and Cables
United Kingdom

Subscriber Set *SSB 2904*—A new subscriber set for operation on common battery systems has been developed for the Belgian telephone administration.

The handset contains a carbon microphone and a dynamic receiver and is connected through a coiled cord. Unbreakable plastic material is used for the handset and the housing. The receiving reference equivalent is 4 decibels better than the existing subscriber set.

All components except the dial, ringer, and transfer button are mounted on a plastic form

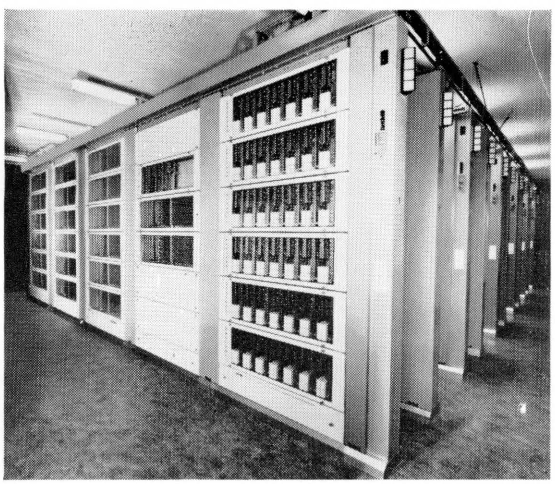

Figure 11—Regensdorf Pentaconta exchange in Switzerland.

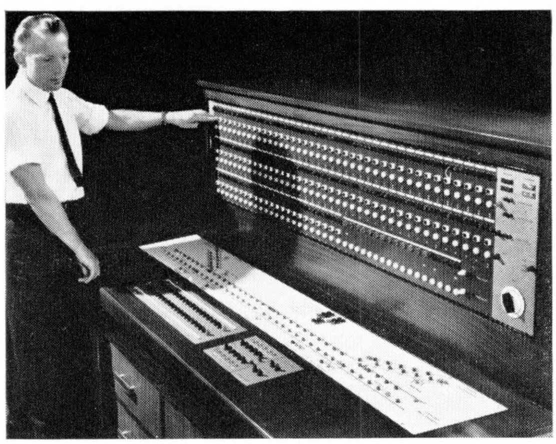

Figure 12—Console for the alarm system to report fires and accidents in the Mersey tunnel.

fastened to the metal base plate. Wiring is on the back of the plastic form. The loudness of the single-coil ringer is adjustable by a control in the base plate and is heard through openings in both the housing and base plate.

Bell Telephone Manufacturing Company
Belgium

Insertion-Loss Measuring Equipment—The type *74905* equipment shown in Figure 13 will measure insertion loss of circuits and networks up to 60 decibels with an accuracy better than 0.1 decibel and up to 70 decibels with lower accuracy. It comprises a sending unit, a measuring unit, and an attenuator. Solid-state circuits are used in the first two equipments.

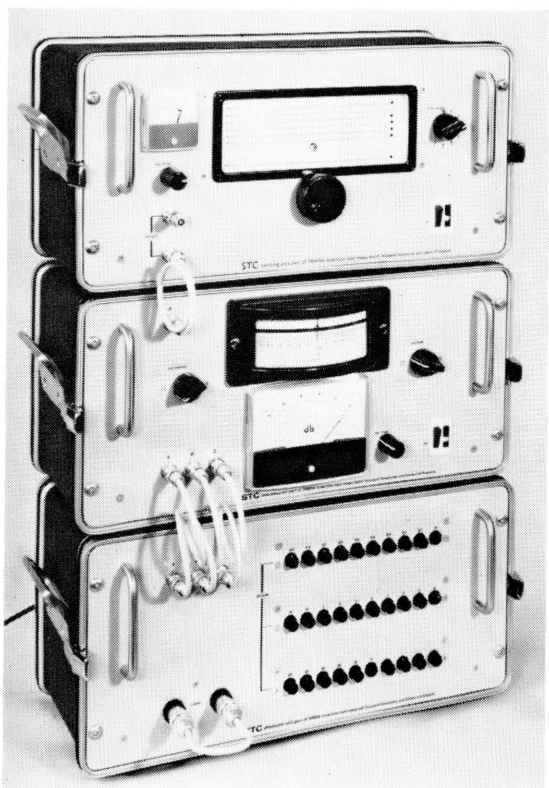

Figure 13—Insertion-loss measuring equipment type *74905*.

