July 1970 / Volume 18 / Number 7

EEE

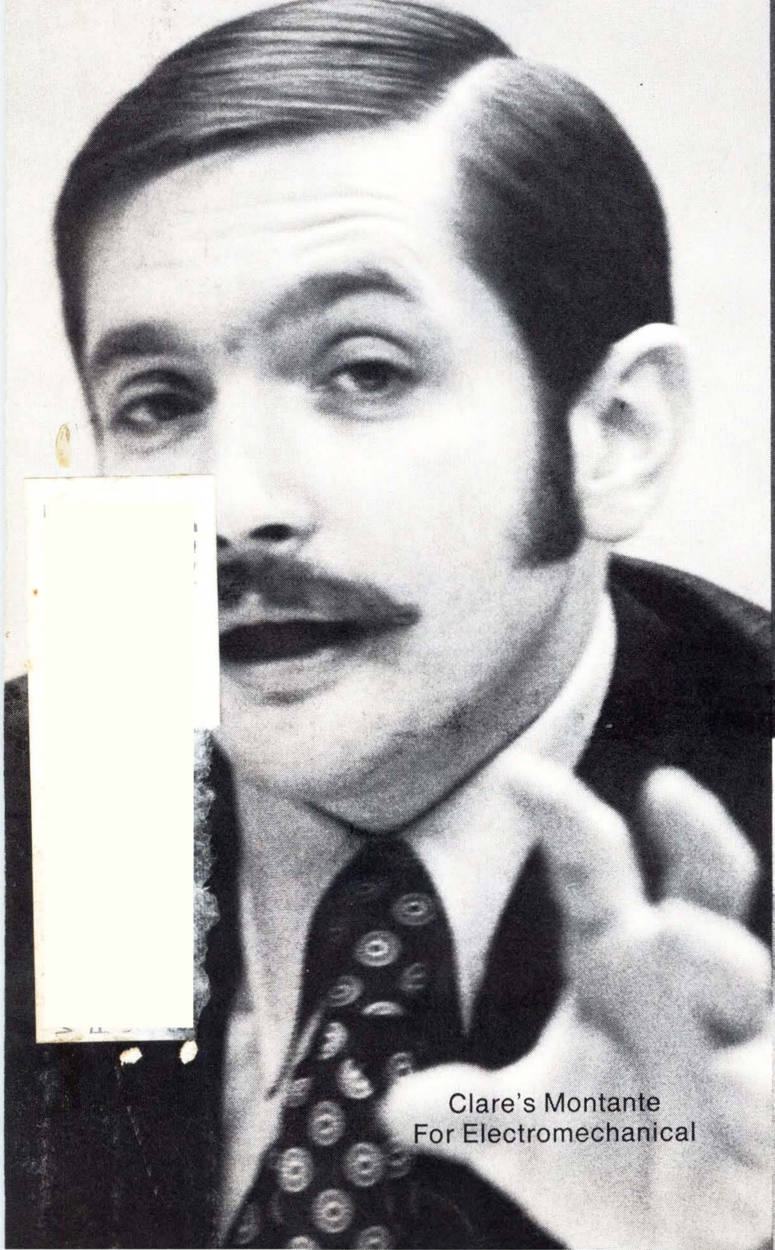
EXCLUSIVELY FOR DESIGN DECISIONS

Charles Montante of Clare
And Roy Mankovitz of Teledyne
Speak Out On
Electromechanical vs
Solid-State Relays

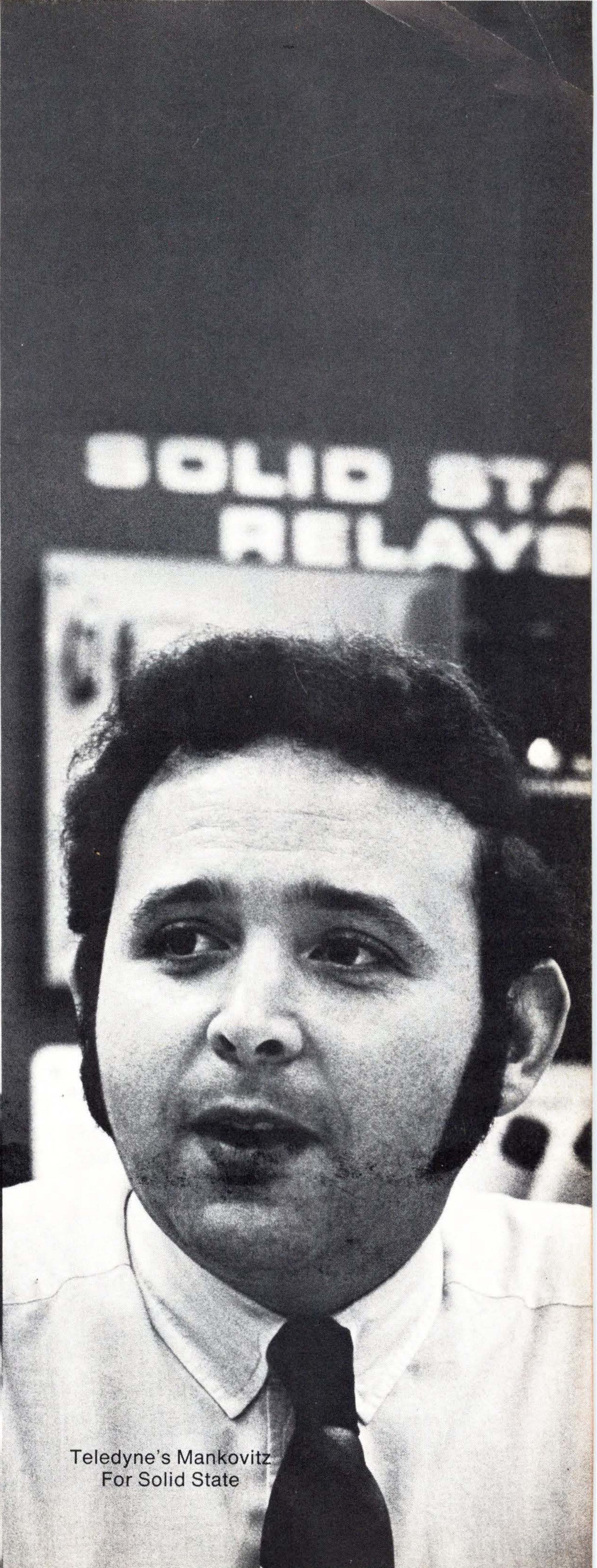
Designer's Guide:
Data Acquisition/Conversion
Part Two

Selecting and Applying
Semiconductor Memories
Part Two

New Developments
In Linear ICs



Clare's Montante
For Electromechanical



Teledyne's Mankovitz
For Solid State

64 bit in stock

You can fulfill your scratchpad requirements from stock with the best 64 bit bipolar read/write memory in the industry. Your system worst case noise immunity is no longer limited by one device. This unit provides a full TTL fan-out of 10, @ 0.4 V, for complete TTL compatibility and full noise immunity. Why take anything less! You can achieve better clock rates with the 12 nsec typical minimum write pulse width. You can build larger memory systems without buffers using TTL gates because of the low 1.2 ma input current. Why buy anything less!

Your high speed scratchpad and buffer memory requirements will be best satisfied with the CM2100 memory. You will have superior performance because these units have the best combination of specifications available.

Computer Microtechnology Inc. continues to bring you advanced products for your memory systems. The CM2100 memory is an example of this with its expansion capability through chip select input and wired-OR outputs. Check the specs.

CM2100 64 BIT BIPOLAR READ/WRITE MEMORY

Organization	16 words by 4 bits
Read Access Time	40 nsec typ, 60 nsec max
Min Write Pulse Width	12 nsec typ, 25 nsec max
Compatibility	DTL and TTL
Packaging	16 lead dual-in-line
Price	$40.00, 1–24
Delivery	Stock

Order yours today! They're in stock!

Computer Microtechnology, Inc

CM AREA OFFICES

Plant	East	West
610 Pastoria	10 Dale Street	1627 Pontius Avenue
Sunnyvale, Calif.	Waltham, Mass. 02154	Los Angeles, Calif. 90025
(408) 736-0300	(617) 891-0002	(213) 478-1285

Circle 100 on Inquiry Card

JULY 1970
VOLUME 18, NUMBER 7

EEE

EXCLUSIVELY FOR DESIGN DECISIONS

Photo by
Bruce E. Brooks
Story on page 46

Photo by
Roger Marshutz
Story on page 47

PROGRESS . . . in Design and Research

FEATURES

CIRCUIT DESIGN AWARD PROGRAM

DEPARTMENTS

EEE

EXCLUSIVELY FOR DESIGN DECISIONS

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Also publishers of Electro-Procurement, BM/E—Broadcast Management/Engineering, Broadcast Equipment Buyers Guide.

Editorial Objectives

EEE serves electronic design engineers exclusively. EEE restricts its editorial coverage to material that can help engineers make design decisions. Such editorial material is intended to help an engineer:

- Decide for one design technique or design philosophy over another;
- Decide for one measurement technique over another;
- Decide for one packaging technique over another;
- Decide for one systems approach over another;
- Decide for one material, component, packaged circuit or instrument over another.

EEE does not publish general-interest material that cannot contribute to a design decision. Nor does it publish material aimed at peripheral interests of an individual.

EEE is dedicated to articulate expression and clear visual presentation. It is pledged to encourage the exchange of sound engineering ideas.

EEE's editorial pages are open to engineers for bylined articles and correspondence.

A member of BPA ABP

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Subscription price to others: $15.00 one year, $25.00 two years. Please notify publisher promptly of any change in job function or address, enclosing your old address label. The publisher assumes no responsibility for opinions of contributions or for the validity of claims reported in advertisements or editorial items. Controlled circulation postage paid at Waseca, Minn.

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Dale breaks metal film value barriers

Exclusive new LMF/HMF Resistors go as low as 1 Ohm... and as high as 50 Megohms!

Now you can use low-priced Dale Metal Film Resistors in more applications than ever. New LMF and HMF Series let you extend the use of high stability metal film parts to your lowest and highest resistance requirements. This Dale breakthrough gives you design and performance uniformity you've never had before. T.C.'s are no longer a problem —packaging is easier, too. The price: Competitive with the non-precision carbon film parts you previously had to use in low and high value situations. Check the specifications at right, then ask Dale for details on the industry's broadest and most useful line of metal film resistors.

Phone 402-564-3131 today
or write:
DALE ELECTRONICS, INC.
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Columbus, Nebraska 68601
In Canada: Dale Electronics Canada, Ltd.
A subsidiary of The Lionel Corporation

DALE

SPECIFICATIONS

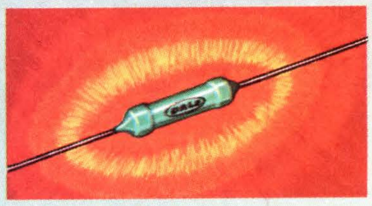
RESISTANCE				T.C.
LMF	1-9.9 ohms	HMF	100K-50M	150 PPM
	5-30 ohms		100K-50M	100 PPM
	10-30 ohms		100K-30M	50 PPM
	15-30 ohms		100K-5M	25 PPM

Tolerance: 1% standard. Special tolerances and T.C.'s available.

Applicable Mil Specifications: MIL-R-10509 (Char. C, D, E), MIL-R-22684 (RL-07, RL-20).

Power Rating:
LMF—1/10, 1/8, 1/4, 1/2 watt.
HMF—1/20, 1/10, 1/8, 1/4, 1/2, 3/4, 1 watt.
Per Char. C & E 125° C rating, MIL-R-10509.

FLAME RETARDANT COATINGS



are standard on all Dale 1/10 thru 1/2 watt conformally-coated metal film resistors.
These resistors have excellent color stability when subjected to short time overloads and prolonged high temperature operation. They have withstood 100 times rated power for as long as 10 minutes without exhibiting flame.

Circle 102 on Inquiry Card

you have to get serious about MSI family planning.

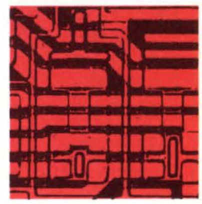
We put together a family plan by taking systems apart. All kinds of digital systems. Thousands of them.

First we looked for functional categories. We found them. Time after time, in a clear and recurrent pattern, seven basic categories popped up: Registers. Decoders and demultiplexers. Counters. Multiplexers. Encoders. Operators. Latches.

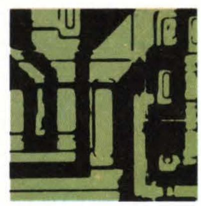
Inside each of the seven categories, we sifted by application. We wanted to design the minimum number of devices that could do the maximum number of things. That's why, for example, Fairchild MSI registers can be used in storage, in shifting, in counting and in conversion applications. And you'll find this sort of versatility throughout our entire MSI line.

Finally, we studied ancillary logic requirements and packed, wherever possible, our MSI devices with input and output decoding, buffering and complementing functions. That's why Fairchild MSI reduces–in many cases eliminates–the need for additional logic packages.

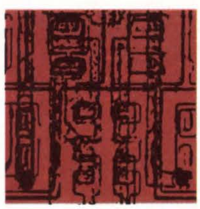
The Fairchild MSI family plan. A new approach to MSI that's as old as the industrial revolution. It started with functional simplicity, extended through multi-use component parts, and concluded with a sharp reduction in add-ons. Simplicity. Versatility. Compatibility. Available now. In military or industrial temperature ranges. In hermetic DIPs and Flatpaks. From any Fairchild Distributor.



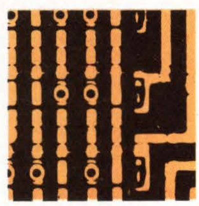
OPERATORS
9304 – Dual Full Adder/ Parity Generator
9340 – Arithmetic Logic Unit



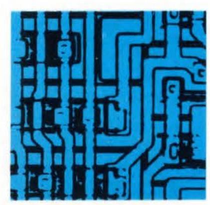
LATCHES
9308 – Dual 4-Bit Latch
9314 – Quad Latch



REGISTERS
9300 – 4-Bit Shift Register
9328 – Dual 8-Bit Shift Register



MULTIPLEXERS
9309—Dual 4 Input Digital Multiplexer
9312—8-Input Digital Multiplexer
9322—Quad 2-Input Digital Multiplexer



DECODERS AND DEMULTIPLEXERS
9301 – One-Of-Ten Decoder
9315 – One-Of-Ten Decoder/Driver
9307 – Seven-Segment Decoder
9311 – One-Of-16 Decoder
9317 – Seven-Segment Decoder/Driver
9327 – Seven-Segment Decoder/Driver

COUNTERS
9306 – Decade Up/ Down Counter
9310 – Decade Counter
9316 – Hexidecimal Counter

ENCODERS
9318 – Priority 8-Input Encoder

FAIRCHILD SEMICONDUCTOR

FAIRCHILD SEMICONDUCTOR A Division of Fairchild Camera and Instrument Corporation Mountain View, California 94040, (415) 962-5011 TWX: 910-379-6435

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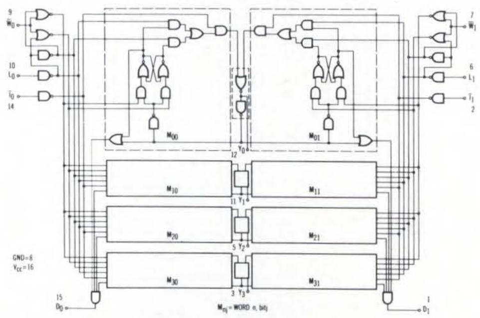
Introducing hardsoftware. Softhardware?

Signetics Content Addressable Memory



Two variations: High Speed 8220; Low Power 8222. Both monolithic arrays incorporate necessary addressing logic and eight identical memory cells organized as four words, each being two bits long. They offer associate, write-in only and read-out only function capability. Complexity: approximately one-hundred gates. Package: 16-pin.

Signetics new memory search devices bridge the gap between hardware and software.

They match input to stored data. They cut the time needed for memory search. And they're available now from our distributors.

Also available for the writing, a copy of the application notes for our new CAM hardsoftware. Softhardware?

Either way, a new medium for the computer architect.

Signetics

Signetics Corporation / 811 E. Arques Ave., Sunnyvale, California 94086 / A subsidiary of Corning Glass Works

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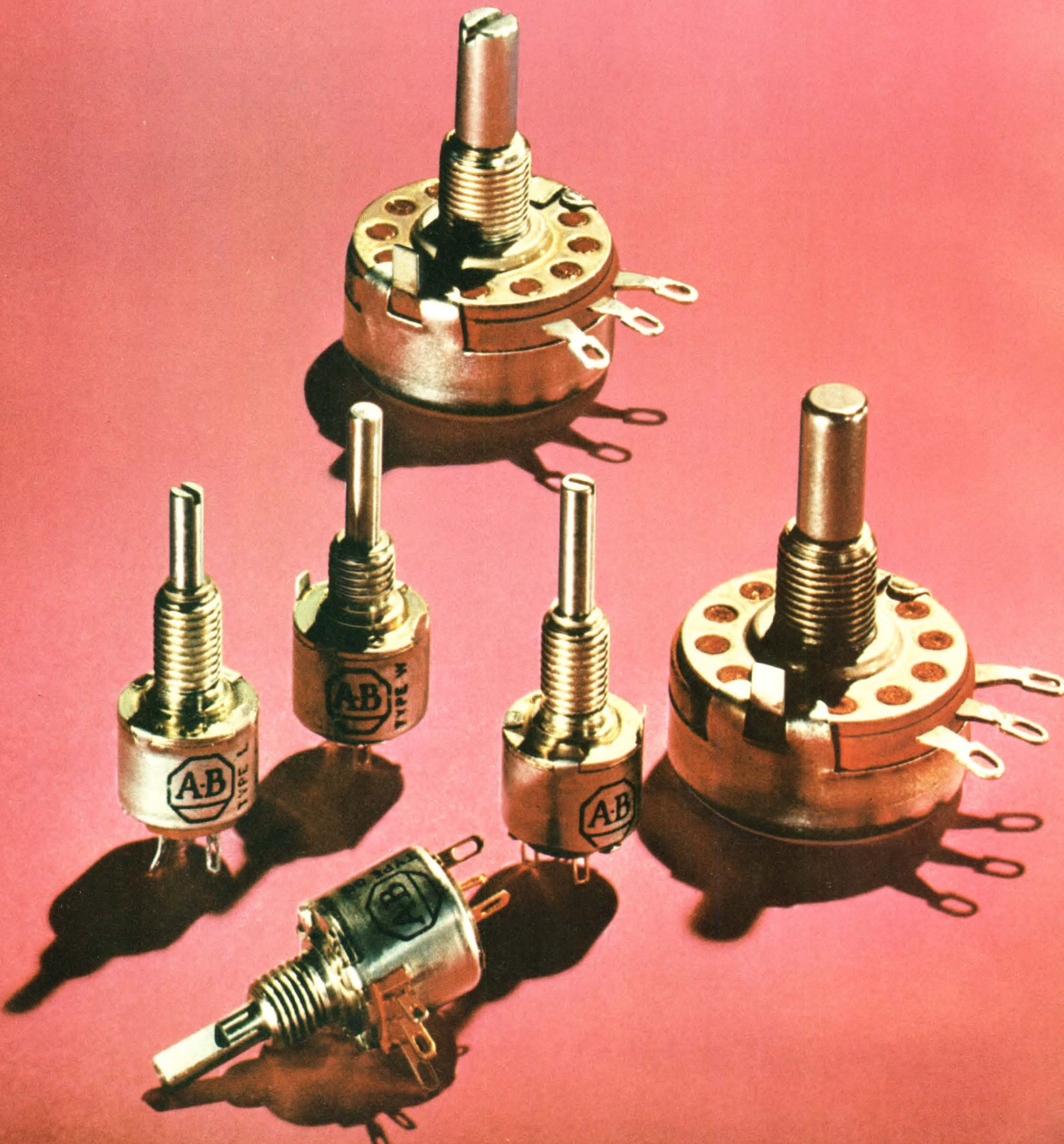
Fight noise pollution



with this quiet family.

Hot Molding with Allen-Bradley's exclusive technique, gives these composition variable resistors an unusually low noise level. And importantly, this low noise level actually decreases in use. Under tremendous heat and pressure the resistance track is molded into place. A solid element with a large cross-section is produced.

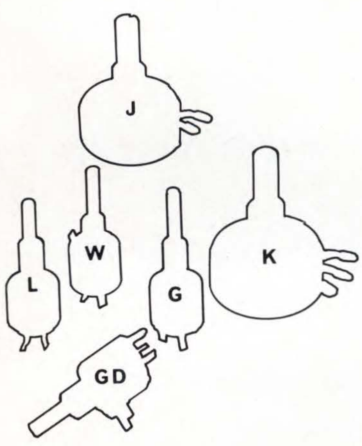
This important Allen-Bradley difference means better short-time overload capacity and a long operating life. Control is smooth, resolution almost infinite. These variable resistors are ideal for high frequency circuits. Why should you trust the performance of your designs or your reputation to anything less than Allen-Bradley quality? Use the most thoroughly "field tested" (over 20 years) variable resistors available today. Quantity stocks of popular types J, G, W and GD available for immediate delivery from your appointed A-B industrial electronics distributor.

For information write: Marketing Department, Electronics Division, Allen-Bradley Co., 1201 South Second Street, Milwaukee, Wisconsin 53204. Export office: 1293 Broad Street, Bloomfield, N. J. 07003, U.S.A. In Canada: Allen-Bradley, Canada Ltd., 135 Dundas Street, Galt, Ontario.

SPECIFICATIONS

	TYPE J— STYLE RV4	TYPE K	TYPE G— STYLE RV6	TYPE L	TYPE W	TYPE GD
CASE DIMENSIONS	5/8" deep x 1-5/32" dia. (single section)	5/8" deep x 1-5/32" dia. (single section)	15/32" deep x 1/2" dia.	15/32" deep x 1/2" dia.	15/32" deep x 1/2" dia.	35/64" deep x 1/2" dia.
POWER at + 70°C	2.25 W	3 W	0.5 W	0.8 W	0.5 W	0.5 W
TEMPERATURE RANGE	−55°C to +120°C	−55°C to +150°C	−55°C to +120°C	−55°C to +150°C	−55°C to +120°C	−55°C to +120°C
RESISTANCE RANGE (Tolerances: ±10 and 20%)	50 ohms to 5.0 megs	50 ohms to 5.0 megs	100 ohms to 5.0 megs	100 ohms to 5.0 megs	100 ohms to 5.0 megs	100 ohms to 5.0 megs
TAPERS	Linear (U), Modified Linear (S), Clockwise Modified Log (A), Counter-Clockwise Modified Log (B), Clockwise Exact Log (DB). (Special tapers available from factory)					
FEATURES (Many electrical and mechanical options available from factory)	Single, dual, and triple versions available. Long rotational life. Ideal for attenuator applications. Snap switches can be attached to single and dual.	Single, dual, and triple versions available. Long rotational life.	Miniature size. Immersion-proof. SPST switch can be attached.	Miniature size. Immersion-proof.	Commercial version of type G. Immersion-proof.	DUAL section version of type G. Ideal for attenuator applications. Immersion-proof.

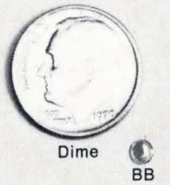
ALLEN-BRADLEY



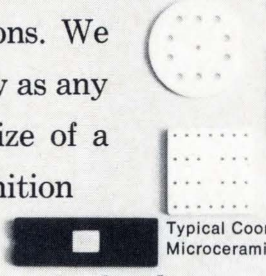
Circle 106 on Inquiry Card

THE WHAT, WHY, WHEN, HOW AND WHOM OF COORS MICROCERAMICS

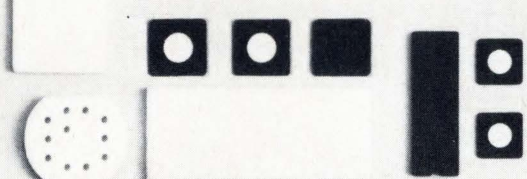
Q. WHAT ARE COORS MICROCERAMICS ANYWAY?



A. Glad you asked. They are small, precise parts of alumina or beryllia ceramic for microelectronic applications. We define small rather loosely as any part between, say, the size of a dime and a BB. The definition of precise is more precise: our standard tolerance is ±1%; tighter tolerances are available if needed.



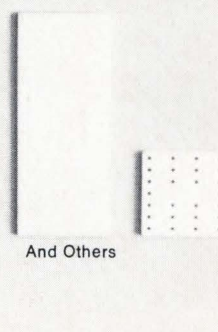
Typical Coors Microceramics



More Microceramics

Q. WHY SHOULD I USE COORS MICROCERAMICS?

A. (1) Because you can be sure they will be manufactured exactly to your specifications and not modified to suit our production capabilities; (2) Because you can be sure they will be of uniformly high quality; (3) Because of (1) and (2) your yields will improve and your unit costs will be lower.



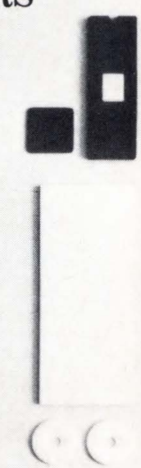
And Others

Q. WHEN SHOULD I USE COORS MICROCERAMICS?

A. When you want ceramic components of highest quality and reliability. Also when you need a ceramic producer with dependable, high-volume production capacity—or one that can turn out prototype and small-run quantities economically. We're geared to do both.

Q. HOW CAN I GET MORE INFORMATION ON COORS MICROCERAMICS?

A. Simply by asking. We'll be glad to counsel with you anytime by letter or phone. Or have our sales engineer in your area contact you for personal assistance. Or send you an informative data pack. Or all three.



Still More

Q. WHOM SHOULD I ASK?

A. Who else?

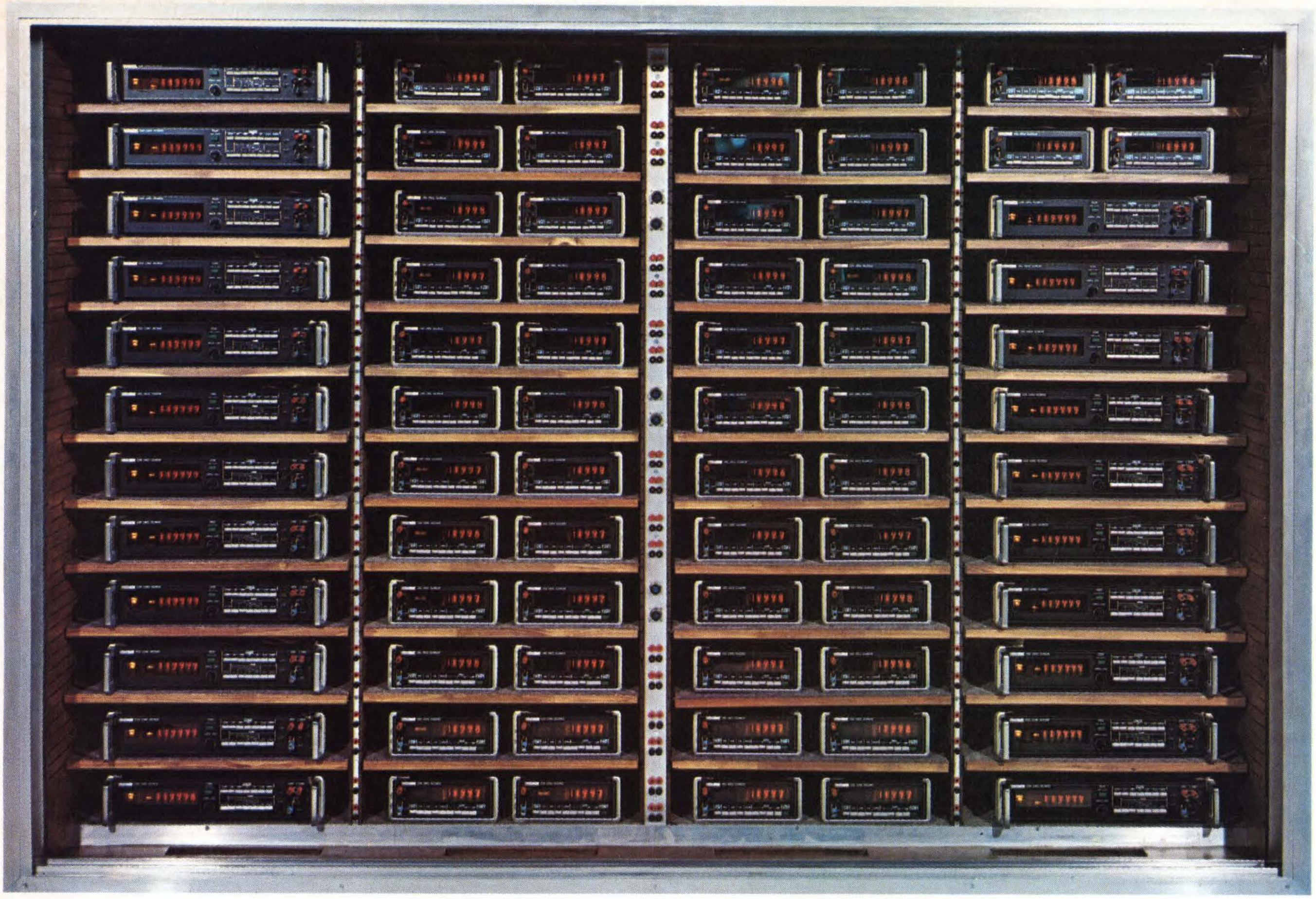
Coors Porcelain Company • 600 Ninth Street
Golden, Colorado 80401 • (303) 279-6565

Coors/CERAMICS

the tough stuff

CP-137

Circle 107 on Inquiry Card



The seven day glitch killer

Every seven days we put another run of new Fluke digital voltmeters in the Fluke "hot box." Here, by continuously cycling the input voltage and "baking in" the instrument at 122°F, we catch the glitches and bugs caused by long term operation in a hot environment.

The "seven day glitch killer" is, of course, only one of the many check-out steps we go through. We control the critical parts by manufacturing all of our own resistors and printed circuit boards and by 100 percent dynamic testing of all active components.

Further, the new Fluke DVM's are designed from the ground up to give you long trouble-free life, low maintenance, and outstanding technical performance. For instance, the Model 8300A has only one-fifth as many components as comparable DVM's. And it's built to work in an 80 percent relative humidity.

In other words, the glitches go before you get the instrument. Another typical Fluke trick.

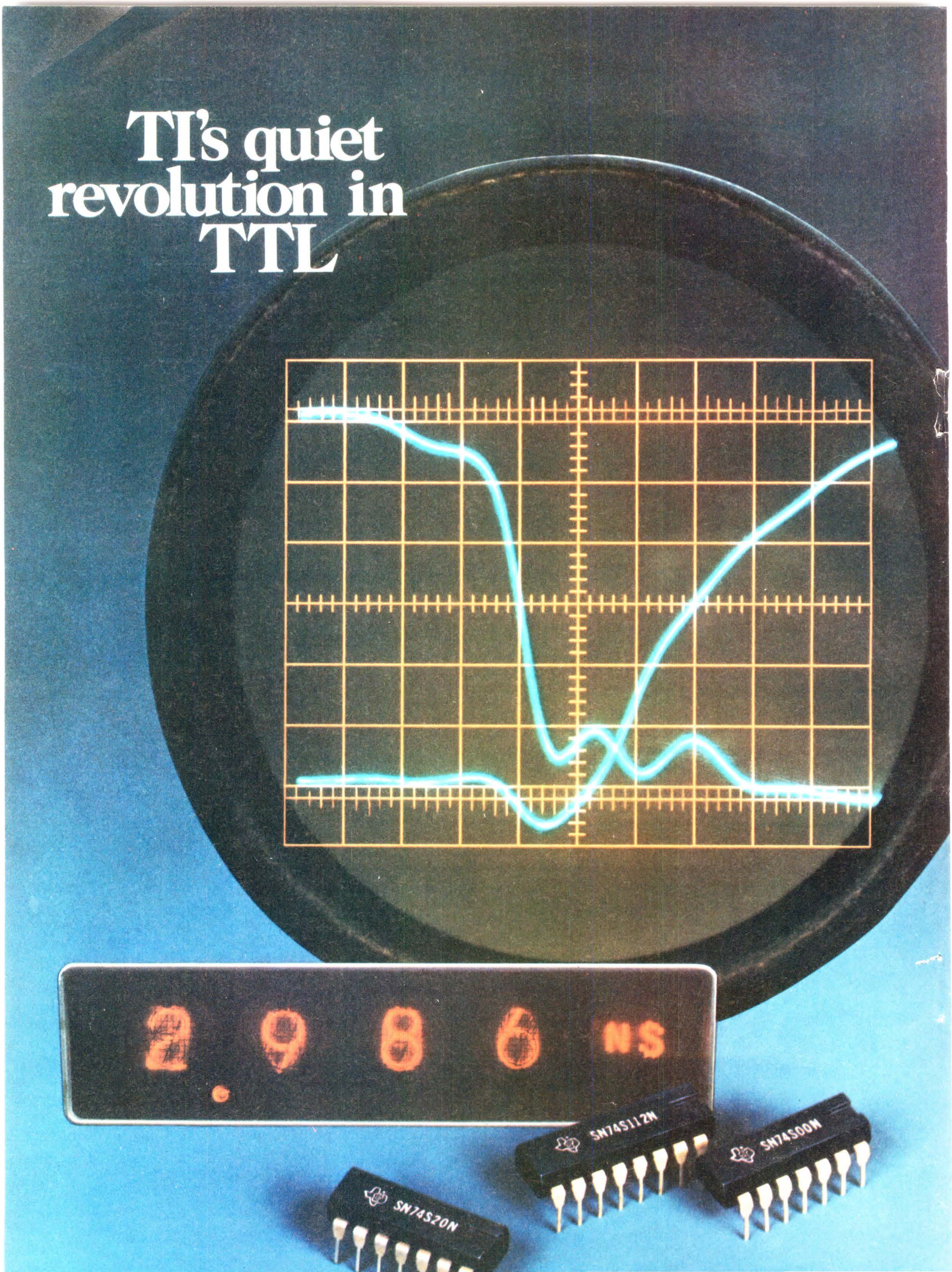
Model 8100A 0.02% Digital Multimeter with complete portability for only $695.

Model 8300A Digital Voltmeter with total built-in systems capability for only $1395.

FLUKE®

Fluke, Box 7428, Seattle, Washington 98133. Phone: (206) 774-2211. TWX: 910-449-2850/In Europe, address Fluke Nederland (N.V.), P.O. Box 5053, Tilburg, Holland. Phone: (04250) 70130. Telex: 884-50237/In the U.K., address Fluke International Corp., Garnett Close, Watford, WD2 4TT. Phone: Watford, 27769. Telex: 934583.

Circle 215 on Inquiry Card


TI's quiet revolution in TTL
2.986 NS
SN74S112N
SN74S00N
SN74S20N

3 ns at 20 mW.

A new technology is born with TI's Schottky-clamped 54/74 TTL.

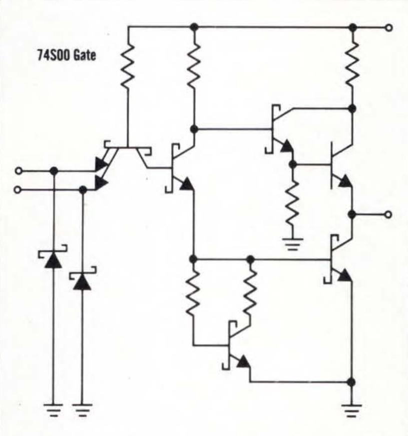
Until now, speeds below 5 ns could only be achieved with current mode (unsaturated ECL-type) technology.

Now, TI has built integrated Schottky-barrier diode clamped transistors* into its popular Series 54/74 integrated circuits. Our new 54S/74S family combines the high speed of unsaturated logic and the low power of saturated TTL logic. The best speed/power combination yet – and priced below competitive ECL logic families.

You gain these advantages, compared to conventional TTL integrated circuit technology:

- Typical gate propagation delay: 3 ns.
- Power dissipation: 20 mW per NAND gate at 50% duty cycle.
- 100 MHz typical flip-flop clock input frequencies.
- Smaller device geometries reduce internal capacitance – and increase speed.
- Schottky-barrier diode input clamps provide fast clamping protection.
- Active pulldown network squares transfer curves and raises logical '1' output level.

*Texas Instruments has patented this technique in U. S. Patent number 3,463,975 titled "Unitary Semiconductor High Speed Switching Device Utilizing a Barrier Diode" issued August 26, 1969 (originally filed in 1964).



Series 54S/74S basic gate operation is compatible with existing 54, 54H and 54L families. All active transistors which saturate are Schottky clamped. Schottky input-clamped diodes offer superior input protection because of low forward voltage drop and fast recovery time.

And you also gain these advantages, compared to current mode logic technology:

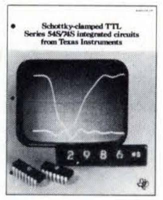
- Lower power dissipation.
- Better noise immunity. Typical d-c noise margins – more than 1V.
- Conventional PC boards may be used due to smaller line reflections with unterminated lines.
- Direct interface with all popular TTL and DTL families – same 5 V power supplies (critical regulation not required), same logic functions, same packaging.

Broad applications. Series 54S/74S Schottky TTL circuits are ideal for applications in all high-speed digital systems:

- Computer central processor units.
- Peripheral controls.
- Digital test and measurement equipment.
- Digital communications systems.

Now available in plastic dual-in-line packages are the SN74S00N – Quadruple 2-input positive NAND gates. The SN74S20N – Dual 4-input positive NAND gates. And the SN74S112N – Dual J-K negative edge triggered flip-flop (separate preset, clear and clock).

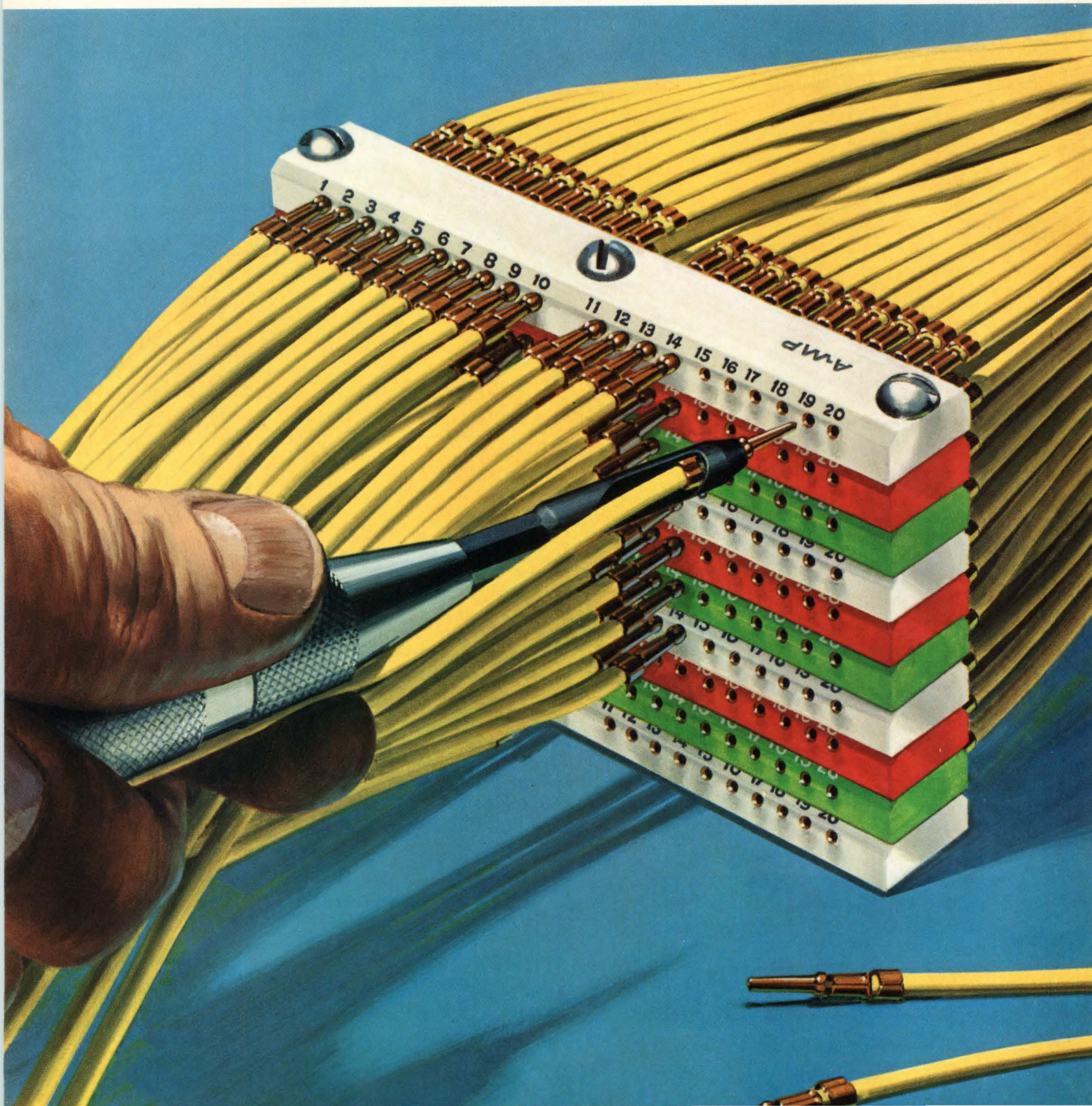
More are coming in 1970. TI is developing 13 circuits in the revolutionary 54S/74S series, including other standard TTL gates (NANDs, AND, HEX inverter, AND-OR-INVERT), dual J-K and D flip-flops, as well as MSI counters and shift registers. Ceramic DIPs and flat packs will be available soon.



For more information on the most significant TTL advance in four years, get our new Bulletin CB-118. Circle 275 on the Reader Service Card or write Texas Instruments Incorporated, P. O. Box 5012, MS 308, Dallas, Texas 75222. Or call your nearest authorized TI Distributor.

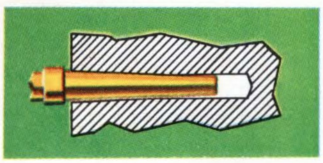
TEXAS INSTRUMENTS

AMP's taper your design

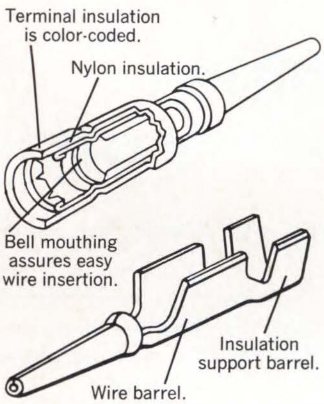


technique liberates imagination.

You're free to go whichever way you like—up, down, left, right—in feed through and feed to designs—in an elongated strip, square solid block or stacked—any way you consider best for your design parameters. Whichever way you go, you can be sure the reliable wedge principle of our taper technique gives you high density, low weight factor, and installed cost economy.



The Wedge Principle utilized in the AMP taper technique makes maximum use of space, and its 16 to 1 design — .016″ length with .001″ change in diameter — and makes taper pins and receptacles self-cleaning and self-locking to assure reliable performance.



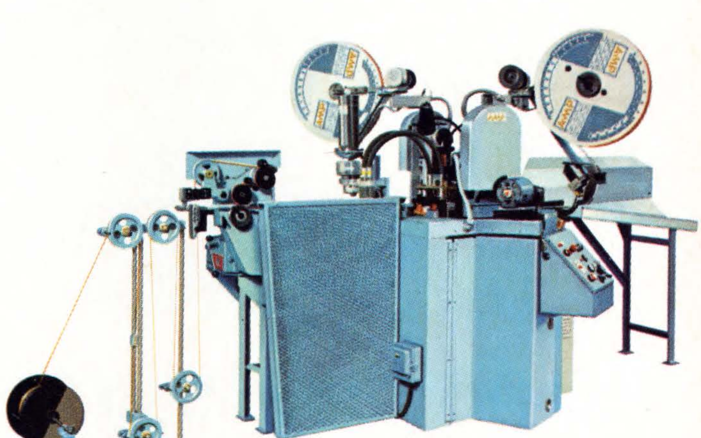
Choose Either Solid or Formed Pins. Pre-insulated solid brass or phosphor bronze pins for wire size #16-26 AWG feature a closed barrel and offer exceptional mechanical and electrical characteristics plus high resistance to corrosion and vibration.

Formed pins are made of electroplated fine grade brass and are available with or without insulation support for wire range #12-28 AWG. These meet and even exceed commercial and military specifications for vibrations, corrosion, heat resistance and electrical conductivity.

Taper Pin Blocks, in solid or two-piece nylon or diallyl phthalate are available in basic units of 10, 20, 30 and 60 cavities. Blocks can be obtained in any combination of single, dual, or multiple commoned taper pin receptacles.

Circuitry Changes and Modifications are easily made in the densest of configurations without disturbing other connections, electrically or mechanically. A single AMP tool not only inserts the pin but can also be used for a pull-out test without destroying the connection. Individual pull-test and insertion tools are also available.

Design-in the Advantages of AMP Economation. AMP's automated crimping tools working right in your own plant will give you the greatest number of reliable connections at the lowest installed cost. You can choose from a full line of automated application tools with speeds ranging up to 10,000 terminated pins an hour. Precise engineering and crimping dies give you terminations of unmatched reliability with an absolute minimum of rejects.