Two sending units are available: the first for use on 75, 125, 140, and 600 ohms between 30 hertz and 300 kilohertz; the second operates only on 75 ohms and covers 30 hertz to 20 megahertz.

The push-button attenuator has steps of 0.1 decibel and is used with a measuring meter graduated in 0.02-decibel steps from +0.6 to −0.6 decibel. Provision has been made for connecting an external counter when the frequency of measurement has to be set precisely.

Each unit measures 21.5 by 9.75 by 10.5 inches (546 by 248 by 267 millimeters) and weighs 25 pounds (11.4 kilograms). The equipment operates from 45 to 66 hertz at 100–125 volts or 200–250 volts.

Standard Telephones and Cables
United Kingdom

Virgin Islands Gets Direct Distance Dialing—Telephone subscribers on Saint Thomas, Saint John, and Saint Croix of the Virgin Islands may now dial each other and subscribers in the United States of America direct without the assistance of an operator. This is the first such overseas telephone system accessible by direct distance dialing to the United States mainland.

Virgin Islands Telephone Corporation
Virgin Islands

Pentaconta Switching Serves Council of Europe—In the modern building of the Palais des Droits de l'Homme in Strasbourg, France, the Council of Europe, with guest representatives of State and members of the European Parliament, inaugurated a Pentaconta telephone exchange.

The new exchange includes 800 extensions and 54 trunks with 6 operators' positions equipped with keysets and 1 supervisor's desk. The extensions can be of 3 classes, those having access to the public network only through operators, those having direct access to the Strasbourg area, and those having direct access to the entire French public network.

A special automatic device at the operator's desk shown in Figure 14 indicates charges for calls instantaneously. Two Telecelere devices are provided to the General Secretariat for rapid key calling of frequently used numbers. The installation is completed with 25 groups of Confort type sets and 12 Dirigent-Universal interphone sets.

Compagnie Générale de Constructions Téléphoniques
France

Undersea Cable Between Venezuela and Virgin Islands—A complete 80-channel undersea telephone cable system linking Venezuela and the Virgin Islands was supplied by Standard Telephones and Cables. The cable was laid by the American Telephone and Telegraph Corporation and the system was placed in operation in August 1966.

The new cable extends between Maiquetia, Venezuela, and Saint Thomas, Virgin Islands, a distance of 550 nautical miles (1000 kilometers). There are 22 repeaters at intervals of 26 nautical miles (48 kilometers) along the route. Lightweight deep-sea cable in which the inner steel wire strength member is enclosed with a box-seamed copper tape to form the center conductor is used for 490 nautical miles (900 kilometers) of the route.

Standard Telephones and Cables
United Kingdom

Figure 14—Operator's desk with automatic call charging device.

Pay Station for Dutch Administration—A pay station designed for the domestic telephone network of Holland permits normal placing of local calls while restricting toll calls to authorized personnel using a special key. The coin box is in a separate compartment and is protected by a cylinder lock. Mercury switches are used to delay the line closure and to allow collection after the call is completed.

Bell Telephone Manufacturing Company
Belgium

Baghdad Airport Installation—A contract has been awarded by the Ministry of Communications of the Republic of Iraq to supply electronic equipment for the new international airport being built at Baghdad. Standard Telephones and Cables is the prime contractor, and Creed and Company and several other major electronics organizations in the United Kingdom will be subcontractors. The contract is for the supply and installation of radio navigation, communication, air-traffic-control, meteorological, and ancillary equipment.

The radio navigation aids include instrument landing systems (ILS), very-high-frequency omnidirectional radio range (VOR), nondirectional beacons (NDB), and very-high-frequency direction-finding equipment. The instrument landing equipment is the *STAN 7/8/9*.