Let your imagination run free with our AMP Taper Technique. We've got the facts to get things started—product specifications, test data and application suggestions—in our Taper Technique Catalog. For your copy write:
Industrial Division, AMP Incorporated, Harrisburg, Pa. 17105.

AMP
INCORPORATED

Editorial

Watchful waiting

The first half of the year is over and it has seen increased opposition to involvement in Southeast Asia, continued liberation of the American woman, inflation, the stock market decline, the Kent State tragedy. The electronics industry has experienced some pain: decreased military business, unemployment, thin profits.

Electro-Technology magazine has passed from the electronics publishing scene. Undoubtedly, the difficult times through which the electronics industry has been going, helped contribute to its demise. The same difficult times are also endangering some of the small, newer electronics companies and perhaps placing some of the large, older firms in jeopardy.

Seeing Electro-Technology pass from the scene was a sad event. Being a New Yorker, I couldn't help but be reminded of how rapidly our great newspapers — the World Telegram, the Sun, the Daily Mirror, the Herald Tribune, the Journal American — disappeared from the newsstands. New York has felt the loss.

If conditions don't improve, some electronics companies will fail. And the industry will feel the loss. Important new technologies are now being explored and the data handling, process control and consumer fields are in for great strides in capability.

For those companies sweating out today's business conditions, there will be more rough months ahead. But the electronics industry has to have one of the brightest futures in business today. And I hope that turns out to be a poignant understatement.

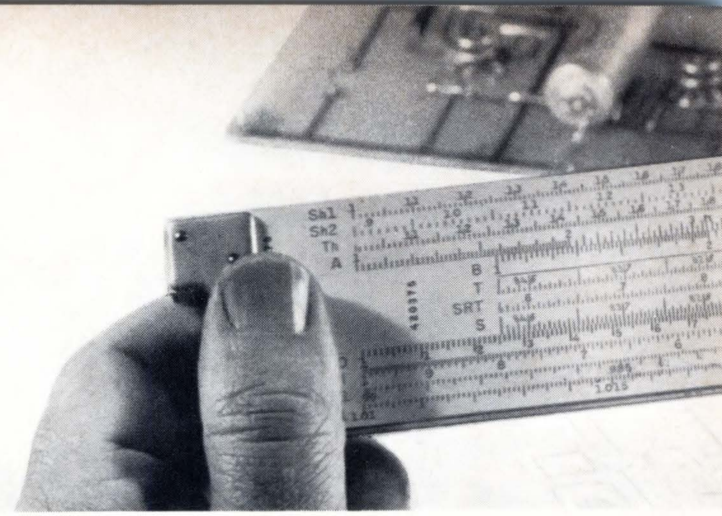
Fortunately, because of the industry's highly competitive nature, development of new products and technology has not slackened during the past six months. (We'll take a look at new instruments and components next month in our semi-annual report on products with significant differences.) Advanced semiconductor memories, LSI, sophisticated linear and hybrid ICs and modules are being designed into prototype equipment.

While the electronics industry may not have been prepared for 1970's sales downturn, it is doing its best to be ready for the turnaround. When the recovery comes, if there are a few less electronics companies around, the industry will be the worse for it.

Jerry Eimbinder

JERRY EIMBINDER

EDITOR



RCA Solid-State Data for Designers

Low-power astable and monostable oscillators

COS/MOS IC's offer unique advantages in low-power astable and monostable oscillator circuits.

A new RCA Application Note (ICAN-6267) describes how COS/MOS IC's in multivibrator circuits:

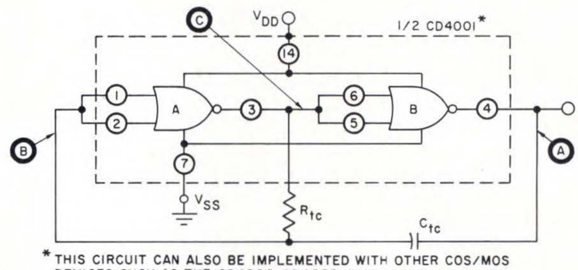
- offer large time-constants without the use of large capacitors
- operate at frequencies up to 1 MHz
- provide excellent frequency-stability over a broad operating-temperature range (−55°C to +125°C)
- permit simple circuit design—only two external components required
- consume only 10 nW @ $V_{DD} = 10$ V, f = 10 kHz

The schematic diagram (Fig. 1) is taken from the referenced application note and shows a typical astable multivibrator circuit using a CD4001 COS/MOS Gate. This circuit is implemented through the use of two of the gates in the COS/MOS IC plus the external capacitor and resistor incorporated to establish timing. Typical operation of the circuit is: multivibrator period approximately 0.6 ms with $R_{tc} = 0.4$ MΩ; $C_{tc} = 1000$ pF @ $V_{DD} = 10$ V. The voltage waveform for the circuit is shown in Fig. 2.

Application Note ICAN-6267 provides data on multivibrator frequency as a function of temperature and supply-voltage variations and includes information on nine circuits for astable and monostable oscillators built around COS/MOS IC's.

See your RCA Representative or RCA Distributor for price and delivery information on COS/MOS IC's.

For a copy of Application Note ICAN-6267, contact your RCA Sales Office or circle Reader Service No. 110.



* THIS CIRCUIT CAN ALSO BE IMPLEMENTED WITH OTHER COS/MOS DEVICES SUCH AS THE CD4000, CD4002, OR CD4007

FIG. 1. ASTABLE MULTIVIBRATOR CIRCUIT DIAGRAM

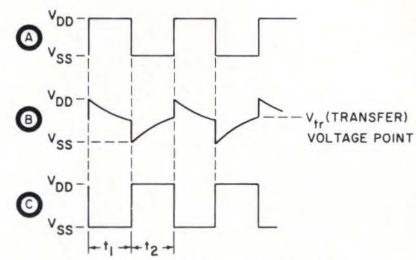
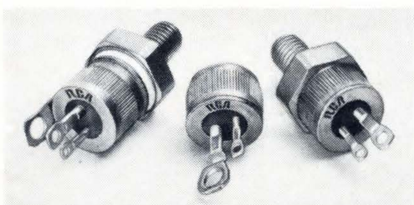


FIG. 2. VOLTAGE WAVEFORM FOR ASTABLE MULTIVIBRATOR



Thinking industrial applications? Think RCA Thyristors

There's good reason why RCA thyristors in stud and press-fit packages should be *foremost* in your mind, where industrial controls or power switching systems are your concern. Simply, RCA's broad line of SCR's and triacs provide the winning combination of quality, reliability, performance and availability for a myriad of key industrial applications. RCA has the right thyristor for the job—available now!

When you look closer, you'll find RCA is a key industrial supplier of SCR's and triacs for numerous types of industrial control equipment, motor controls, computer power supplies, heating controls, lighting controls, and power switching systems.

A broad line it is, when you consider, too, the wide selection of current ratings available from stock:

SCR's—10, 20, and 35 A

Triacs—10, 15, 30, and 40 A

Each unit is available in press-fit, stud, or isolated-stud packages. Families of RCA SCR's are rated 25 to 600 volts, and triacs are rated from 100 to 600 V—depending upon type and your requirements.

Circle Reader Service No. 111.

300-A power circuit

The RCA developmental TA7628 is a single-package power circuit containing both the TA7629 driver and the TA7630 output module—a combination suitable for use as a positive or negative switch when driven from IC logic.

The TA7628 may be used as a motor control (5—10 hp); brushless commutator assembly (300 A DC), or a high current relay (300 A).

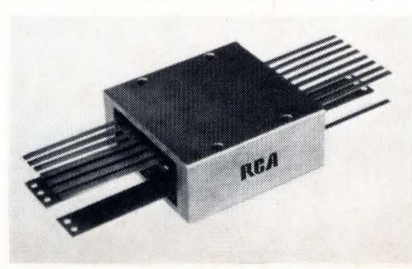
The TA7629 and TA7630 may each be purchased separately. The TA7629 provides 40-A switching capability from IC logic. The TA7630 affords higher current switching capability when suitably driven.

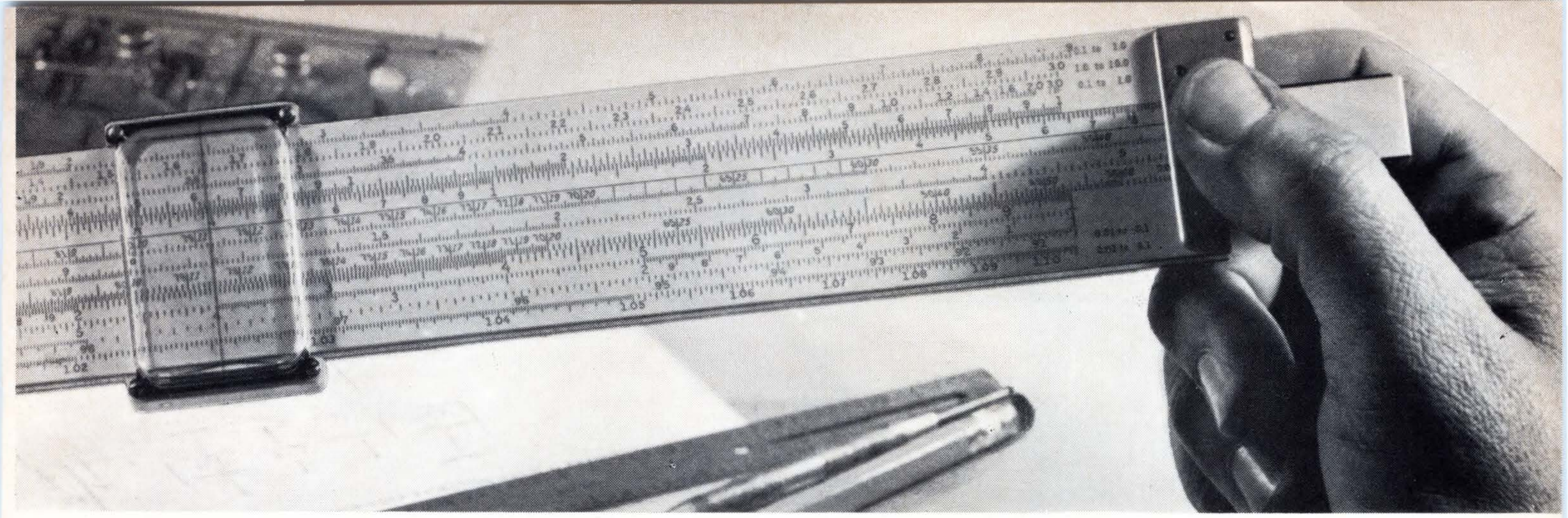
Each of these devices is obtained from basic array power modules which may be interconnected in a variety of ways to form such structures as:

- high current voltage regulators
- 4000-W inverters
- 50-A, 3-phase bridges

The basic array module used to form the TA7629 is the TA7631. It contains six 7-A and three 1.5-A n-p-n transistors; three 1.5-A p-n-p transistors; and 12 thick-film resistors. The basic array module used to form the TA7630 is the TA7632. It contains six 50-A transistors and six 50-A rectifiers. All components are electrically isolated from the case.

The TA7631 and TA7632 may be





purchased in unconnected form. Access is provided to the terminals of each internal device—permitting complete versatility in developing circuitry. These interconnections can readily be manufactured by RCA to fill your volume requirements.

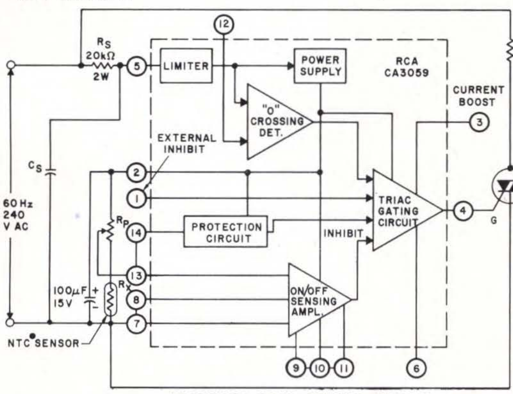
Circle Reader Service No. 112.

IC Triac control circuit with built-in protection

An IC Thyristor Trigger, RCA's CA-3059, offers the power circuit designer significant advantages:

(a) Switching transients and RFI are reduced since the IC permits switching to occur only at zero supply voltage

(b) Built-in protection against sensor failure



PROTECTED TRIAC CONTROL CIRCUIT

*NEGATIVE TEMPERATURE COEFFICIENT

In the heater application shown here, the protection circuit removes power from the load if the sensor shorts or opens. To utilize the protection circuit, connect terminal 13 to terminal 14, as shown, and then:

Set the value of R_P and sensor resistance (R_X) between 2 kΩ and 100 kΩ. Hold the ratio of R_X to R_P within 0.25 and 4. If the ratio falls outside these limits, a resistor must be added, in series with the sensor or across the sensor, to provide a resistance ratio within this allowable range.

For Triacs specifically intended to operate with the CA3059, check RCA's 2.5- to 40-ampere, 100-600 volt series, Types 40693—40734.

Circle Reader Service No. 113.

VERSAWATT: the stereophile's choice

Many "top-of-the-line" stereo manufacturers are studying the RCA 2N5494 silicon transistor—and other transistors of the VERSAWATT family—for use in their high-fidelity solid-state equipment.

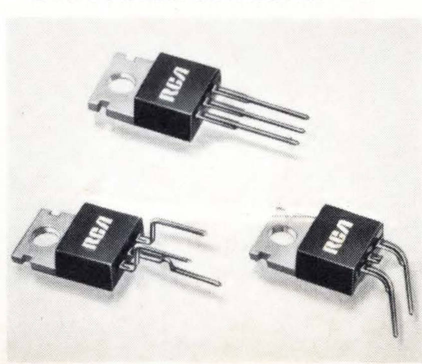
VERSAWATT TYPES FOR AUDIO APPLICATIONS

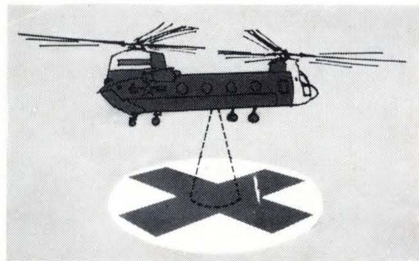
	watts	amperes
2N5296	4	1.0
2N5298	9	1.5
2N5490	16	2.0
2N5492	25	2.5
2N5494	35	3.0

Using the 2N5494 in the output of a quasi-complimentary symmetry circuit, one manufacturer finds this low cost, 3 A n-p-n transistor especially suited to audio amplifier applications. It has a low thermal resistance rating, and its current and voltage capability contribute to high performance. An added bonus: VERSAWATT transistors employ Hometaxial-base construction to provide freedom from second-breakdown problems.

VERSAWATT transistors are available in three basic configurations—straight lead (JEDEC TO-220 AB), TO-220 AA (direct replacement for TO-66) and a package with leads shaped for easy PC board mounting.

Circle Reader Service No. 114.





High power GaAs Lasers for portable range finding devices

When a helicopter lands in a swirl of dust, the aircraft's safety may depend upon the pilot's ability to gauge distance between copter and ground.

A laser altimeter is only one device in which RCA TA7705 and TA7787 gallium arsenide (GaAs) lasers find application. They may be used in ship-docking instrumentation, anticollision devices, and many other portable ranging systems.

Since these GaAs laser diodes have short pulse duration and fast rise time ratings, equipment accuracy of a few inches is possible over a measured distance of a few feet to several hundred feet... allowing vital range resolution.

The TA7787 is unique! It is the largest single lasing chip available—55 mil source dimension. Minimum radiant power output is 60 watts at 100 PPS. The TA7705 is identical to the TA7787 except that its output is 40 W min. Drive current for both types is 250 A (typ); output pulse is 100 ns. Both units radiate at a center wavelength of 9050 angstroms.

The TA7705 and TA7787 are available in OP-12 coaxial stud packages. Why not design them into your portable ranging equipment?

Pulsing circuit diagrams for these lasers are available upon request.

Circle Reader Service No. 115.

For price and availability information on all solid-state devices, see your local RCA Representative or RCA Distributor. For specific technical data, write RCA, Commercial Engineering, Section 51G /UM5, Harrison, N. J. 07029. In Europe: RCA International Marketing S.A., 2-4 rue du Lièvre, 1227 Geneva, Switzerland.

RCA

ACROSS THE Editor's Desk

Filter Speak-Out filtered

I believe there are some "errors" in Sam Perry's Speak Out on rfi-filter specs. Please note that I use "errors" in quotes because, in a restricted sense, they may not be errors. I contend, however, that Perry's definitions of "insertion loss" and "attenuation" are confusing and misleading (EEE, March, 1970, pp 86-89).

He states that source and load impedances *must be the same* for insertion loss to be expressed by 20 log V_1/V_2, where V_1 and V_2 are the load voltages without and with the filter, respectively. This overly restrictive definition is no longer acceptable and no longer used by today's designers.

For example, in his *Simplified Modern Filter Design,* Rider, 1963, Phil Geffe states that ". . . . Insertion loss is defined regardless of whether the source and load impedances are equal." Further, Geffe states that insertion loss in decibels equals 20 log $|E_1|/|E_2|$ where E_1 and E_2 are the load voltages without and with the filter, respectively.

In a booklet published three or four years ago, ADC Products gave the same definitions and emphasized them with the statement, "The most widely accepted and perhaps most nearly correct definition of insertion loss is ". . . regardless of the values of source and load." Further confirmation of these definitions appears in *Electrical Filter Handbook* by White Electromagnetics, in *Electrical Wave Filters* by Stolarczyk and Jackson of A.R.F. Products and ITT's *Reference Data for Radio Engineers.*

In his Speak Out, Perry also states that "attenuation" is 20 log V_1/V_2, where V_1 is the voltage across the filter input and V_2 is the voltage across its output. Geffe, on the other hand, calls this ratio the "transfer function" rather than the "attenuation" and he states, further, that in most cases this quantity is not of value to the user and is not a measure of filter performance.

These contradictions could use some additional explanation. Perhaps Mr. Perry would like to supply it.

Edward E. Wetherhold
Senior Engineer
Honeywell
Annapolis, Md.

Yet another printer. In our survey in the April issue of *EEE* we listed 25 manufacturers of lab digital printers. Add one more to the list. Newport Labs (Santa Ana, Calif.), recently introduced a compact drum printer; but, unfortunately, the information arrived too late for inclusion in our survey. Newport's new Model 800 is claimed to have the smallest configuration of any rotating drum printer. The panel height is only 5¼ inches. Its price including electronics is only $895. Among the many special options available are an integral digital clock and sequence counter.

For more information circle 687.

Continue critical

Dear EEE:
As an attendee of your first European Seminar on Integrated Circuits and Advanced Measurements in Paris 1969, I have been receiving *EEE* for almost a year now. I want to congratulate your editorial staff for its critical attitude towards manufacturers' specs. Such controversial material makes your magazine quite different from all others and it is really a great help for me and my colleagues.

J. Lauwers
Studiecentrum Voor Kernenergie
Mol-Donk
Belgium

Not so shrewd

Dear EEE:
Shrewd observations (the phrase was yours) led off your editorial in the April 1970 edition of EEE.

Yet not once, but twice did you refer to "the 710" as a voltage-regulator (directly or by implication). As reference to your page 24 would have revealed, it is of course a comparator.

I did not see the October 1967 story by Murray Siegel which you refer to later in your editorial, and our library does not retain copies of EEE for long enough to make the article easily retrievable. But I wonder if Mr. Siegel's criticism of the binary-divider capability may possibly have been an assumption derived from the manufacturer's actual description. If the part offered and described is anything like the SN7490N, there are definite benefits that can come to the user as a result of the decade being chopped up into a divide-by-two and a divide-by-five. Could it be that the manufacturer did not really intend to suggest that the decade should be used where a far simpler and less expensive flip-flop would suffice?

Lawrence W. Johnson
Manager, Materials Engineering
Hewlett Packard
Santa Clara, Calif.

The phrase, incidentally, was Sir Alexander Fleming's not ours. But you're right we goofed in our editorial reference to the 710—the 710 most certainly is a voltage comparator. Siegel's point was that some manufacturers mention applications on their data sheets that are technically feasible but not economically practical. Reader Johnson, we suspect, is questioning only the specific example cited by Siegel and not his viewpoint.

Low energy switching problem? Leave it to our "GOLDIE"...

"Goldie"—the new Cherry gold crosspoint contact switches solve practically every low energy switching problem. They do it with a contact design innovation that helps prevent the two main causes of contact failure:

1. Formation of insulating chemical films on contacts
2. Mechanical interference of foreign particles on contacts.

Our new "Goldie" switches combine a solid layer of gold alloy (69% gold, 25% silver, 6% platinum) contact material with a crossed knife-edge configuration. These provide interfaces inert to chemical action and virtually eliminate contact closure interference from foreign particles. Low contact resistance is maintained throughout the switch lifetime, which is measured in millions of operations. Initial insertion resistance is below 50 milliohms.

Take a closer look at our problem-solving "Goldie" switches. Send for the sample of your choice today.

Hewlett-Packard Desk Top Calculator uses 63 Cherry "Goldies"

FREE SAMPLE SWITCH

E69 Push Button	E53 Low Torque	E63 Subminiature	S31 Open Miniature	E21 Miniature
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CHERRY Makers of patented Leverwheel/Thumbwheel, Matrix Selector and Snap-Action Switches.

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Circle 118 on Inquiry Card

Get Bright, Flicker-Free Displays and Storage with HP's New, Half-Rack Systems Monitor

"Freeze" your displays, vary their fade rate. Here, is the first systems monitor using HP's mesh-storage CRT – that eliminates low rep-rate flickering, and eye-fatiguing erase-flashes . . . the HP 1331A.

Storage Capability – Waveforms can be stored for up to 15 minutes, just by pressing a button. An important advantage of the HP mesh-type storage tube is that writing rate and trace brightness do not deteriorate. Also, with mesh storage, stored traces "dissolve" off the screen, rather than being "flashed" off.

Variable Persistence—Trace persistence can be varied from 0.2 seconds to more than a minute. This enables you to quickly and accurately compare traces, analyze trends, determine the effects of input variables, eliminate flicker of low rep-rate information.

High-Intensity Display—For systems operators, traces can be observed in high ambient light, without having to sit "glued to the screen," because traces are displayed at a brightness of 100 ft-lamberts. This is many times the intensity of displays on other storage monitors.

Wide Bandwidth – Utilizing electrostatic deflection, the HP 1331A is capable of handling signals ranging from dc to 1 MHz. This provides fast, 1 μs settling time, which reduces computer waiting time when generating rasters, alpha numeric, X-Y or other fast-changing displays.