Among the very large quantity of communication equipment are extended-range ground-to-air and land mobile equipment, ground-to-air selective calling systems, internal and external telephone installations, and teleprinter systems. The high-frequency communication equipments are the *DS.12* transmitter and *RX.10* and *RX.11* receivers, which will be used for point-to-point communication between Baghdad and other Middle East aeronautical centers. The extended-range very-high-frequency equipment consists of the *DU.6* transmitter and the *RX.25* receiver. Other items are a Plessey weather radar, a meteorological broadcast center, an intercommunication system, speech recorders, and air-traffic-control consoles for the control tower and air-traffic-control centers.

In addition to the new equipment, the contract provides for the transfer of apparatus at present installed at Baghdad West Airport, which will close on completion of the new airport.

Standard Telephones and Cables
United Kingdom

Mössbauer Spectrometer—The Mössbauer effect gives rise to an extremely sharp atomic resonance, the Q value being of the order of 10^{13}. Small relative velocities of a gamma-ray source with respect to an absorber, comprising the material under examination, cause Doppler shifts which are used to modulate the gamma-ray energy about the absorption maximum. By using several velocity settings, the resonance curve can be obtained.

The spectrometer can give information about lattice properties of crystals, valency states, magnetic properties, and isotopic lifetimes of certain elements. It is sensitive enough to detect the effect of gravity on photons and has been used to demonstrate other such effects involving relativity concepts.

A prototype gamma-ray source drive unit has been developed which is capable of moving with velocities ranging from 0.01 to 100 millimeters per second. It comprises two coils mounted on a shaft, to the end of which the source can be fixed. These coils move in independent radial magnetic fields set up by two permanent magnets. One of the coils is energized by a stable triangular-wave generator, and the other monitors the resultant voltage, which is then used for controlling and stabilizing the velocity of the system through a feedback servo loop. The movement is continuously monitored on an oscilloscope. See Figure 15.

A trigger unit is provided to start and stop the scaler and timer units during the velocity cycle, in either forward or reverse direction. The gamma-ray counting is done in one direction only during the period in which the velocity is constant.

The gamma-ray counting equipment, which employs a xenon proportional counter, is of a standard type that would be found in any radiochemical laboratory.

Standard Telecommunication Laboratories
United Kingdom

Private Automatic Branch Exchange for Düsseldorf—The Düsseldorf municipal administration has ordered a crossbar Citomat telephone branch exchange equipped for 195 trunks, 2600 extensions (200 of which use push-button calling), and 260 connecting links. An ultimate required capacity of 385 trunks, 5000 extensions, and 500 links is well within the 8000-line rating of the equipment.

The 2400 dial extensions are in 6 groups of 400 each. The use of 100-outlet crossbar switches in the group switching stages provides

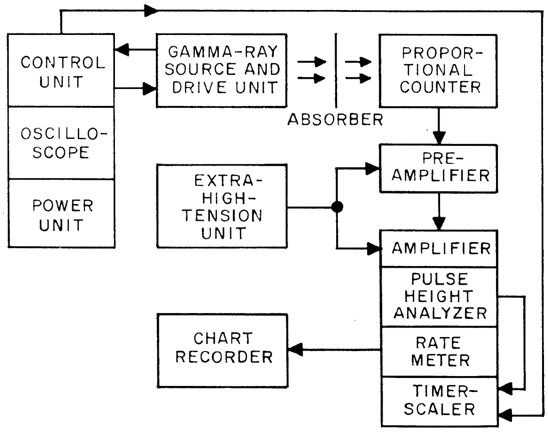

Figure 15—Arrangement of components in the Mössbauer spectrometer.

economical grouping and trunking. A concentrator and answer control distributes the load uniformly among the 7 operator positions, each of which is connected to a supervisory position. A total of 78 tie-line and interswitchboard line relay sets provide for various outside offices.