Z-Axis Gray Scale—The exclusive ability of the CRT to display varying trace intensities, gives the HP 1331A a capability to show "shades of gray" —for added realism in 3-D displays, and added clarity in two-dimensional displays or photos.

Compactness – Measuring only 7¾" wide by 6½" high by 16" deep, the HP 1331A takes up only half of a standard systems rack width.

Choice of Standard or Programmable Models – Model 1331A has front panel operating controls, to allow easy manual control. Model 1331C is designed for remote programming operation in system applications of computer displays—alpha numeric or graphic. It has the operating controls and programming input connector mounted on its rear panel.

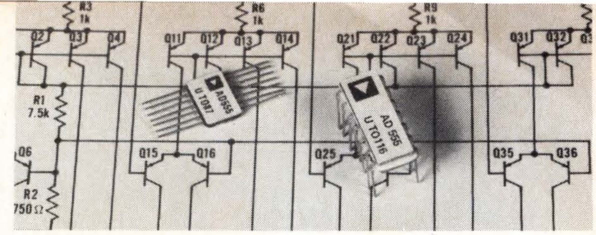
For the complete story on the 1331A or 1331C, contact your HP field engineer. Or, write to Hewlett-Packard, Palo Alto, California 94304. In Europe: 1217 Meyrin-Geneva, Switzerland. Price: $1575; OEM discounts available.

080/13

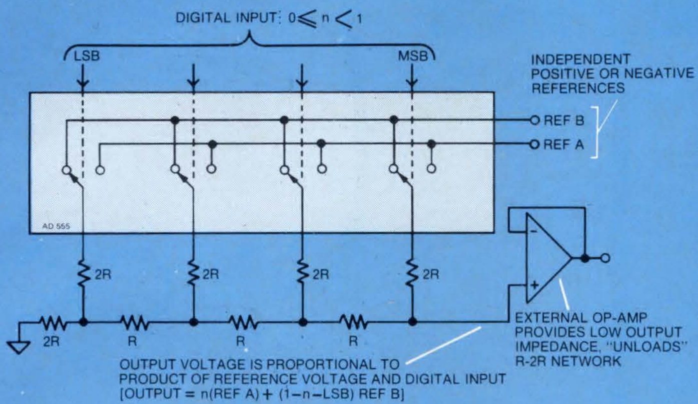
HEWLETT hp PACKARD

OSCILLOSCOPE SYSTEMS

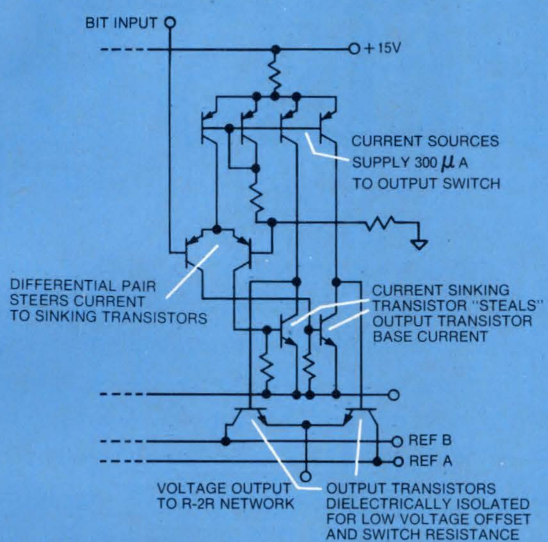
Circle 119 on Inquiry Card



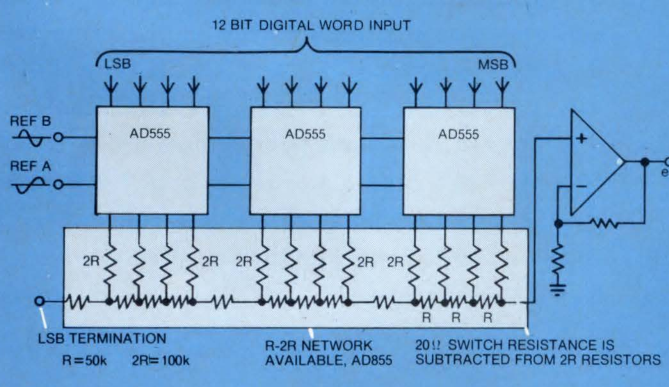
EQUIVALENT CIRCUIT AD555 QUAD SWITCH



SINGLE SWITCH CELL OF 4 SWITCH QUAD



12-BIT MULTIPLYING D/A CONVERTER



μDAC 555

The World's First Monolithic IC Multiplying D/A Converter

- **4 SPDT SWITCHES ON A SINGLE CHIP**
- **12-BIT ±½LSB ACCURACY**
- **FULL 4 QUADRANT MULTIPLICATION CAPABILITY**
- **±5ppm/°C MAX TC, −55°C TO +125°C**
- **IDEAL FOR DIGITAL-TO-SYNCHRO APPLICATIONS**
- **MEETS MIL-STD 883. . . FLATPACK OR DIL**

Second in a series of monolithic IC D/A converter circuits, the Analog Devices Model AD555 μDAC is intended for applications which require variable reference inputs. This feature permits full 4 quadrant multiplication of the analog and digital inputs, useful in many avionic applications such as digital-to-synchro conversion, digital gain control, etc.

The μDAC AD555 is comprised of 4 dielectrically isolated voltage switches driven by logic input buffers compatible with all popular DTL or TTL logic. With the addition of an R-2R resistor network, each AD555 becomes a 4-bit D/A converter. All critical parameters are matched to permit three such μDAC's to be simply interconnected to form a monotonic 12-bit converter with ±½LSB accuracy.

Proprietary design techniques yield switch performance similar to discrete-component solid state switches, but with inherently better tracking. Switch "ON" resistance is 20 ohms, matched to ±5 ohms within each chip. Precision 12-bit thin film R-2R resistor networks, matched to switch ON resistance, are also available from Analog Devices. Voltage offset is 1mV ±1mV max. Switching delay time is typically 3.5μs.

For free new application notes giving complete specifications and theory of operation of this new series of monolithic D/A converters, or to request evaluation samples phone your local sales office or Mr. Richard Ferrero collect on the ANALOG HOT LINE . . . (617) 969-3661.

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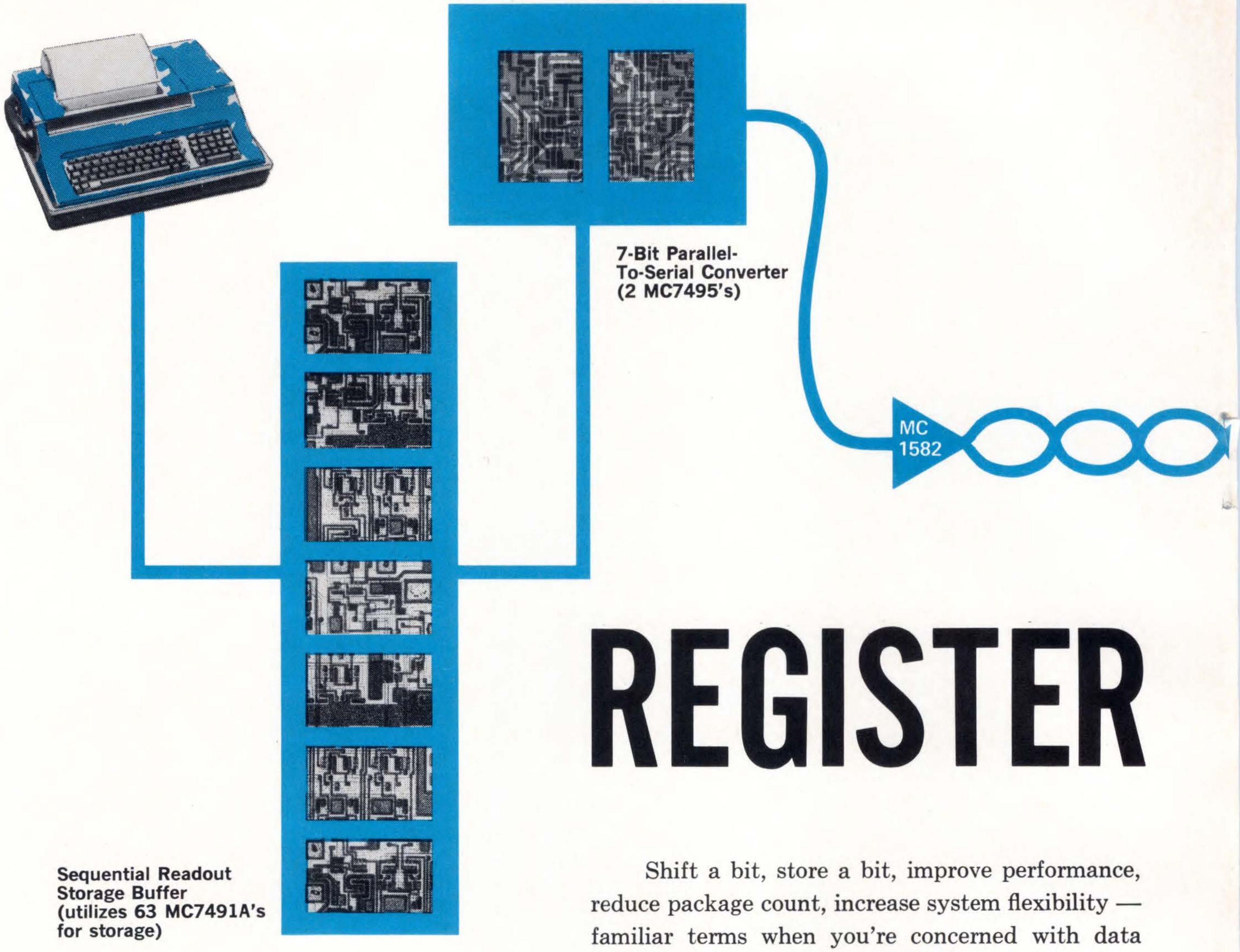
ANALOG DEVICES INC

LINEAR INTEGRATED CIRCUITS



REGISTER

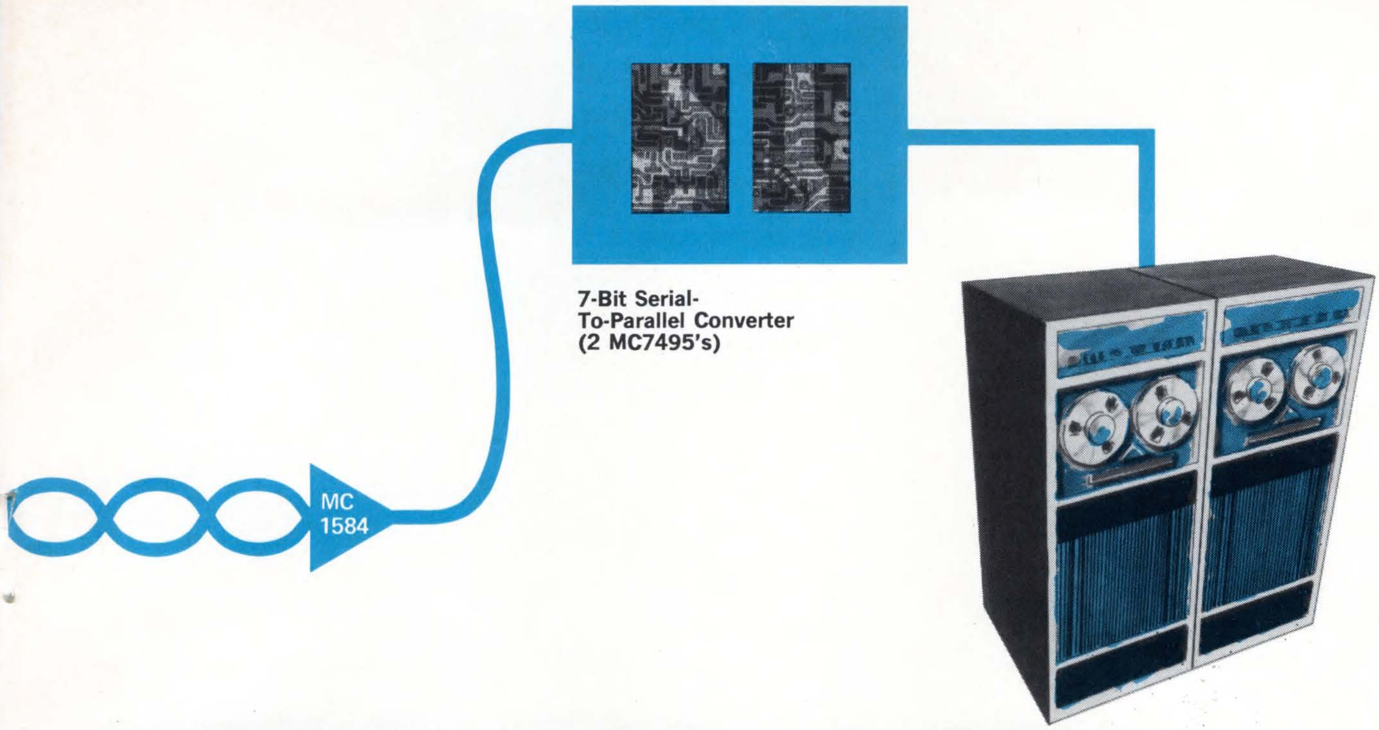
CHECK THESE 54/74 MSI CIRCUITS

Available Now		Coming Soon	
MC7441A	BCD-To-Decimal Decoder Driver	**MC7445**	BCD-To-Decimal Decoder Driver
MC7442	BCD-To-Decimal Decoder	**MC7448**	Seven Segment Decoder
MC7443	Excess-3-To-Decimal Decoder	**MC7449F**	Seven Segment Decoder
MC7444	Excess-3-Gray Code-To-Decimal Decoder	**MC7470**	Edge Triggered J-K Flip-Flop
MC7446	Seven Segment Decoder	**MC7483**	4-Bit Full Adder
MC7447	Seven Segment Decoder	**MC7494**	4-Bit Shift Register
MC7475	Quad Latch	**MC7496**	5-Bit Shift Register
MC7480	Gated Full Adder	**MC74121**	One-Shot Multivibrator
MC17482	2-Bit Full Adder	**MC74150**	16-Bit Data Selector
MC27482	2-Bit Full Adder w/Excl. OR Outputs	**MC74151**	8-Bit Data Selector
MC7490	Decade Counter	**MC74192**	Decade Up/Down Counter
MC7491A	8-Bit Shift Register	**MC74193**	Binary Up/Down Counter
MC7492	Divide-By-Twelve Counter		
MC7493	4-Bit Binary Counter		
MC7495	4-Bit Universal Shift Register		

Shift a bit, store a bit, improve performance, reduce package count, increase system flexibility — familiar terms when you're concerned with data transmission. Now Motorola offers two versatile TTL shift registers that provide a variety of storage capabilities and system configurations. For instance, apply the MC7491A 8-BIT SHIFT REGISTER as a shift counter. Any pattern of ones and zeros may be set into the MC7491A and then shifted to provide a divide-by-N function. Or, use the MC7491A to form delay lines, and to act as buffers in computer systems when interfacing is required between modules operating at different speeds. The MC7495 4-BIT UNIVERSAL SHIFT REGISTER is capable of both serial and parallel operation. As such, the MC7495 meets requirements for serial to parallel and parallel to serial data converters, ring counters, and parallel arithmetic processors.

The two registers are ideal choices for data

– where the priceless ingredient is care!



HERE FOR DATA

transmission in teletype-computer interface systems. In these systems, each character on the teletype keyboard is expressed in a 7-bit ASCII code for transmission to the computer. As each teletype key is depressed the 7-bit code for that character is presented at the inputs to the storage buffer. The buffer, utilizing MC7491A's for storage, accumulates the ASCII coded characters until an end of transmission signal is received. Next the 7-bit words are converted to serial by the 7-bit parallel-to-serial converter which is comprised of two MC7495's.

The serial data is applied to the MC1582 DUAL LINE DRIVER and transmitted over a twisted pair to a MC1584 DUAL LINE RECEIVER. To be interpreted by the computer, the data is converted to parallel by two MC7495's in a serial-to-parallel mode. For computer-modem interfacing an RS-232C Line Driver/Receiver pair is substituted for the MC1582 and MC1584 circuits. Typically these would be the MC1488L QUAD LINE DRIVER and its companion, the MC1489L QUAD LINE RECEIVER.

If you are concerned with data transmission and the application of shift registers, you'll find our MTTL Designer's Note on the MC7491A and 7495 useful. This note describes numerous applications for the devices including the teletype-computer interfacing system briefly detailed above. Just write to us at P. O. Box 20912, Phoenix, Arizona 85036 and ask for MOTOROLA TTL DESIGN KIT #2. Register now for data and increase the logic design capability of your system.

MOTOROLA 5400/7400 TTL

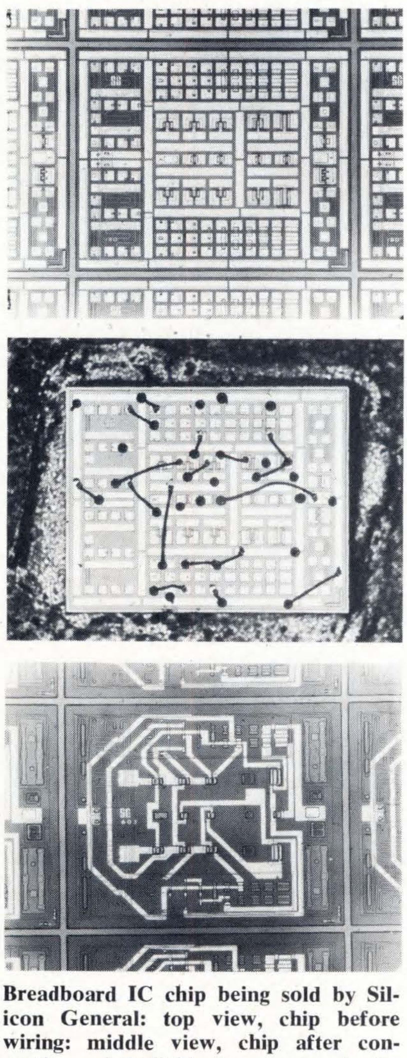
Circle 121 on Inquiry Card

Progress in Design and Research

IC activity strong

PROGRESS IN MICROELECTRONICS

ACTIVITY IN the IC industry continues at a hectic pace with considerable new device announcements, more second sourcing and price cutting. The biggest single area of action continues to be in semiconductor memories, both MOS and bipolar, but new developments in the linear and conventional digital ICs fields are coming along rapidly as well.



Breadboard IC chip being sold by Silicon General: top view, chip before wiring: middle view, chip after connection of individual components by wire; bottom view, monolithic version of same circuit.

Price drops

Price reductions are starting to show up on medium-scale-integration (MSI) products as well as conventional ICs. Ed Winn, Digital Product Manager at Signetics, attributes the price decreases on complex devices to "markedly increased MSI yields."

Here are some averages for price cuts on both MSI and conventional ICs announced recently: Hughes, approximately 20% on MOS counter circuits and 300% on some silicon-nitride MOS logic devices; Signetics, 65% on a comparator and a quad "Exclusive OR" gate, 46.6% on certain multiplexers and reductions on its 8200 family of 37 devices; Qualidyne, an average of 40% drop on its sense-amplifier line.

Signetics has also reduced prices on 22 devices in its Utilogic II line by up to 38%. Texas Instruments has lowered some series 54/74 IC prices by up to 40%.

Devices in Sylvania's new 7400N TTL line in ceramic packages are priced equal to or below competitive plastic-package devices according to H. M. Luhis, the company's IC marketing manager.

Not all prices in the semiconductor industry however are on a downward trend. Several suppliers of silicon-controlled rectifiers, for example, have recently increased prices — the latest being International Rectifier with an average 6% hike on 60% of its line and General Electric with a 5% increase on some devices.

Alternate sources

Second sourcing of ICs continues on the upswing. In the linear IC area, Fairchild has brought out the μA795C, its equivalent to Motorola's MC1495 four-quadrant analog multiplier; Signetics and National Semiconductor have become the latest second sources for the SN7524/7525 sense amplifiers introduced by Texas Instruments (the National numbers are LM354A/LM354). Precision Monolithics and Advanced Micro Devices are supplying replacements for several Fairchild and National Semiconductor operational amplifiers and other linear ICs.

In the digital arena, Advanced Micro Devices has unveiled seven Fairchild 9300-series types, the 9300, 9301, 9304, 9309, 9310, 9312, and the 9316 (two counters, two multiplexers, a 4-bit shift register, a decoder and a dual full adder). Recently Philco-Ford also entered the 9300 competition with six devices. Sylvania has announced fourteen ICs in the 7400N Texas

(Continued on page 28)

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Circle 122 on Inquiry Card

Instruments line (NAND and AND-OR-INVERT gates, dual "D" and "J-K" flip-flops) and promises more soon. Philco-Ford says it will add 17 more TTL devices to the 23 already in its 7400 IC line.

Build-your-own ICs

Monolithic breadboard ICs, pioneered and sold by Westinghouse before it dropped out of the semiconductor-device business, are available again. The newest version, called a "QuikChip," is being produced by Silicon General. The Westminster Calif. company, owner of much of the defunct Westinghouse operation's equipment, supplies the breadboard ICs in chip form or mounted on TO-100 10-pin headers with pressed-on caps.

The QuikChip contains 50 separate components including 11 transistors, diodes, capacitors and 30 center-tapped resistors on a 70 by 85 mil chip as shown on page 26 (top photo). A circuit individually wired for evaluation is depicted in the middle photo. The bottom view shows the same breadboard circuit but with wire connections and metalized bonding pads replaced by a metal interconnection pattern.

Breadboard ICs are also available from Canadian Westinghouse Company Limited in Hamilton, Ontario. The Canadian Westinghouse IC, the WS178, contains 13 transistors, three diodes and 13 tapped resistors.

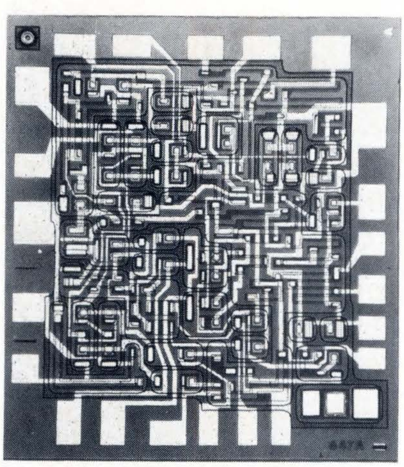
Phase-locked-loop ICs

A pair of phase-locked-loop ICs have been added to the Signetics line. Intended for application in modems, telephone signaling systems, telemetry, tone decoders and various radio and recording equipment, the ICs duplicate frequency and demodulate fm signals without using tuned circuits.

The phase-locked-loop IC contains a *voltage-controlled oscillator* which generates a frequency near the incoming frequency; a *phase comparator* (mixer) which combines the incoming and oscillator signals and produces a dc signal output; and a *low-pass filter* which restricts how far apart the oscillator and input signals can be separated in frequency. The difference signal put out by the phase comparator controls the oscillator so that the frequency of the incoming signal is duplicated.

The phase-locked-loop IC can be used to clean up a noisy signal or as a tracking filter. In an fm application, because the error voltage controls the oscillator, direct demodulation of information is obtained without using tuned circuits.

The Signetics NE561B is similar to the NE560B but it also includes provision for a-m synchronous demodulation.

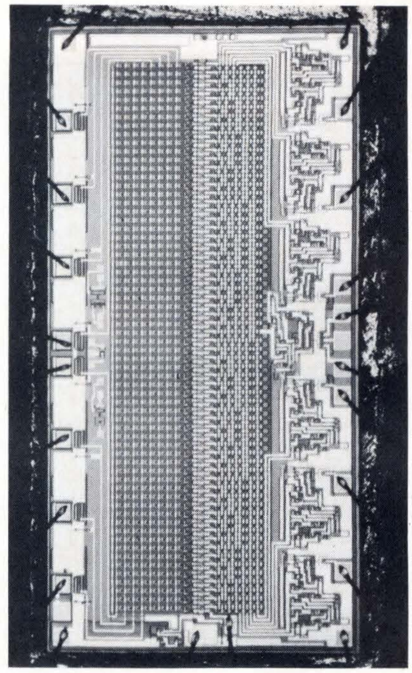


Phase-locked-loop IC developed by Signetics.

Field programmable ROM

A bipolar read-only memory which can be field programmed after the chip has been hermetically sealed is being offered by Radiation. The 512-bit 0512 eliminates the final-pattern custom mask step normally required in building programmable ROMs to specific customer orders. It permits a user to stock the 0512 and finalize its circuitry while breadboarding. Volume requirements can subsequently be ordered directly from the factory.

All bits in the memory matrix are supplied set at "0." A "1" can be patterned at a particular bit by sending a 30-mA current to its location to create an open circuit. The 64-word by 8-bit memory matrix is addressed through a 6-input decode address which accepts binary codes and allows the random selections of any one of the 64 words. The eight open-collector output buffers can drive up to 20 mA of current into a 30-pF load at room temperature.



Radiation's field programmable bipolar ROM.

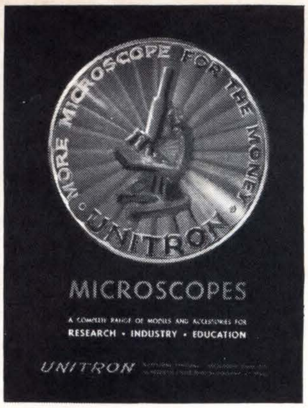
New power hybrid IC developed by RCA.

Power hybrid ICs

RCA is sampling two high-frequency power hybrid ICs — an amplifier which can deliver 16 W at 350 MHz and a power combiner/divider. The amplifier, designated TA7702/7703, in a feedback modulation system with a low-pass rf filter, is capable of more than 85% modulation with less than 10% audio distortion. Efficiency in 225-to-400-MHz applications runs 50 to 75%.

The TA7747/7748 is an equiphase, equiamplitude 3-port IC

(Continued on page 30)



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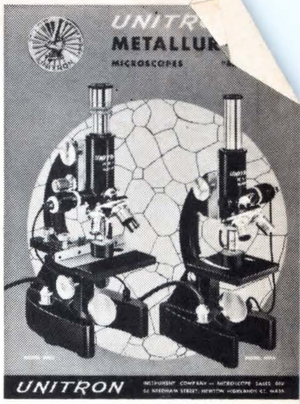

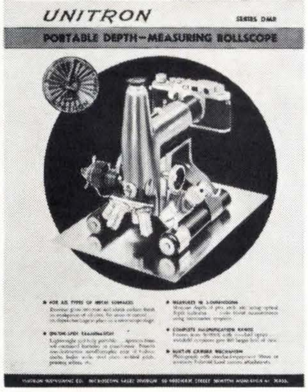

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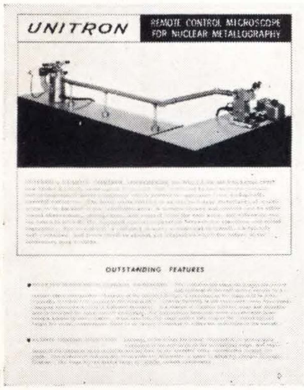

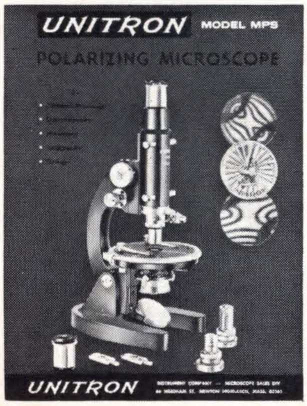

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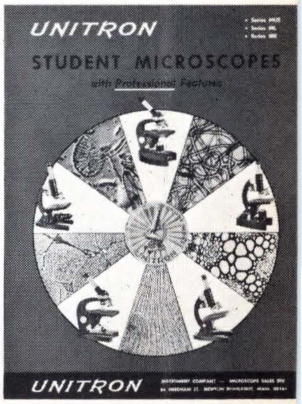

power combiner or divider (when used as a divider, the output ports are isolated).

For high-power requirements, the power amplifiers and power combiners can be teamed up. For example, two of the amplifiers can be paralleled by the combiners and driven by a third amplifier to provide 32 watts with 13 dB of gain across the 225-to-400-MHz band.

The TA7702 and TA7747 packages have studs; the TA7703 and TA7748 are studless. Developmental samples cost $750 and $85 for the amplifier and the combiner, respectively. ■

For more information on products mentioned in this article, circle the indicated inquiry numbers: Silicon General's breadboard IC, 610; Signetics' phase-locked-loop ICs, 611; Radiation's ROM, 609; and RCA's power hybrid ICs, 612.

CAD system for IC artwork generation

PROGRESS IN MICROELECTRONICS

A NEW INTERACTIVE graphical system, the Design Assistant from Applicon of Burlington, Mass., generates a computer representation of circuit mask layouts for any type of bipolar or MOS digital IC. When a layout is complete, the Design Assistant produces digital data to drive an automatic artwork generator. Applicon feels that this will greatly increase the efficiency of the design and layout process of an IC and eliminate manual preparation of data for automatic artwork generation.

The overall system is composed of a graphics terminal consisting of a Computek storage tube display, keyboard, data tablet and an IBM 1130 with Applicon's program stored on a disk memory. Two to three programs may be stored in this memory. The system is not capable of time sharing and no substitutions are permitted in the type of computer or terminal. In addition, the purchaser is not allowed to modify the stored program.

In a typical operation, the user begins by retrieving his basic mask layout from the disk memory. The operator then instructs the program with the keyboard, lightpen and data tablet, in order to use his own symbols for editing commands.

With these programmed commands the user can add components to a layout's previously defined library components, such as transistors, resistors or more complex cells. When a library component is added to a layout, the Design Assistant updates the display and all 16 index levels. Layout editing capabilities include adding, deleting, stretching, shrinking, rotating, flipping and moving selected components. The layout may be examined in the 16 index levels of magnification. The system allows the use of over 32,000 components in a layout.

This system is aimed at large and medium IC producers. It should be noted that Motorola at its "Digital Systems '70" seminar described a similar system called CAMP (Computer-Aided Mask Preparation) which the company is already using for LSI and MSI masks. However, the Design Assistant is flexible enough to be used for other applications such as printed-circuit layout or NC (numerically controlled) machining.

The total cost of the Design Assistant (not including the 1130) is $63,000. ■

For more information, circle 653.

Look ma, no hands in solid-state watch with LED readout

PROGRESS IN TIMEKEEPING

A COMPANY WITH time on its mind for 77 years has introduced, with the help of Electro/Data, an electronics company, the first solid-state, LED-readout wristwatch. But Hamilton Watch doesn't like to call it a wristwatch. Rather it's the Pulsar, "a wrist computer programmed to tell time."

The Pulsar is the first consumer product to use light-emitting diodes for readout, but you may not see it on the wrists of too many consumers. It costs $1500. Further, production isn't scheduled till 1971. Hamilton announced it early because rumors of its existence had begun to circulate to points as far as England and, apparently, if the English know about it, one might just as well tell the world.

Unlike other watches we've seen, the Pulsar doesn't show time at a glance. A user must press a "demand" button to illuminate the LED readout. A single touch lights the hours and minutes digits for 1-1/4 seconds. That interval gives a man enough time to focus on the watch and assimilate the information while it conserves battery power. If the man keeps the demand button depressed, the hours and minutes disappear, and LED digits count off seconds.

The time-on-demand feature, which some may regard as an inconvenience, has been turned to magnificent advantage, probably by some genius in the publicity department. The company states that pushing the button gives a man a feeling of involvement. Others may consider the Pulsar particularly useful for a man with two hands who wants something to do with one of them while he's checking the time.

High accuracy, cost

In addition to the involvement feature, Pulsar offers unprecedented stability in a wristwatch —3 seconds per month. That's even better than the minute per year quoted for Bulova's Accuquartz (which includes a quartz oscillator and a tuning fork), introduced early in April. The Accuquartz is somewhat less costly than Pulsar—at least for men.

(Continued on page 32)

Teledyne Philbrick Nexus introduces its combination "Hole-in-One" Chopper Stabilized Operational Amplifiers. The 1412 "Mini-Chopper" that is hermetically sealed and the 1701 Low Cost Discrete Chopper Amplifier, both individually designed to meet your most exacting requirements. Looking for a better than par score? Read the card below.

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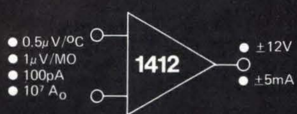

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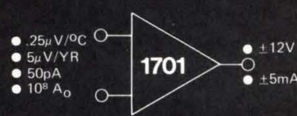

For further information, contact your local Teledyne Philbrick Nexus representative or Teledyne Philbrick Nexus, 21 Allied Drive at Route 128, Dedham, Massachusetts 02026. Telephone: (617)329-1600 Prices F.O.B. Factory U.S.A.

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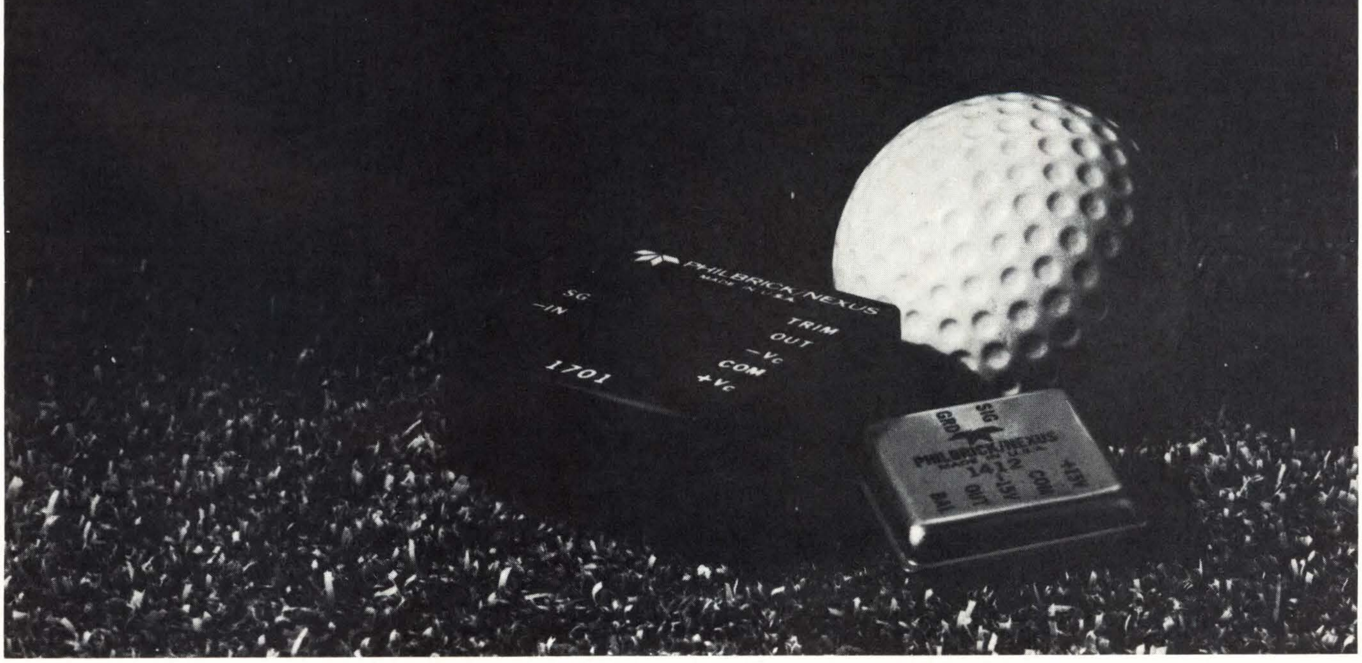


Circle 124 on Inquiry Card

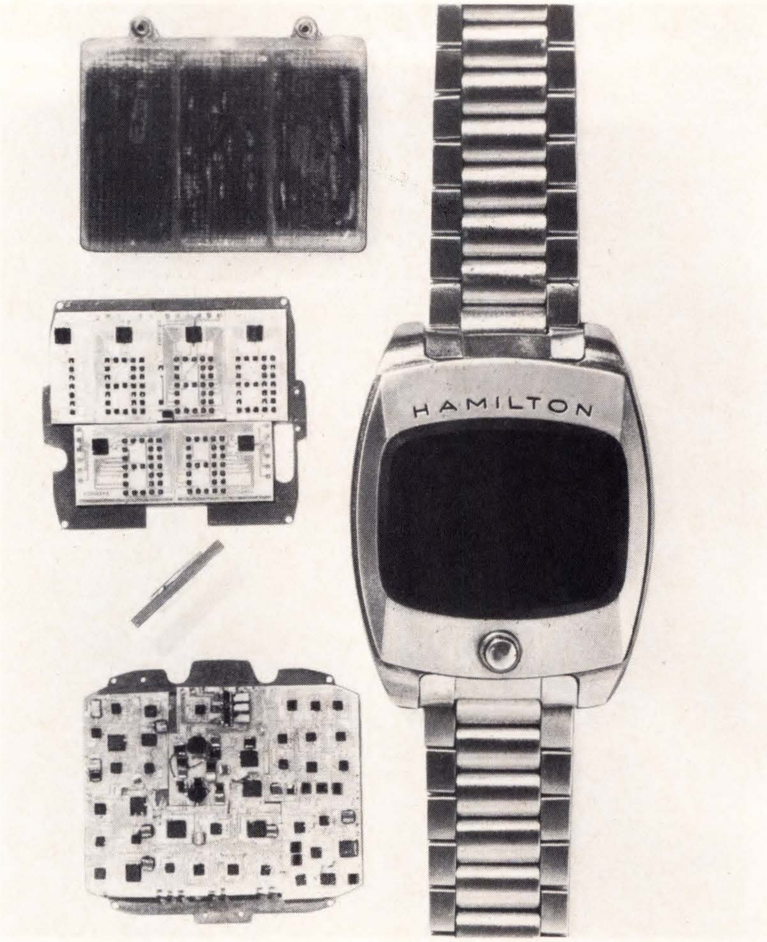
The "gents" version goes for $975 to $1325 depending on the choice of watchband. A diamond-brooch version for the girlfriend costs $50,000.

Since the Pulsar has no moving parts (except the demand button, two tiny buttons for resetting the time and an internal capacitive trimmer for tuning the quartz time base to "exactly" 32,768 Hz) and since all components are potted in epoxy, the watch should have an exceptionally long, trouble-free life—after prototype bugs have been exterminated. So far, faults have been found in six watches. Six have been produced.

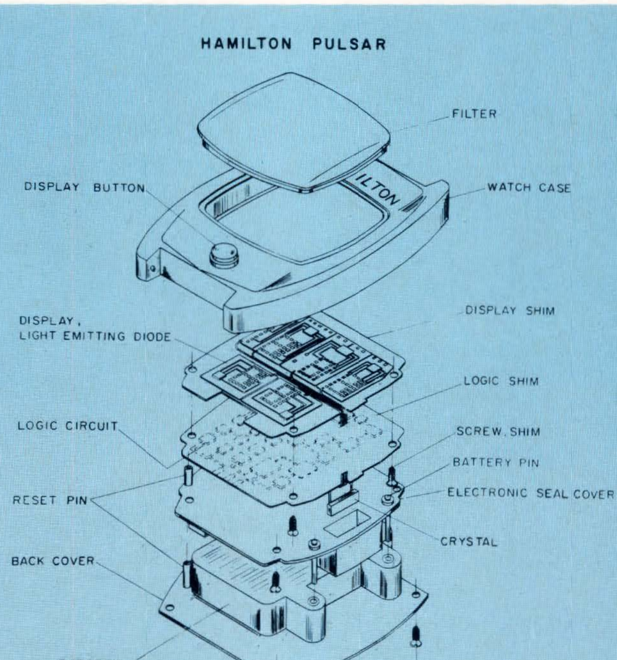
Complex circuitry, mostly MOS

Though no larger than a conventional watch, the Pulsar is jammed with circuitry. There's an equivalent of 3474 npn and pnp transistors, most of them in 44 complementary-symmetry MOS ICs. A handful of discrete passive and active components includes three phototransistors to adjust LED brightness to compensate for ambient light level.

Much of the circuitry is required for decoding for the LED readouts. For each character, except the first hour digit, the diodes occupy 27 positions in a 5 × 7 dot matrix. Use of diodes in the second column from the right provides more attractive one's and four's, while use of half that column makes for a better looking seven.



Hamilton's Pulsar uses three basic modules — the battery (top left), display (center left) and a hybrid-circuit substrate.



All the circuitry for the first all-solid-state wristwatch is mounted on a single alumina substrate between the silver-zinc battery and the LED readout.

Most of the remainder of the circuitry is used for countdown from the 32,768-Hz oscillator to provide timing for seconds, minutes, hours and the 1-1/4 second duration of the hours and minutes display.

Thick-film-hybrid construction is used for all the circuitry, with active and passive components in the form of bare chips. The logic is driven by a sustaining battery, which is constantly recharged by the main battery. When the main battery, a 4.5-V silver zinc, runs down (after about six months of normal use), the watch owner can recharge it himself. With a jeweler's screwdriver, he removes four tiny screws that secure the back of the watch case, being very

(Continued on page 34)

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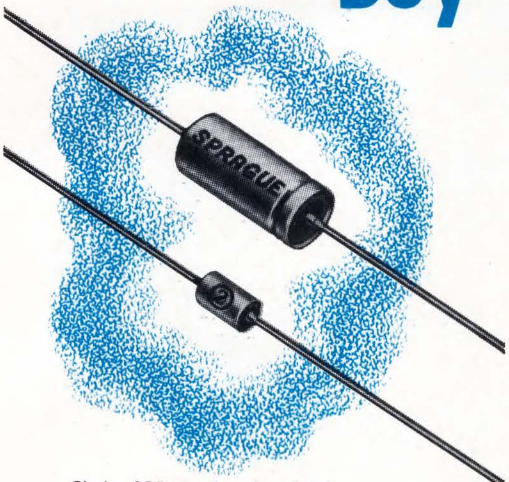

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careful not to lose a screw. He removes the main battery, allowing the sustaining battery to keep the works running without missing a tick (sorry, the Pulsar doesn't tick).

He installs a spare battery and places the discharged battery in a recharge box. One battery can take 50 charge-recharge cycles. The spare and rechargers are included in the Pulsar's price. ■

Solid-state converter works with anyone's synchros

PROGRESS IN PACKAGED CIRCUITS

A NEW synchro-to-sin/cos dc converter, from Transmagnetics, is insensitive to line-voltage variations. And, unlike other modules that are claimed to provide good line rejection, the Transmagnetics 655NVR doesn't assume that the synchro is a perfect transformer; thus the circuit will work with just about any synchro—even those of World War II vintage.

PPI displays

Probably the most common application for synchro-to-sin/cos dc converters is in PPI displays for radar equipment. Basically, this type of converter consists of a Scott-T Transformer and a dual demodulator. The converter generates dc voltages proportional to the sine and cosine of antenna synchro angle. These voltages can then be used to generate linear ramps having slopes determined by synchro angle and by another voltage representing radar range. When the ramps are applied to the deflection plates of a CRT, the resulting display rotates with the antenna. The major problem with this basic arrangement, however, is that, if the synchro line voltage varies, the radar range calibration also changes—hence the need for line-invarient converters.

Various methods have been suggested for eliminating the effects of line-voltage variations. One popular scheme[1] is illustrated in Fig. 1. In this circuit, ac line variations are sensed, converted to dc, and applied as the denominator inputs to a pair of analog dividers. Because the numerator inputs to the dividers depend on both the line voltage and the synchro angle, while the denominator input varies proportionally with the line only, the divider outputs will vary only with synchro angle — line variations should be cancelled out.

But the circuit of Fig. 1 has a serious disadvantage. It assumes that the synchro acts as a perfect transformer — that its output voltage is directly proportional to the line voltage. In practice, however, this assumption isn't always justified.

If one tries out the circuit of Fig. 1, using a synchro simulator, it works fine; ten-percent line variations cause an output variation of less than 0.1 percent. But, with real synchros, the output variation may be as high as two percent for a ten-percent line variation. This is because, with some synchros, the output may change only eight percent when the line voltage changes by ten percent. The reason is partial saturation in the iron cores of poor-quality synchros.

Transmagnetics' new 655NVR module uses the improved circuit of Fig. 2. Package size is 3.19 x 3.44 x 1.78 inches.

Unfortunately, Mil specs for synchros tell us nothing about variations in transformation ratio as a function of line voltage. And manufacturers usually don't test for this effect unless specifically requested to do so. The solution to the problem, then, is either to pay a higher price for specially tested synchros (this alternative may not be available in a retrofit situation) or to design a conversion circuit that doesn't depend on the synchro characteristics.

(Continued on page 36)

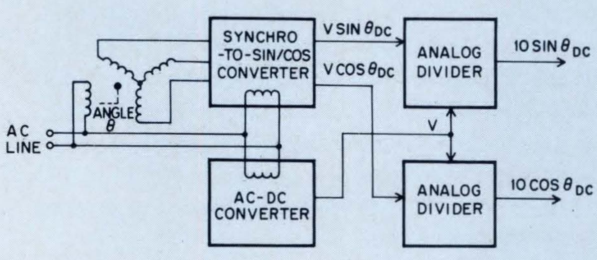

Fig. 1. One method for improving the line rejection of a synchro-to-sin/cos converter is to connect a pair of analog dividers at the output and to drive the dividers' denominator inputs with a voltage proportional to line voltage. But this method has the disadvantage that variations in synchro transformation ratio will affect the output.