Standard Elektrik Lorenz
Germany

Pentaconta Exchange in Morocco Hotel—The Grand Hotel, a luxury tourist hostelry, was recently inaugurated at Restinga, on the Rif Coast of Morocco, in the presence of four Morocco Ministers for Home Office, Post and Telecommunications, Tourism, and Development. The hotel, a casino, and a commercial center will be served by the Tetuan airport, the restoration of which is under study. The hotel is equipped with a 166-station Pentaconta telephone exchange.

Compagnie Générale de Constructions Téléphoniques
France

Microwave Filters Using Evanescent Waves—Microwave components built into waveguides normally operate at frequencies above a critical value, depending on the waveguide dimensions, at which a progressive wave can propagate. Below this critical frequency, the wave is said to be evanescent, and it is generally assumed that energy will not be transmitted.

Recent work has shown that this long-entrenched scientific belief, dating back to Lord Rayleigh's original predictions in 1897, does not hold under certain conditions. Energy transfer can, in fact, be achieved by introducing reactive elements at intervals along the waveguide. Thus in typical H_{01} rectangular waveguide (which below the critical frequency behaves like a pure inductance), it is sufficient to make the impedance of the elements the conjugate of the waveguide impedance.

This discovery, apart from its scientific interest, has useful engineering applications, enabling exceptionally simple and small waveguide band-pass filters to be constructed. Such filters consist simply of capacitive tuning screws inserted at suitable intervals along the waveguide, down which energy travels in a series of standing-wave patterns, not unlike those occurring in conventional waveguide resonators. The functional shape of the wave pattern, however, is hyperbolic and not sinusoidal. Such a filter is shown in Figure 16.

Standard Telecommunication Laboratories
United Kingdom

***7EN* Rotary Exchanges**—The modern version of the widely used *7E* rotary telephone switching

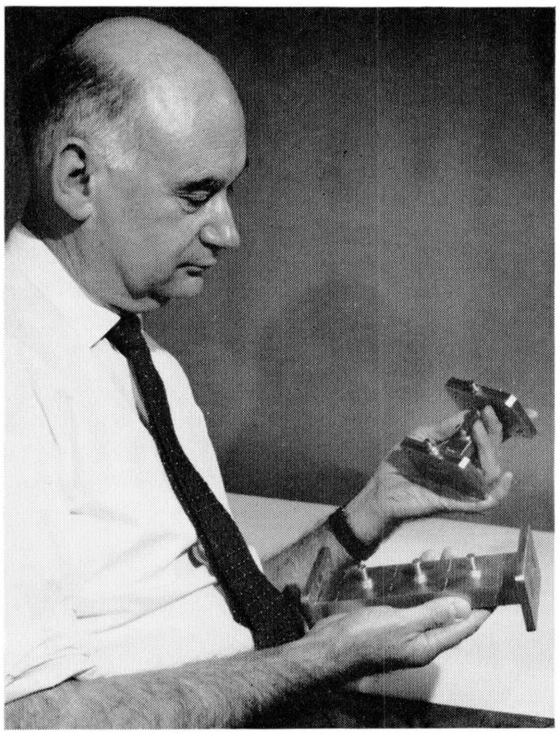

Figure 16—George Craven, the inventor, shows how a 3-section, 4-gigahertz filter of the new evanescent-mode type compares with a conventional filter, the volume of which is 8 times greater. The new filter is built in *X*-band waveguide with a cross section of 0.9 by 0.4 inch (2.3 by 1 centimeter).

system is called the *7EN*. The major improvements include the following.

(A) Replacement of flat-type relays by spring and reed relays.

(B) Use of transistors in the phase comparator and other circuits.

(C) Printed circuits.

(D) Self-compelled multifrequency signaling.

(E) Capacitance store for routing, tariff setting, and identification of the class of the called line.

(F) Wrapped wire connections.

(G) Translators for national, international, and intercontinental signaling.

During September 1966, the following five *7EN* exchanges were cut over.

Beverwijk, Netherlands, local and toll exchange with 3000 local lines.