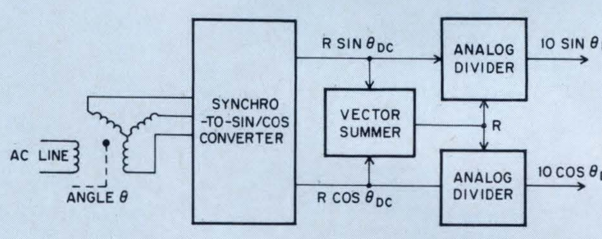

Fig. 2. An improved method of eliminating the effects of line-voltage variations is to combine the sine and cosine outputs with a vector summer. The resulting denominator input for the divider is proportional to just that part of the line voltage that appears in the output of the synchro. Thus the circuit doesn't depend on the transformation ratio of the synchro.

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Burndy gives you immediate delivery on the Compact Bantam in all shell styles.

BURNDY

Bantam Products/Norwalk, Connecticut

Now, engineers at Transmagnetics have come up with a clever scheme for eliminating the effect of line-voltage variations. The improved circuit shown in Fig. 2, still uses analog dividers; but, the denominator input to the dividers is derived from a vector-summing circuit instead of being taken from the reference line. The vector summer computes the vector sum of $R \sin \theta$ and $R \cos \theta$, and the result, of course, is just R. Because both sets of inputs to the analog dividers are derived from the output side of the synchro, variations in synchro transformation ratio do not affect the output of the circuit.

Another advantage of the improved circuit is that it will work over a much wider frequency range than other circuits. Thus a single circuit can be used for 50-hertz, 60-hertz and 400-hertz synchros. Though the synchro transformation ratio may change with frequency, this will have no effect on the output from the converter.

Transmagnetics' 655NVR is a complete synchro-to-sin/cos converter module using the new approach to eliminate the effect of line variations. All the circuitry — including a Scott-T transformer, phase-sensitive demodulators, a vector summer, and a pair of analog dividers — is packaged in a compact module, 3.19 × 3.44 × 1.78 inches. The circuit has an output variation of ±0.2% f.s. and a total conformity of ±0.5% f.s., for input variations of ±10% and frequency variations of ±5%. Maximum outputs are ±10 Vdc. Required dc supply voltages are ±15 V and +5 V.

Versions are available with operating temperature ranges of 0 to +70° and −55 to +85°C. Total conformity temperature coefficients are ±0.01%/°C and ±0.02%/°C, respectively.

Approximate price of the standard version of the 655NVR is $595 in quantity. Delivery is 4 to 6 weeks. ■

Reference

1. Nathan Sussman, "Applications for Trigonometric Computing Modules," *EEE*, September 1969, p. 73.

For more information, circle 648.

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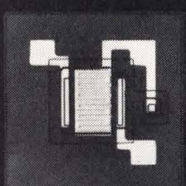

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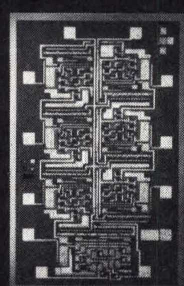

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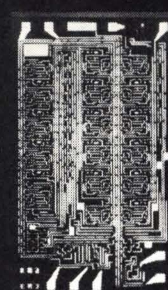

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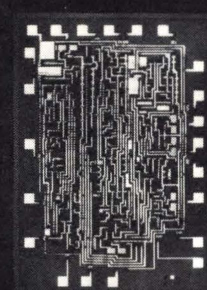

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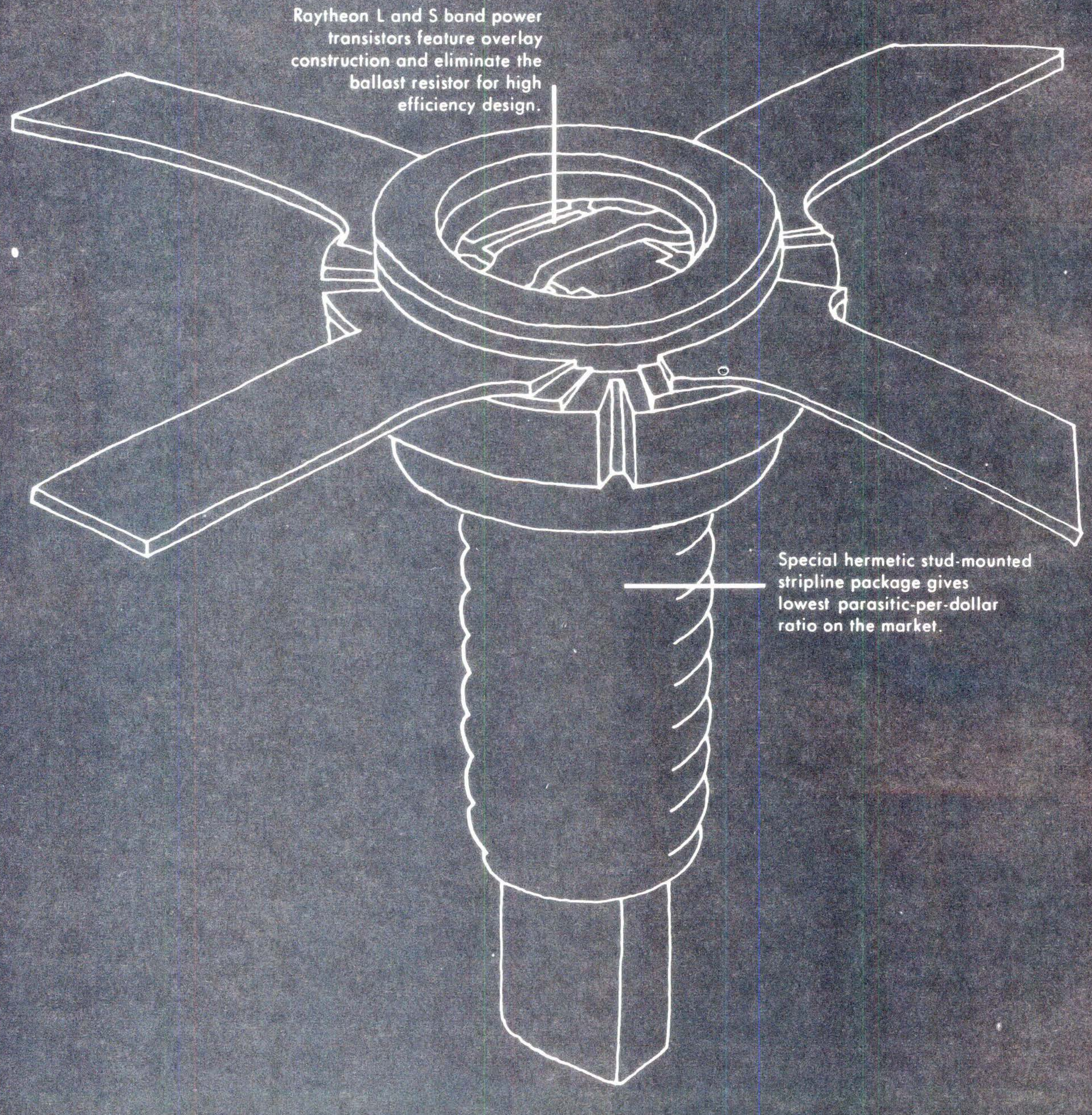

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LS1604	Stripline	1.0 GHz	4.0 W	6 dB	60%	30.00
LS1602	Stripline	1.0 GHz	2.0 W	6 dB	50%	21.00
LS1701	Stripline	1.0 GHz	1.0 W	7 dB	50%	17.00
LS1501	Stripline	1.0 GHz	1.0 W	5 dB	45%	12.00
2N5108A	TO-39 Case	1.0 GHz	1.0 W	5 dB	40%	9.30
2N5108	TO-39 Case	1.0 GHz	1.0 W	5 dB	35%	9.25
2N4428	TO-39 Case	500 MHz	0.75 W	10 dB	35%	5.00
2N3866	TO-39 Case	400 MHz	1.0 W	10 dB	40%	1.50
2N3553	TO-39 Case	175 MHz	2.5 W	10 dB	60%	3.18

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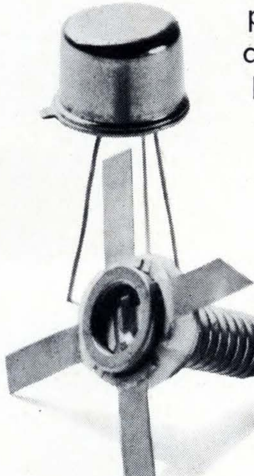

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Selecting and Applying Semiconductor Memories

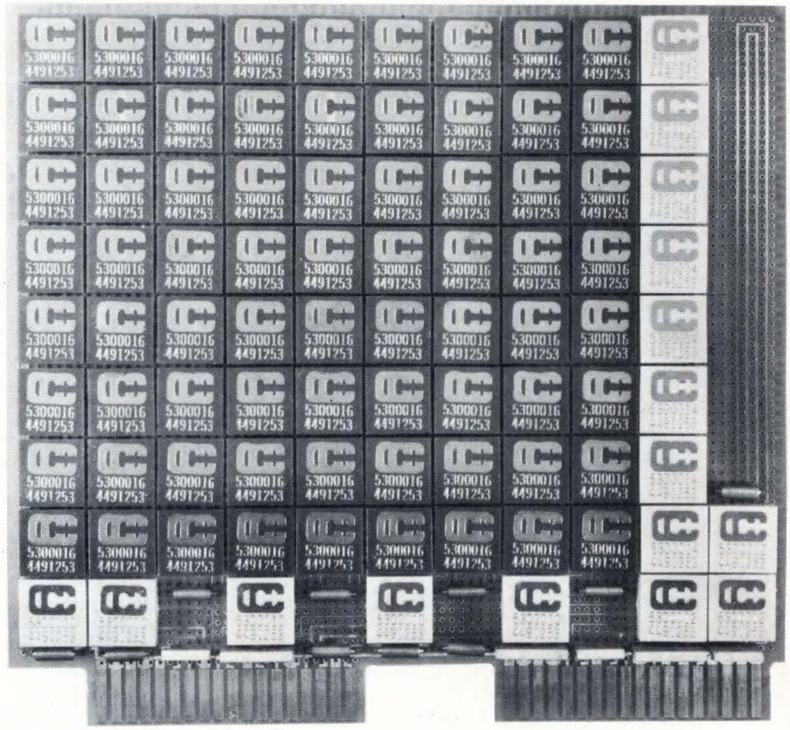
Part Two July, 1970

In this month's look at the semiconductor-memory field, Bob Norman, President of Nortec, discusses the various ways in which an IC user may get involved in memory buying. He examines various points in the semiconductor-memory design-and-processing cycle at which the user may turn over the reins to outside help.

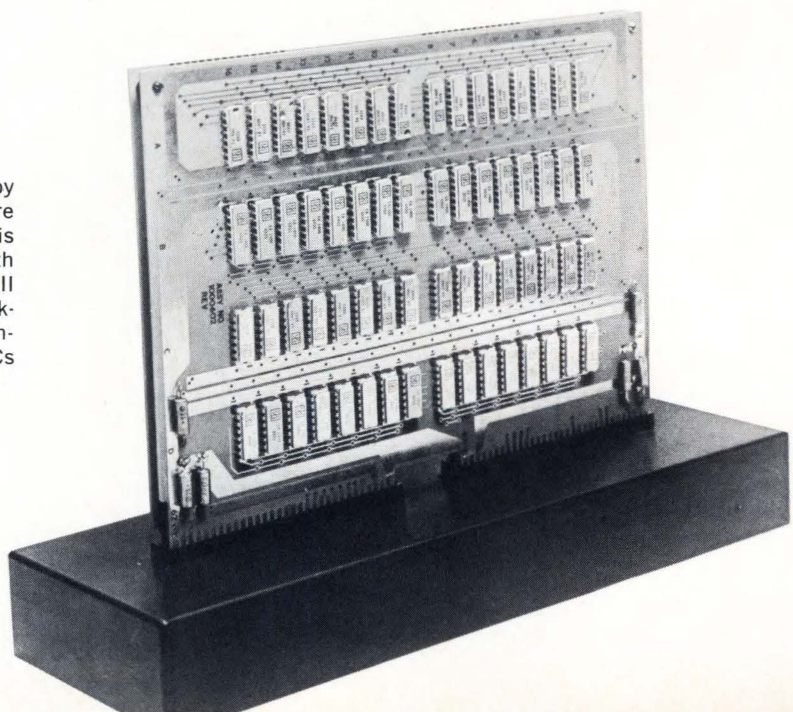
Norman feels that the lack of qualified people available to run a semiconductor operation is a key reason for large users of semiconductor memories to avoid putting in their own installations. But he believes that for the next two years, it will pay for companies to employ custom memory design and to participate in the design work. After that he feels that "it will be more advantageous to buy standard memory from semiconductor manufacturers who will have volume parts available."

For more information, circle indicated inquiry numbers on reader service card.

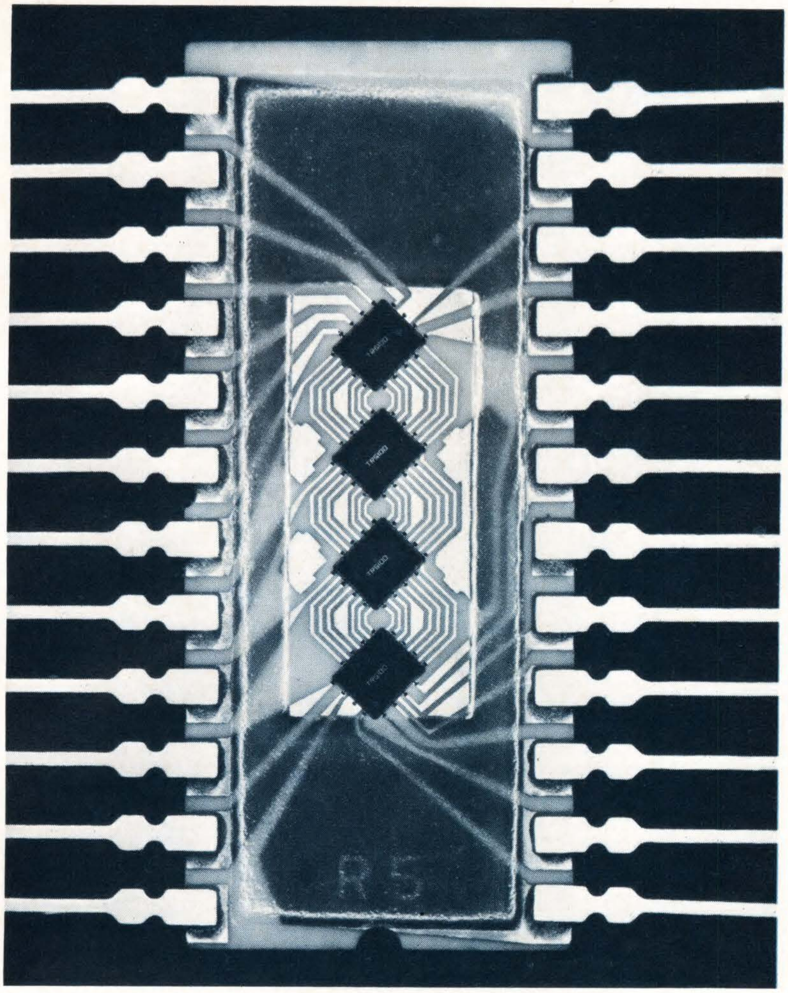
New Semiconductor Memory Products



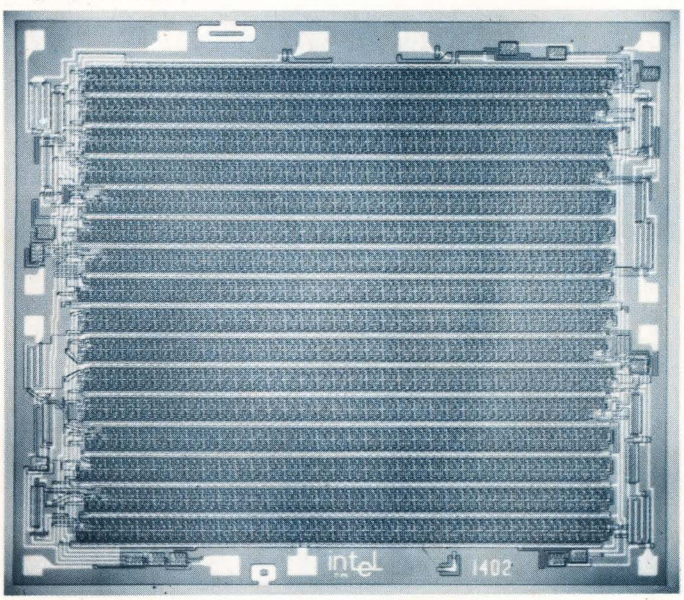
Cogar's 08C10 is a 1024-word-by-8-bit bipolar read/write memory (the 08C06 1024-word-by-9-bit card is also available). The ECL-compatible system, built with random-access-memory ICs, has 40-ns access time and 80-ns cycle time. The dark modules are the memory arrays; the light ones are the support circuitry (buffers, decoders, sense amplifiers and data latches). Guaranteed for five years, in quantities of 10 or more the 08C10 costs $2460, the 08C06 sells for $2760 (circle **684**).



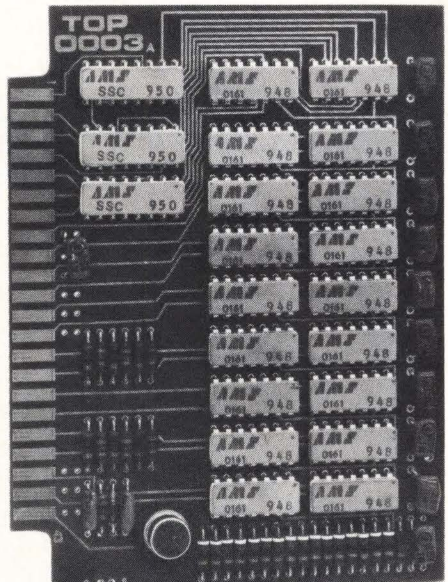
The Mostak II memory system made by Electronic Arrays can directly replace core memory systems of the same size. It is a 1024-word, 8-bit-per-word memory with a 1-μs full-cycle time. The Mostak II uses two boards—one contains the clocking and timing circuitry, the other contains MOS random-access-memory ICs (circle **683**)



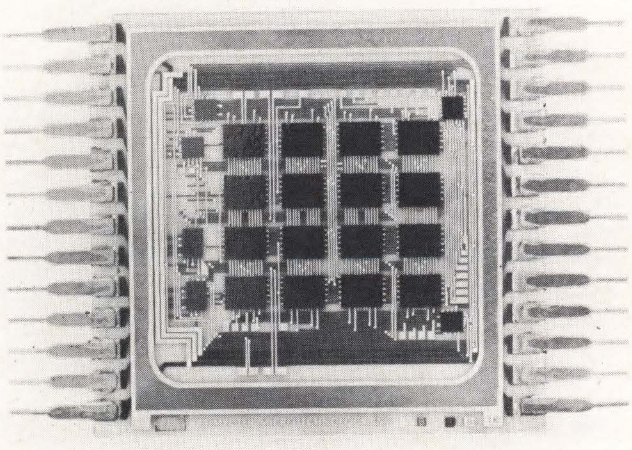
Raytheon's RR6110 is a 24-pin 256-bit fully-decoded random access memory. It uses four 64-bit bipolar ICs, each a 16-lead beam-lead device. A completely monolithic version will replace the four-chip arrangement later this year. It's expected to sell in the $160 range (circle **681**).



A 1024-bit dynamic shift-register line with on-chip multiplexing is being developed by Intel. It will consist of a 1402 quad 256-bit shift register (see photograph), a 1403 dual 512-bit register and a 1404 single 1024-bit register. All three of the silicon-gate MOS ICs will have a minimum 5-MHz data rate. Prices are expected to be 2.5¢ a bit at 100-unit quantities. (circle **685).**



A read-write bipolar memory card is available in two versions from Advanced Memory Systems: the 128-word-by-8-bit 1288E (shown in photo) and the 128-word-by-9-bit 1298E. Both cards are compatible with emitter-coupled-logic (ECL) systems. The cards use AMS 0641 64-bit, 7-ns memory ICs and SSC (storage support circuit) ICs and can be operated at 4 V. The cards also include bypass capacitors and resistor networks. Prices in 100-unit quantities are $850 for the 1288E and $955 for the 1289E (circle **682).**



Computer Microtechnology's 1024-word-by-4-bit CM1024 uses 16 256-bit static MOS RAM ICs. A total of 22 ICs are employed in the read/write system; besides the MOS ICs, four 1-of-8 bipolar decoders and two bipolar dual sense amplifiers are used. The system has 300-ns access and 450-ns cycle times. Inputs and outputs are TTL. Other available versions of the CM2400 are the 2048-word-by-2-bit CM2401 and the 4096-word-by-1-bit CM2402. All three are priced at $600 in 100-up quantities (roughly 15¢ per bit). Computer Microtechnology expects the price will drop to 8¢ per bit early next year (circle **686).**

Semiconductor Memories:

As is evident from the title, this article will not contribute to the debate between core and semiconductor memory. As a matter of fact, it will not even get involved in the current controversy over which is the best semiconductor-memory technique to use. In addition, it won't answer the question, "Who should make or buy?" It will explore the considerations involved in arriving at a make or buy decision.

Make or buy is by definition an economic decision. The decisions that are made concerning memories today will affect the expenditure of large amounts of money over the coming years.

Five years ago many systems architects were pleading for a breather in technological change so that decisions being made then would not be obsolete by the time they were implemented. Instead, LSI was invented.

Semiconductor memory is now receiving the concerted attention of highly skilled technologists steep in integrated-circuit know-how. Considering that a memory is a well-defined, closed system relative to the other problems that the same technologists have attacked in the past, considerable rate of growth in semiconductor-memory technology can be expected. It is conceivable that all current concepts of data-handling-system architecture will be obsolete in five years.

The systems-company decision-maker finds himself making decisions which affect his position in a market which is in motion and which depends on source technology which is in itself in motion. Decisions which are made within these fluid constraints must be consistent with each company's resources, goals and aspirations. The problem for the engineer, today is to take this fluid technology and put it to work for his company to enhance its position in the exploding marketplace in a manner consistent with the resources and the profitability and return on investment aspirations of his company.

Who buys memory?

In the final analysis it is the end user of a data processing service who buys memory. He is not concerned whether the memory is core or semiconductor or ants. He is not concerned with the question of MOS versus bipolar. His concern can be simply stated: he requires that the value of his data processing system be greater than its cost. The data-handling market is exploding because system costs have been reduced below the value of the systems to the end-user.