Wezembeek, Belgium, local exchange of 7000 lines.

Barvaux, Belgium, local and toll zone center with 1000 local lines.

Hamoir, Belgium (near Barvaux), local exchange with 500 lines.

Brussels, Belgium (Jette 4), local exchange with 3000 lines connected directly to *7A2* Jette exchange in the same building.

Bell Telephone Manufacturing Company
Belgium
Nederlandsche Standard Electric Maatschappij
The Netherlands

Gemini *11* Television Coverage—Millions of fascinated television viewers on two continents watched on 15 September 1966 the incredibly close "on-target" splashdown and recovery of the Gemini *11* astronauts. The landing was so close to the U. S. S. Guam, the recovery ship, that the space vehicle could be seen swinging on its parachute as it descended to splash gently on the water.

This was the fifth live television presentation of astronaut recovery operation. The portable earth station installed for this event on the aircraft carrier was built by ITT Federal Laboratories and operated by ITT World Communications in coordination with the Communications Satellite Corporation, whose Early Bird satellite provided the link to the television networks of both the United States and Europe. The National Aeronautics and Space Administration and the United States Navy contributed substantially to the success of this broadcast.

ITT World Communications
ITT Federal Laboratories
United States of America

Pay Station for Export—An extension in the design of the pay station developed for export * is the inclusion of a circuit to account for the value of the deposited coins. Periodic metering pulses from the exchange may be by reversal of line polarity, by 50-hertz pulses with ground return, or by 16 000-hertz pulses. A warning system informs the user when to insert more coins to prolong the connection. It also indicates the reason for disconnection when the allotted time has been used.

Bell Telephone Manufacturing Company
Belgium

Pentaconta Switching Installed in Bahamas—The installation of a private Pentaconta telephone exchange in Nassau adds the Bahama Islands to the 70 countries in which Pentaconta switching systems are operating. The new exchange has a capacity of 100 extensions that are served by 14 trunks. However, this is not the first Pentaconta crossbar exchange in the West Indies, where Columbus landed in 1492.

Compagnie Générale de Constructions Téléphoniques
France

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* "Export Pay Station," Recent Achievements, *Electrical Communication,* volume 40, number 2, page 167; 1965.

United States Patents Issued to International Telephone and Telegraph System; August–October 1965

Between 1 August 1965 and 31 October 1965, the United States Patent Office issued 124 patents to the International System. The names of the inventors, company affiliations, subjects, and patent numbers are listed below.

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P. R. Adams and M. Rogoff, ITT Laboratories, Transmission Systems, 3 202 764.

P. R. Adams, J. A. Fingerett, and R. von Buelow, ITT Federal Laboratories, Cumulative Digital Computing Systems, 3 204 088.

H. H. Adelaar, Bell Telephone Manufacturing Company (Antwerp), Interconnecting Network for a Telecommunication System, 3 204 033.

H. H. Adelaar, F. Clemens, and J. L. Masure, Bell Telephone Manufacturing Company (Antwerp), Time Division Multiplex Signalling System, 3 211 839.

H. H. Adelaar, F. Clemens, and J. L. Masure, Bell Telephone Manufacturing Company (Antwerp), Selection System, 3 204 039.

M. A. Argentieri, ITT Laboratories, Display System, 3 200 498.

R. E. Arseneau, ITT Kellogg, Multi-Frequency Tone Signalling System, 3 201 524.

R. E. Arseneau and J. Bereznak, ITT Kellogg, High Speed Electronic Switching Telephone System, 3 204 043.

M. J. Beer and R. E. Schemel, Standard Telephones and Cables (London), Frequency Deviation Detector, 3 207 995.

J. Bereznak, ITT Kellogg, Electronic Switching Matrix, 3 201 520.

P. Best, Standard Telephones and Cables (London), Bonding of Metals to Ceramic Materials, 3 203 084.

F. T. Bilek, ITT Kellogg, Miniature Plug and Jack Explosion Proof Connector, 3 204 053.

F. T. Bilek, ITT Kellogg, Wire Spring Pushbutton Assembly, 3 205 318.

J. M. Blackhall, ITT Kellogg, Automatic Toll Ticketing Systems, 3 200 200.

J. P. Blanchenot, Cannon Electric Company, Mating Electrical Pin and Socket Contacts and Insulator Therefor, 3 200 367.

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F. H. Bray, N. H. Martin, and J. M. Ridler, Standard Telephones and Cables (London), Automatic Identification, 3 200 203.

W. G. Brown, ITT Federal Laboratories, Pulse Code Modulation Coder, 3 201 777.

E. Burstein, ITT Laboratories, Continuous Operation Two Level D.C. Pumped Maser Amplifier with Semiconductor Interface, 3 201 708.

R. A. Canty and R. G. Griffin, ITT Components, Capacitor Electrolyte, 3 202 611.

H. N. Capen, F. A. Modavis, and L. M. Vallese, ITT Laboratories, Antenna Utilizing the Hall Effect, 3 204 186.

G. F. Carlson, ITT Bell and Gossett Hydronics, Hot Water Heating System Having Auxiliary Pressurizing Means, 3 202 355.

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L. E. Clements, ITT Federal Laboratories, Contrast Control Circuit, 3 204 027.

J. R. G. Collard, ITT Federal Laboratories, Cryogenic Cooling Devices, 3 203 477.

R. Dahlberg, Intermetall (Freiburg), Method and Means for Contacting and Mounting Semiconductor Devices, 3 200 468.

T. E. Dahlen, Cannon Electric Company, Electric Connector Having RF Filter, 3 200 355.

P. P. Danesi, Royal Electric Corporation, Electrical Plugs, 3 204 215.

D. W. Davis, ITT Federal Laboratories, Storage Screen Assembly for Information Storage Tubes, 3 202 856.

C. L. Day, ITT Federal Laboratories, Target Electrode for Barrier Grid Storage Tube, 3 201 628.

G. W. Dean, ITT Cannon Electric Company, Contact Terminal for an Electrical Conductor Member, 3 201 744.

R. A. De Rose and H. E. Tauscher, ITT Kellogg, Flexible Ribbon Cable Connector, 3 214 725.

B. Dietrich, Clevite Corporation (Purchased Invention), Semiconductor Amplitude Modulation Circuit, 3 202 940.

C. F. Drake and R. H. Hutchins, Standard Telecommunication Laboratories (London), Color Photoengraving Techniques for Producing Conductor Devices, 3 202 509.

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E. H. Eberhardt, ITT Federal Laboratories, Image Tube Target Locating Device, 3 207 997.

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W. Fischer and D. Schafer, Standard Elektrik Lorenz (Stuttgart), Device for Use in Magnetic Tape Conveying Equipment, 3 207 402.

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A. Gerlach, Intermetall (Freiburg), Switching Circuit, 3 201 603.

A. F. Giordano, ITT Federal Laboratories, Stereoscopic Projection Apparatus, 3 200 702.

R. D. Grayson, ITT General Controls Company, Water Heater Control, 3 198 432.

R. D. Grayson, General Controls Company, Control Device for Temporarily Altering the Temperature Setting of a Thermostat, 3 203 258.

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H. Grundig, Standard Elektrik Lorenz (Stuttgart), Rotary Switch With Interchangeable Contact Structure for Shorting and Non-Shorting Positions, 3 201 532.

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W. Hauer and J. L. Garnier, ITT Federal Laboratories, Distributing System for Transfer of Articles, 3 203 533.

J. S. Hawkins, Jennings Radio Manufacturing Corporation, Electro-Magnetic High-Current-Carrying-Capacity Vacuum Relay, 3 200 222.

A. J. Henquet, R. V. Cavin, and M. Feuillepain, Compagnie Générale de Constructions Téléphoniques (Paris) and Le Matériel Téléphonique (Paris), Control of Remote Telephone and Like Equipment, 3 204 041.

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L. Himmel, ITT Laboratories, Identification System, 3 201 757.