Who sells memory?

Memory is sold in the end by the system supplier who installs data processing systems for the end user. He may purchase and lease out data processing systems, assemble them for end users, manufacture them, or he may manufacture some portion of the end-item hardware and purchase the rest. As he uses the hierarchy of input/output devices and a hierarchy of logic and memory distribution among them, he also uses a hierarchy of memory — all aimed at providing maximum values to the end user at minimum cost.

It is inconceivable that modern cost effective systems would make no use of magnetic memory. It is just as inconceivable that modern cost effective systems would make no use of semiconductor memory. Today's system supplier must provide a hardware and software configuration which is adequate to the needs of the end-user at minimum cost. This will involve a mix of memory types.

Who buys semiconductor memory?

The company that buys semiconductor memory does so to fill some part of its total memory requirement based on the performance/flexibility/cost characteristics of semiconductor memory relative to other techniques not because it is popular today or because of its romantic appeal. The buyers of semiconductor memory are: (1) systems manufacturers and/or suppliers, (2) computer manufacturers, (3) peripheral-equipment manufacturers, and (4) memory manufacturers.

The nonmanufacturing systems supplier will most likely buy semiconductor memory as a complete memory unit which can be simply attached to his other purchased systems components. The memory manufacturer, on the other hand, will most likely buy only wafers, chips or packaged dice. The remaining companies may buy semiconductor memory in any form or any combination of forms.

How can semiconductor memory be bought?

Semiconductor memory can be bought in almost any form. For example the memory user can purchase (1) unprocessed silicon, (2)

Author: Bob Norman is president of Nortec, Santa Clara, Calif.

Make or Buy?

by Robert Norman

processed wafers, dice, packaged devices at vendor risk, (3) processed wafers, dice, packaged devices at customer risk, (4) assembled memory modules/subsystem, or (5) packaged memory systems.

Each of these alternatives can be evaluated in terms of several considerations of interest to the buyer. As part of the assessment, time must be taken into account. Solutions which seem best for the short term may not be best for the long haul and vice versa. The important business considerations are the effects of the decision on the profitability and return on investment characteristics of the company and available resources. The technological considerations are flexibility in the application of the memory and insensitivity to technological obsolence.

Two considerations which affect memory decision making today are that, in the years ahead: (1) semiconductor memory will be manufactured, sold and used in very large quantities and (2) only the LSI configuration can easily be "standard" product.

As a consequence, the semiconductor memory will represent a major source of revenue to major semiconductor manufacturers and to that newly emerging segment of the semiconductor industry which specializes in memory alone. The effect of these considerations is shown in the price projection of Fig. 1. These projections indicate a continuous decrease in the cost of fabricating semiconductor memory throughout the decade. It is expected that the cost will be less than the price of medium-size core memories sometime before the end of next year.

The price of semiconductor memory should decrease until it becomes comparable to the price of cores; then there will be no further reason for reduced prices until sometime about the middle of the decade. Then even though memory use will be very large, it will be matched by memory fabrication capacity. At that time competition among the fabricators will force the price down towards the semiconductor-memory cost level. The price could drop earlier because of the well-known semiconductor industry pricing practices. These reductions will be achieved through continuous technology and technique improvements aimed at cost reduction.

It is now appropriate to examine the alternative ways of purchasing semiconductor memory.

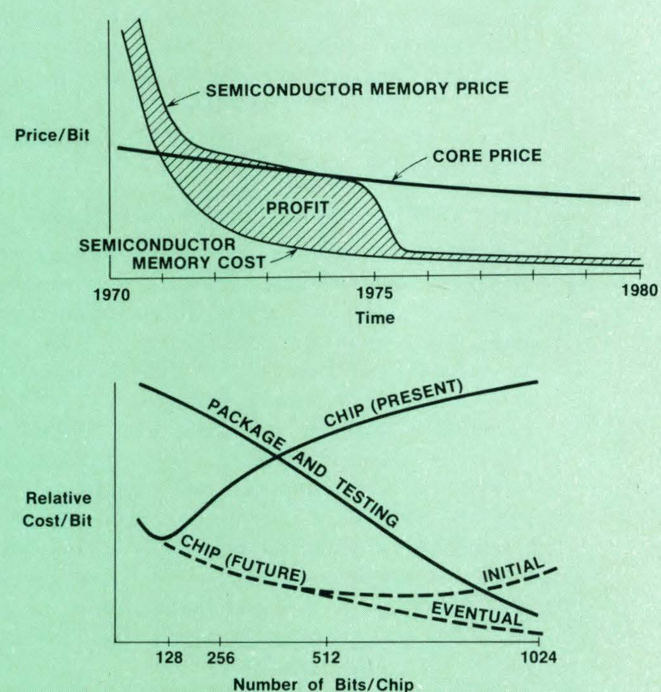


Fig. 1. Price-per-bit curve for semiconductor memories will eventually approach cost curve. Present cost relationship between chip and packaging/testing will change in future.

Unprocessed silicon

Companies that purchase memory as silicon already have an operating semiconductor fabrication plant as part of their capability. On the surface by operating in this fashion, they have absolute control of the design of the memory and can therefore optimize it for their own use. They are able to incorporate new technology at will for improving memory performance when needed and improving cost. They also have the highest value-added approach since the cost of materials for memory with good yield is about two mils per bit. As shown in Fig. 1, during the first half of this decade, for this type of memory-using company, the investment can be modest, and the return on investment good.

Why doesn't everybody take this approach? One reason is that the supply of managers capable of operating a semiconductor plant effectively is critically short. The data processing systems manufacturer may well be able to come up with the several million dollars required to get into the semiconductor memory business, but it may not be able to discriminate against its existing staff sufficiently to recruit and retain the key personnel needed to man a semiconductor facility.

Risks that must also be considered when contemplating installation of your own semiconductor operation are: (1) unbelievable operating running losses, (2) inability to implement any technology beyond that with which the facility started, and (3) frozen memory designs in order to achieve "manufacturability" of the memory. If problems occur, you may also be faced with the loss of inside customers to outside sources.

Wafers, chips or packaged devices (vendor risk)

Semiconductor memory may be purchased as finished devices either on wafers or separated into chips or in packages. With standard products, the vendor assumes the risk for the parts he sells, that is, you pay for good devices. Over the long haul it can be expected that memory purchased this way will be highly competitive in price and performance. Usually more than one source for parts will be available. Proper exercise of the purchasing function will permit the highest degree of assurance of having an adequate supply of parts for your data processing systems, at a level which still permits room for value added in assembling the parts in memory subsystems.

The penalties attached to buying memory this way are: (1) performance will tend to lag one to two years behind the state-of-the-art, (2) prices may stay at core levels for a few years as mentioned earlier (this may not occur since the semiconductor industry sometimes lowers prices even when it is not supplying the available market), and (3) memory subsystem packages will be subject to continuous redesign to accommodate continuously increasing number of bits per device through which lower costs are achieved.

Companies that buy wafers of chips from semiconductor suppliers and do their own packaging may not achieve significant value added because memory dice will always be relatively expensive. Reduced bit costs will be achieved principally in higher bit densities thus maintaining the price level of the finished device while reducing the per-bit price.

Wafers, chips or packaged devices (customer risk)

The time required for a new product incorporating new memory technology to appear on the market can be shortened by purchasing memory as wafers, chips or packaged devices but fabricated to your design by a semiconductor processing facility. It is possible to anticipate competitive commercially available memory one to two years down stream, and incorporate such memories at a "competitive" price in current equipment designs. This permits significant value-added during this interval, and memory cost to track the memory cost curve shown in Fig. 1 rather than the price curve. The risks, of course, are well spelled out — the design is the customer's. The customer by definition will tend to freeze the technology he is purchasing but once again he is possibly one to two years ahead of commercially available technology.

Assembled memory modules subsystems

Several semiconductor companies have been established which fabricate memories in assembled memory modules/subsystems form. Examples are Computer Microtechnology, Advanced Memory Systems and Cogar. When memory is purchased this way it is not necessary to redesign the system memory every time a new device appears on the marketplace. The vendors in this case normally sell memory in larger blocks and make their decisions based on optimum number of bits per chip and on-chip or off-chip locations for decode drive and sense circuitry. Such companies make available standard blocks of memory whose performance and price will improve over the years but with relatively stable functional characteristics. The price one pays for this, of course, is low value-added on your part, and minimum flexibility in fitting the memory both functionally and physically into the system.

Memory systems

A few memory companies such as Electronic Memories & Magnetics Corp. and Advanced Memory Systems are entering the semiconductor-memory systems field. These companies will buy devices either from their own subsidiary (SEMI in Phoenix for EM&M) or from other companies, and assemble them in memory systems comparable to those which they may already be selling as magnetic memory systems. Memories are purchased this way to add onto other data processing equipments to satisfy systems requirements. All of the value added goes to the memory-systems manufacturer, not the equipment manufacturer.

Packaged memory devices will be bought in large quantities by customers who would not have considered buying core planes simply because memory devices are compatible with their circuitry and the development and manufacture of memory subsystems is far simpler than the comparable task using cores. At the other end of the scale, major equipment manufacturers who commonly have their own core plane and memory subsystem fabrication plants will also buy semiconductor memory as processed devices, wisely avoiding the pitfalls of entering the semiconductor business. **EEE**

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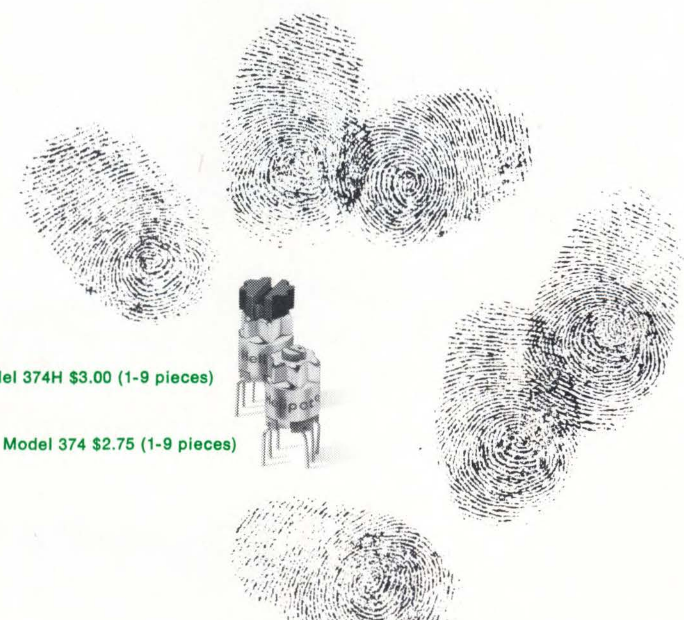

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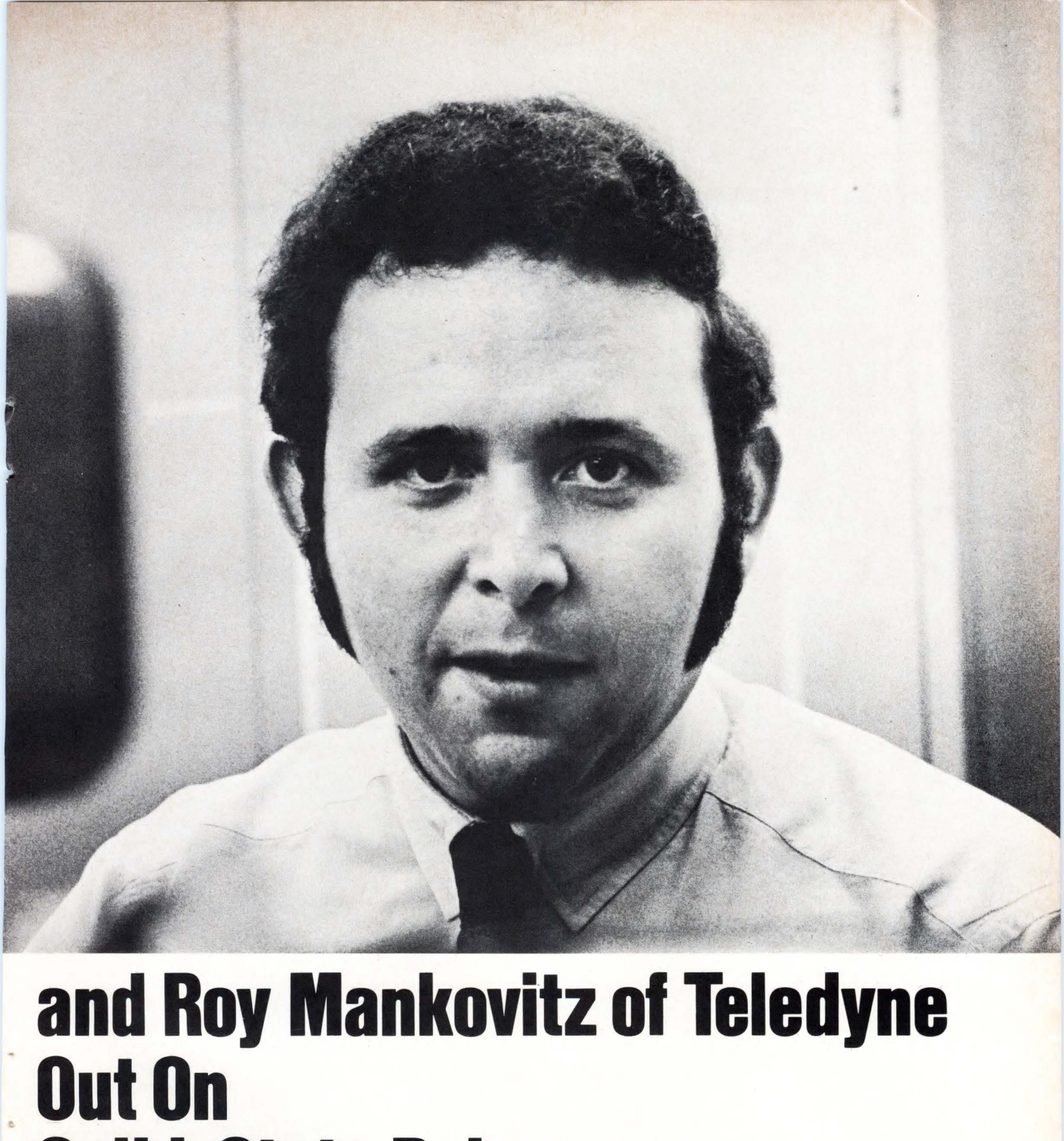
Charles Montante of Clare Speak Electromechanical vs

Archimedes in 250 B.C. said that Greece could stop training engineers and scientists because there was no further need for them; all that there was to invent or discover had been invented or discovered! With an equal amount of foresight, every decade or so an effete soothsayer informs the technical world that the demise of the relay is imminent. First it was the tube, then the transistor, and now—the solid state relay." Each was going to kill the "old fashioned" electromechanical relay. It didn't happen.

As an engineer you are interested in creating

(Continued on page 48)



and Roy Mankovitz of Teledyne Out On Solid-State Relays

Let's face it. Electromechanical relays can whip solid-state units in lots of jobs. And there are plenty the solid-state relays can't touch—not now, at least. They're certainly not convenient for multipole switching. And they don't readily offer fractional-ohm contact resistances and near-infinite open-circuit resistances. On these counts we have to hand the crown to electromechanical relays.

But in many applications, solid-state relays (let's call these SSRs) beat electromechanicals hands down. The great misfortune lies in the fact that lots of engineers are so hypnotized

(Continued on page 51)

(Charles Montante continued from page 46)

designs that best perform their intended functions. These enhance your company's probability of success, as well as your own. To do this, you try to keep abreast of alternative methods of performing circuit functions—their weaknesses and their strengths.

In switching components, you can choose between solid-state devices (transistors and thyristors, in most instances) and relays (mercury-wetted, dry-reed, general-purpose, telephone-type, crystal-can, TO-5). Both families of devices have advantages and disadvantages. Some of your designs will be best satisfied by one, and some by the other. I'd like to point out some of the advantages and disadvantages of relay and solid-state switching, and then bring these to bear on "solid-state relays."

As a generality, solid-state switching components offer the greatest advantage in applications requiring:

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1. Extremely Long Life. Electromechanical relays (EMRs) are capable of life in excess of one billion operations for mercury-wetted types, and from less than a million to hundreds of million operations for other types. In those applications where you genuinely need longer life, solid-state components are your best choice.

2. High Operating Speeds. The turn-on time for semiconductor devices ranges from the low nanoseconds for emitter-coupled-logic packages to microseconds for power transistors or thyristors. Relay turn-on times range from less than one millisecond for some mercury-wetted types to less than five milliseconds for dry-reed relays to about 10 milliseconds for general-purpose and telephone-type relays, to about 50 milliseconds for power relays and contactors. Therefore, if your circuit really requires switching times shorter than the millisecond range, a transistor or thyristor is your best choice.

3. Large Quantity of Logic. A system or subsystem with a large number of logic elements is obviously implemented with one of the many available IC logic technologies. The relay computer has gone the way of the water clock. But, when the logic is simple, the use of a relay may be the most economical and simplest way to go. If, for example, you want to start a small motor when an operator pushes a button, and you keep the motor energized until the cycle is complete, a relay can be easily used as shown in Fig. 1.

Here, S_2 is a switch or contact that momentarily opens at the end of the process cycle. It can be operated by a limit switch, a sensor or cam. When the operator pushes S_1, the relay coil is energized through S_2, which is closed. The relay contacts close. K_1 starts the motor, and K_2 keeps the supply voltage across the relay coil, latching it in the operated state. Swith S_1 now has no further control over the motor. When S_2 opens momentarily at the end of the process cycle, the motor stops and the circuit is ready to repeat the sequence. Circuits of this type can be found in office copiers, machine tools and burglar alarms, among others. They're simple. They're reliable. And they're inexpensive.

4. Lower Power Level, Spst, On/Off Switching. In the milliamp range, heat-sinking requirements of solid-state components are minimal and they can be used conveniently. As the number of poles increases, this approach becomes increasingly less economical, especially if double-throw (form C) action is required. When the switching levels are very low, semiconductors may present difficulties. The voltage and current requirements may be insufficient for device operation, or may place it in a marginal operating region.

Electromechanical relays as switching components offer greatest advantage in applications requiring:

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1. High Input/Output Isolation. A relay typically has greater than 1000 megohms insulation resistance and 500 to 1000 Vac dielectric strength. This means that the resistance seen between the input and output, and between output circuits is at least 1000 megohms. This is about 100 times that of a semiconductor. The dielectric strength means that the potential difference between the input and output, or between output circuits, can be 1000 Vac without developing difficulties like device destruction. An EMR's isolation is much less dependent on time, temperature, radiation exposure and supply voltage than is that of a semiconductor.

2. Multipole Switching. You've undoubtedly encountered many cases where it's necessary to have one input switch many outputs. You may, for example, wish to turn on a motor, change the status of an indicator light from "motor off" to "motor on," and inhibit the operation of another circuit. A 3-pole relay can do this quite easily and inexpensively. You need one spst normally open (form A) contact for the motor, one spdt (form C) contact for the indicator light, and one spst normally closed (form B) contact for the inhibit. A 3-pole double-throw (3 form C) relay, appropriately wired, is probably your best choice. It is readily available from many vendors and inexpensive.

A multipole solid-state equivalent can be designed or purchased. But it's likely to be bulkier and much more costly, and it will require more of your time to properly engineer. That's

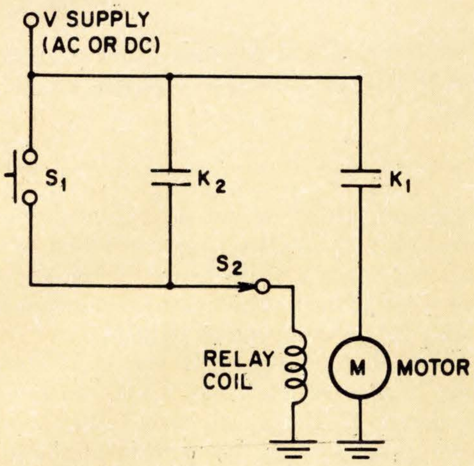

Fig. 1. It's awfully hard to beat the simplicity and economy of this arrangement for controlling a motor.

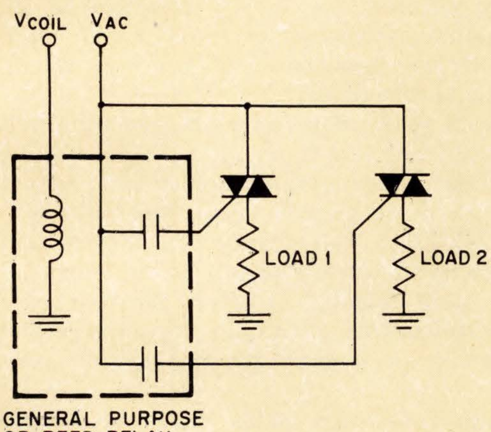

Fig. 2. Here's a superbly simple method for obtaining genuine isolation in a triac circuit.

time you can spend better on more important parts of your design. In most instances, you will find that the disadvantages far outdistance the benefits.

3. Switching Low-Level Loads. Very low level signals may not be sufficient to operate a semiconductor. In addition to avoiding this problem, a relay also offers a lower "on" resistance — one that's also independent of temperature and supply voltage. If the signals are analog, you will generally obtain lower crosstalk with an electromechanical device.

4. Simple Logic. With an electromechanical relay, it's easy to implement simple logic. Speaking at an Ohmite "Think-In" seminar last year, one industry spokesman, William A. Paulson, expressed this very well. "The majority of machine-tool control panels," he said, "are rather simple from the viewpoint of integrated logic systems, and relays will continue to be widely used. In small systems one of the chief attractions of relays is the ease with which the power switching and logic functions are combined at a considerable economic advantage, as in simple interlocks."

5. Low Power Dissipation in the Switched Circuit. You can't avoid the junction voltage drop in junction semiconductors. At high current levels, this can sap a substantial amount of power from your system and it can raise the temperature of heat-sensitive components. The contact resistance of 50 milliohms or less in a relay is substantially more efficient.

6. Operation in High Ambient Temperatures. At high temperatures, the leakage-current increase and the voltage-standoff reduction of semiconductor elements may render them useless for your circuit.

7. Immunity to Transients. When you can't afford the possibility of false triggering or device destruction because of transients, you should use a relay.

There's an aspect of design we sometimes overlook. Yet it can be more important than all the others put together.

If your company manufactures equipment used by human beings, you must consider safety in your designs. You have to plan carefully to avoid potential hazards. That's an important part of your personal end-product. It's too easy to forget, for example, that low input/output isolation in switching components can cause circulating currents between chassis, raising the danger of shocks. The "hot" cases of thyristors present similar difficulties.