R. C. P. Hinton, E. H. P. Bigo, and P. Pleshko, ITT Laboratories, Logic Circuits Employing Negative Resistance Elements, 3 204 112.

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G. S. Johnson, Cannon Electric Company, Tool for Inserting and Extracting Removable Electrical Contacts, 3 197 849.

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H. Mach and H. Kudritzki, Standard Elektrik Lorenz (Stuttgart), Carrier Storage Arrangement in a Pneumatic Tube System, 3 201 062.

D. C. J. Magotteaux, Bell Telephone Manufacturing Company (Antwerp), Phase Modulated Pulse Recording and Reading Systems, 3 202 975.

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F. P. Mason, G. J. L. Stevens, and F. G. Smith, Creed and Company (Brighton), Facsimile System Having Provision for High Speed Skipping of Blank Areas, 3 201 512.

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R. Quesinberry, Barton Instrument Corporation, Valve Control Mechanism, 3 211 013.

W. A. Ray, General Controls Company, Oil-Filled Solenoid Valve Construction, 3 211 417.

W. A. Ray, ITT General Controls Company, Polarized Solenoid Actuating System, 3 200 591.

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R. D. Salmon, Creed and Company (Brighton), Centrifugal Speed Governor which Minimizes the Effect of Contact Erosion, 3 202 780.

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D. M. Sharp, ITT Federal Laboratories, Radio Receivers, 3 201 696.

W. Sichak and Z. G. Lyon, ITT Laboratories, Single Sideband Communication System, 3 201 692.

S. Simon and M. Voeve, Bell Telephone Manufacturing Company (Antwerp), Alternating Current Signal Receiver, 3 200 307.

J. A. Stamm, C. E. Rumsey, and R. F. Franke, ITT Federal Laboratories, Apparatus for Accurate Formation and Presentation of a Visual Display, 3 200 724.

A. P. Stein, ACF Industries (Purchased Invention), Tensiometer, 3 203 235.

F. Steiner, Standard Elektrik Lorenz (Stuttgart), Arithmetic Unit, 3 202 810.

F. Steiner, Standard Elektrik Lorenz (Stuttgart), Analogue Indicating Device, 3 207 121.

R. M. Stuart, Cannon Electric Company, Reusable Peripheral Seal Joint, 3 200 366.

W. L. Tack, Clevite Corporation (Purchased Invention), Furnace Apparatus and Conveyor Therefor, 3 202 406.

L. D. O. Tearne, Airmatic Systems Corporation, Horizontal Central Transfer Point, 3 201 063.

R. L. Thorne, ITT Industrial Products Division, Stroboscopic Display with Sample-and-Hold Circuit, 3 201 641.

G. Trautwein, Standard Elektrik Lorenz (Stuttgart), Error Detecting System for Pulse Communication Systems, 3 204 189.

F. Ulrich, Mix & Genest Werke (Stuttgart), Arrangement for Storing and Scanning Information in Ferrite-Core Storage Devices, 3 204 226.

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H. Wollmann, T. Grewe, and O. Kolb, Standard Elektrik Lorenz (Stuttgart), Circuit Arrangement and a Method of Adjusting the Permanent Flux in a Magnetizable Element, 3 204 224.

N. H. Young, Jr., ITT Laboratories, Beyond-the-Horizon Communication System for Air Vehicles, 3 209 260.

W. K. C. Yuan, ITT Kellogg, Ring Counter and Marker, 3 200 204.

F. Zendeh, Standard Elektrik Lorenz (Stuttgart), Self Correcting Coding Circuit, and Circuit Arrangement for Decoding Binary Information, 3 201 783.

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H. C. La Paro and B. Burkhoff, ITT Laboratories, An Audio-Visual Apparatus, Des. 202 075.

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The following list includes papers published in other periodicals and, in some cases, presented at meetings and not yet published. Some unpublished papers may be available in limited quantities and requests should be directed to *Electrical Communication*. Requests for published papers should be made to the indicated publication and not to *Electrical Communication*. The affiliation of the author is given in parentheses.

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