You also have to worry about the cost of a failure. I don't mean just the cost of the part — though that can be quite costly to replace

Who is Charles Montante

He's a Taurus-Technocratica — one born under the sign of a technical bull. Since he learned to use his hands, Charles J. Montante has been taking things apart or putting them together.

An early winner of science-fair competitions, he began designing a machine to play tick-tack-toe when he was a seventh grader. With nothing more than a basic knowledge of electricity, he developed an approach that would now be called wired logic. The first model used many slide switches and resulted in a citation from the Future Scientists of America during his sophomore year in high school. A second version, using relays rescued from old pinball machines, was completed in his junior year.

This experience led Charles, with a specific interest in computer design, to Villanova University to study electrical engineering. Between his sophomore and junior years he took his first course in computer programming, learning machine-language programming of the IBM 1620. As graduation approached in 1965, Charles decided to prepare for broader responsibility in the working world.

Three weeks after graduation from Villanova, he began classes at the University of Chicago. In March 1967, he received his MBA from Chicago with a concentration in Finance, and Math Methods and Computers.

Charles first worked for C. P. Clare during the summer of 1966, doing special projects for the Executive Vice President. Upon graduation he rejoined Clare as Assistant to the Treasurer. Eight months later, Charles was made Marketing Assistant to the General Sales Manager. The general-purpose relay market was one research project he handled during this period. When Clare decided to enter the market, Charles was given the responsibility for getting the first product designed and into production.

In May 1969 he was made Marketing Manager, then in March 1970, Product Manager for one of Clare's three major product areas.

Charles lives on the near north side of Chicago. He is an avid movie and play-goer, as well as hi-fi enthusiast. On weekends you may find him wandering around with his Nikon or at a summer cottage in Wisconsin. To gain a greater appreciation of the non-technical side of his life, Charles has been taking night courses in Philosophy for the past two years.

in the field. But what about the cost of a failure to your customer?

Will false triggering of a semiconductor result in significant loss for the end user of your product? Will it ruin a melt of steel? Render a copy of a document illegible? Remember, too, that semiconductors can fail short, thus losing their ability to block forward current in the output circuit. EMRs, in contrast, tend to fail open — that is, safe.

Let's consider, for a moment, the things we take pride in and the things we get paid for.

As engineers, all of us can be proud of our ability, not only to design equipment and systems that work, but also to design them at an attractive cost. That's how our managements rate us and that's what we're paid for.

Now it's a fact of life that the solid-state equivalent to a multipole relay costs two to 25 times as much. If the application doesn't require the speed or life of a semiconductor approach, it isn't economically reasonable to specify it when the cost is higher. It's difficult to justify a $40 component if it must operate only 50,000 times, when a $2 device can easily take the job in stride. So it's important to obtain realistic estimates of the required number of device operations and choose switching components accordingly.

After 15 years of propaganda, the term "all solid state" has lost its magic for most people. If having all-solid-state components offers buyers no demonstrable advantage, they will not be willing to pay a dime more for it, and probably never were. The solid-state television set is a good example. It offers the purchaser little demonstrable advantage for a large differential in price, and it's not selling very well.

Though transister radios were much more expensive than equivalent table models, they offered the buyers the first truly portable radio — a tangible improvement. So don't be swayed into believing that prospects will stampede to your company's door to purchase your new widget because it's "all solid state," and costs only 10 percent more. They won't!

If, after studying the requirements of a particular circuit, you reach the conclusion that semiconductor switching components are the best choice, you must ask yourself, "Should I design a triac into a circuit with electromechanical relays, or specify an all-solid-state relay?"

The SSR people may tell you that they will save you design time. In most instances this will not be true because you will still virtually have to specify the output thyristor. As James E. Davies, Manager of Engineering at Cutler-

Hammer's Specialty Products Div., expressed it at an Ohmite "Think-In" seminar, "I think you have to specify the application so finely on a solid-state relay that's it's going to be difficult to sell such an item as an off-the-shelf item. . ." You must be certain that the output device can withstand the expected system transients, energization dV/dt and dI/dt, impressed voltage extremes, etc.

The SSR supplier may tell you his device gives you the input/output isolation you can't get by doing it yourself. Well, you can easily, and less expensively, obtain this isolation by using a reed or general-purpose relay to switch a triac or SCR gate as shown in Fig. 2. To avoid expense, the SSR vendor probably provides isolation with a tungsten or neon lamp activating a photocell. If it is a tungsten lamp, where is the reliability, long life, shock resistance and all-solid-state construction? Very simply, they are gone. If it is a neon, you are committed to a "coil" voltage greater than 75-100 volts, the firing point of the neon. This is a cumbersome arrangement, to say the least.

The SSR manufacturer may provide isolation with a light-emitting diode/photocell pair, or oscillatory coupling. All that this means to you is more cost for equivalent performance when compared to a relay switching the triac gate. In addition, you are saddled with an inflexible device — one most likely unusable in all but one particular application. Wouldn't it be better to be able to standardize on the input/output isolation component (a relay) and have to tailor only the power switch (SCR or triac) to the application?

What, then, does the SSR manufacturer do for you? He takes an output device that you specify, couples it with an isolation producer, puts it in a package (reducing your board- and chassis-layout flexibility and increasing the package bulk) and charges you for the components, assembly cost, his overhead and profit.

That's not much of a deal when *you* still have to choose the output semiconductor, and can easily buy a reed or general-purpose relay for $1.00 - $2.00, use it as a gate switch and, *voila!*, solid-state switching, 1000-megohms isolation, hundreds of millions of operations, complete freedom in board and chassis layout, lower inventory costs through reduced number of components stocked, and an accolade from management because of your outstanding business sense. The choice is yours. **EEE**

(Roy Mankovitz continued from page 47)

by one or two limitations of SSRs that they ignore these devices even where they shine. Let me show you just a few areas where SSRs dramatically outperform EMRs.

Licking emi/rfi with electromechanicals is really tough. With solid-state relays it's a snap.

We all know how serious are the problems of electromagnetic and radio-frequency interference. Using an EMR sure doesn't help. Every time you shoot current into that coil you can inductively couple some of that energy into nearby sensitive circuits. And when you interrupt the current, the collapsing magnetic field can wreak even worse havoc.

With ac SSRs, you can use zero-voltage synchronous switching and practically wipe out these transients. That's why such units have been used to meet the tough emi emission and susceptibility requirements of specs like Mil-Std-461. These devices are clean enough for operation with sensitive computer logic. And they work just as well in the severe high-noise environments of air-traffic control or aircraft power switching.

Some people think SSRs are extremely sensitive to transients. Not so. You can get units to withstand all the aircraft power-supply variations called out by Mil-Std-704. With dc loads, SSRs can use controlled turn-on/off times to slash generated interference. They can use internal filtering to increase rise and fall times to several milliseconds for heavy loads—even when input signals have extremely fast transitions.

Which relay would you expect to handle surges better?

Inductive, capacitive or lamp loads normally cause enormous current surges. EMRs must have substantially oversized contracts to cope with these surges, which can be 10 times as large as the steady-state load.

Solid-state relays, in contrast, can handle these surges without sweat—as part of their steady-state ratings. For instance, a 5-amp SSR easily takes the 50-amp surge you can expect with a 5-amp tungsten load. An EMR, in contrast, would need a 10- to 25-amp rating, depending on the number of operations required.

SSRs offer tremendous advantages in sensitivity and speed.

With electromechanical relays, the contact-current rating and the response time both affect the required input power. EMRs for high-current loads, especially if they're to be switched rapidly, require several watts of coil power. Thus, to operate most EMRs from low-level signals, like 5-volt logic, we need extra driver stages and, in some cases, extra power supplies.

Maximum power gains for EMRs are typically a few thousand. SSRs, on the other hand, can have power gains in the millions. We can control a 5-kW load with as little as 2 milliwatts. And we can directly interface with computer logic. High sensitivity in an SSR does not mean susceptibility to transients.

The response time of SSRs is inherently in the microsecond region, and that's untouchable by mechanical devices. One area where this is a tremendous advantage is in telegraph relays. Solid-state telegraph relays have been built to Mil-R-2777, which requires operation at 1200 baud with less than three percent distortion. Operation at rates above 4000 baud can be achieved, significantly increasing data rates above those attainable with mechanical units.

Another area where operating speed can be used to advantage is in light dimming in dc systems. Used as a switching regulator, the SSR is cycled at approximately 100 hertz. By adjusting the duty cycle, we get the lamps to respond to the average value, so we can provide flickerless light dimming without the high power dissipation of series limiters. Rfi is reduced by using a controlled response time.

Let's take a closer look at input characteristics.

EMRs require a different relay type or model number for each coil voltage. For SSRs, we solve this problem with a universal "coil." Units are available to allow the operation of a *single* SSR with inputs of 3 to 280 Vac and 3 to 300 Vdc.

SSRs also overcome the inherently large input hysteresis of mechanical relays. An EMR with a 12-volt pull-in could have a 0.5-volt drop-out. With SSRs, the input deadband (difference between turn-on and turn-off voltages) is typically less than 0.5 volt, permitting the relay to function as a level detector, comparator or time delay with a minimum of external components. An EMR usually needs level-shifting circuitry to interface with TTL logic, to ensure that the delay drops out in the logic "0" state.

Due to the inherently slow response of EMRs, overload protection and fault clearing usually require at least 10 milliseconds. Solid-state power controllers (which are essentially SSRs and remotely resettable solid-state circuit breakers in a single package) can beat these speeds without trying. Ac types can provide overload protection and circuit interruption in 1.25 milliseconds or less. Dc devices provide active current limiting in an overload condition, in addition to the trip-out function. These devices can operate into repetitive short circuits without damage, and without overloading the dc bus.

These controllers not only provide improved fault clearing, impossible with mechanical devices, but also significant weight, volume and maintenance advantages.

What about contact bounce and arcing? The only way you can get an SSR to bounce is to pot it in rubber. No bounce and no arcing, even when de-energizing inductive loads, make the SSR ideal for use in explosive atmospheres.

When we come to vibration and shock, there's just no contest.

Generally speaking, the higher the power required, the larger the relay. The larger the relay, the larger the masses of individual contacts, springs, armatures, etc. The conclusion is obvious: the higher the power, the more sensitive to shock and vibration. Solid-state devices are orders of magnitude more rugged. In addition, since most power SSRs are designed short and squat to provide maximum area for heat sinking (with a resulting low center of gravity), and mounted with large screws, the stresses on the mounting surfaces are usually low.

We all know what happens to contact resistance of an EMR as a function of load, cycling rate, number of operations, test conditions, age and condition of the test socket, phase of the moon, etc., etc. It wouldn't be so bad if you could at least correlate some of these factors and come up with a good guess.

Unfortunately as the relay clacks through its normal life span, material transfers between contacts, platings disappear, deposits of undiscovered original continually reappear. The result is changing parameters. And it's not only contact resistance. We also find

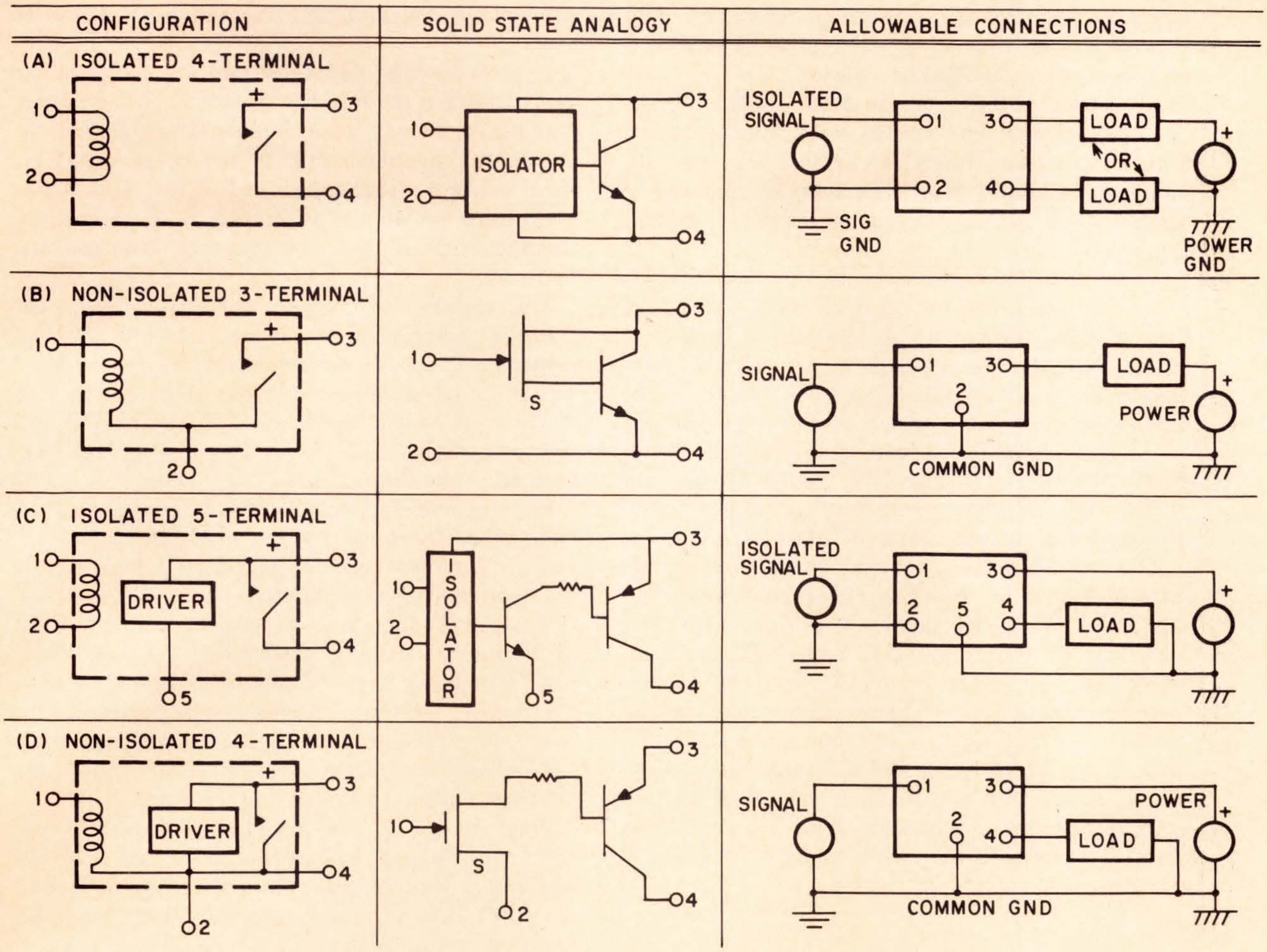

Fig. 1. Typical configurations available in 3-, 4- and 5-terminal solid-state, spst relays.

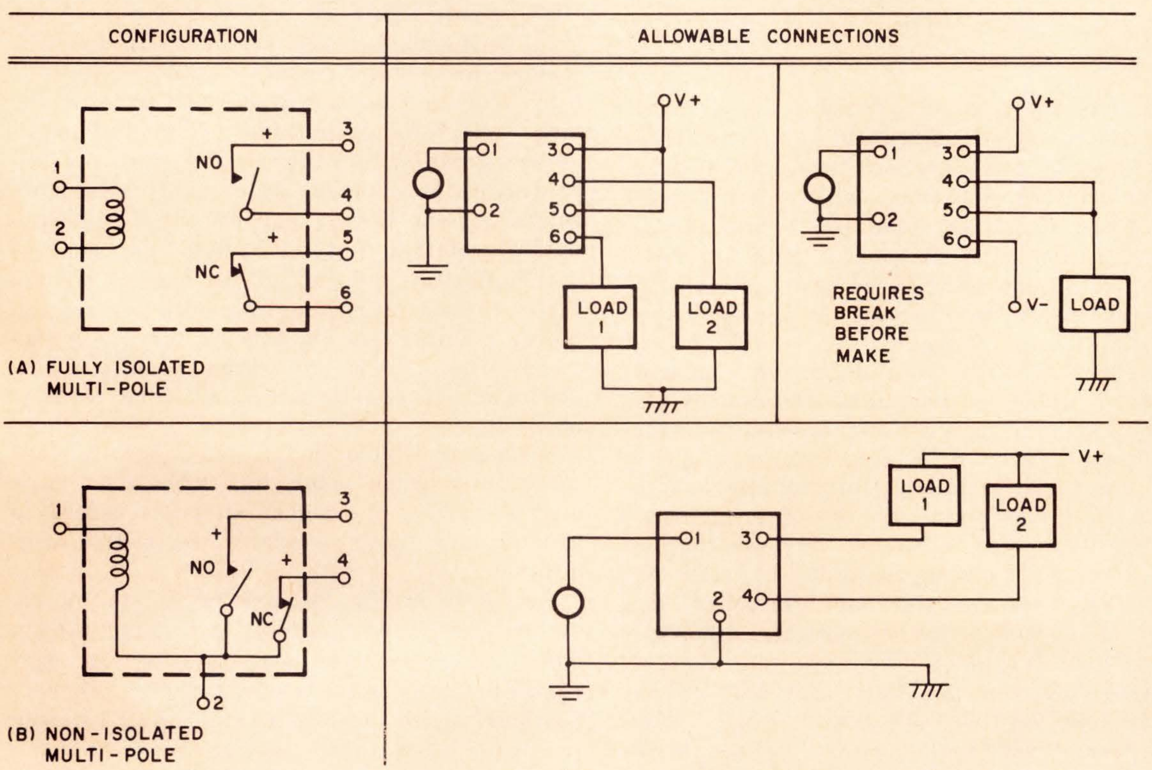

Fig. 2. Configurations for multipole, isolated and non-isolated solid-state relays.

changes in pick-up, transfer, drop-out and bounce times as well as dielectric breakdown and insulation-resistance values.

No such thing occurs with SSRs. True, "contact resistance" varies with load current, temperature, etc. But the variations are easily measurable and, most important, completely independent of load type, number of operations, etc.

The life advantage is so obvious that it's almost embarrassing to expound on it. The only area which may not be so obvious is the "condition" of the relay during its normal life. EMRs are like people. They deteriorate with age. Sooner or later they die a certain death. What is of special concern is the health of the relay during its failing life. Towards the end of its life, an electromechanical power relay normally becomes more and more bouncy.

The result is the generation of increasing rfi and shortened life for other current-carrying mechanical contacts in series with the contacts of the dying relay. Ten or 15 times as many bounces mean 10 or 15 (or more) times fewer operations of some other mechanical contacts. In addition, if the load is an arc generator, it is more likely for the contacts to weld closed. Last, but not least, as the end of life approaches, wear particles tend to distribute themselves within the relay and produce short circuits.

Now let's backtrack a bit. We've been talking about solid-state relays as if everyone knew what they were. It's time we defined them.

The name itself would lead you to believe that these devices were constructed using completely solid-state components. There are devices on the market, however, which incorporate limited-life items like reed relays and incandescent and neon light sources with semiconductors. In many instances it's difficult to determine from the literature if the device is all solid state or hybrid.

The second part of our definition concerns the word "relay." The crucial differences between a solid-state relay and a semiconductor switch (transistor, SCR, etc.) can be summed up in one word: isolation. Unfortunately, there are at least four areas where the term isolation can be applied. Some are very misleading.

We have input-output isolation—between the "coil" terminals and the load "contacts." We have pole-to-pole isolation—between different sets of load "contacts." We have open-contact isolation—between the load "contacts" when they're open. And we have circuit-to-case isolation—from "coil" and "contact" terminals to the case.

The degree of isolation can usually be specified and measured with a breakdown test, dc-leakage test and high-frequency capacitance test.

Circuit-to-case and open-contact isolation do not provide a direct clue to the definition problem since, in one case, isolation is primarily a packaging problem and, in the other case, the open-contact properties of any solid-state switching device are ultimately limited by semiconductor breakdown voltage and leakage currents.

The real key to the SSR definition lies in the feature of total input-output isolation. We can compare the isolated relay and a non-isolated semiconductor switch in parts *A* and *B* of Fig. 1. Note that with an isolated, four-terminal spst network, signal and power grounds can be kept separate, avoiding ground loops that feed noise and transients back to the signal circuitry. Further, since the output floats with respect to the input, "contacts" can be placed anywhere within the load circuit is restricted.

The block shown as "isolator" would consist of circuitry (usually proprietary) which yields total isolation, from dc to the megahertz range. There are several methods of performing this function: photon coupling, rf coupling, magnetic-field coupling, electric-field coupling, thermal coupling, stress coupling, etc.

Part *B* of Fig. 1 shows the problems inherent in a non-isolated three-terminal switch. The signal and power grounds must be common (which is prohibited in many military and aerospace systems), and placement of the "contacts" in the load circuit is restricted.

A common misconception is that the use of FETs alone can provide true isolation. A typical FET circuit (Part *B*) can isolate *one* of the input terminals, but this does not eliminate the common ground and restricted-load problems. To help clear up the confusion, let's reserve the term "relay" for devices that exhibit *full* input-output isolation, and the term "switch" for other devices. Most people who specify solid-state relays assume they're getting complete input-output isolation. But the fact is that some of the "solid-state relays" on the market are actually three-terminal devices, with control and power grounds tied together. If there is a way to keep the input isolated from the output with that kind of configuration, I'd love to hear about it.

With a multipole device, you may also need isolation between poles, but with some units on the market, one leg of all poles is tied to ground and that's a highly restrictive condition.

As shown in Fig. 2A, a fully isolated dc relay with form A and form B isolated, break-before-make contact pairs, allows the user complete freedom for a variety of circuit connections, such as switching one supply between two loads, or one load between two supplies.

At the opposite extreme from the non-isolated three-terminal devices, we find solid-state relays that are in reality five-terminal devices as in Fig. 1C. The fifth terminal usually supplies drive power to the output device or bias to a normally-closed pole. This fifth terminal may require continuous standby power. In general, if a relay manufacturer requires five terminals he should justify their use by providing significant circuit functions in addition to the basic relay function. Some manufacturers require a fifth terminal for such functions as zero-voltage switching for ac units, or supplying bias to maintain a contact pair closed. Neither really requires the additional terminal, however.

One example of a five-terminal network providing significantly more than a relay function is the solid-state power controller, which combines the isolated relay function with a remotely resettable solid-state circuit breaker and current limiter. For this application, the fifth terminal provides a source of drive power as well as power to operate the circuit-breaker and current-limiter circuitry.

Let's find out what we really need and what it really costs.

Now that we have defined the solid-state relay, we must evaluate our requirements. First, is input-output isolation required? Ninety percent of relay applications require it. If not, chances are we don't need an SSR, so we can save money and look into FET analog switches, power transistors and SCRs.

But we must check our circuits carefully. One man recently compared the cost of a simple triac circuit with that of a fully isolated solid-state ac relay. Initially, he thought he didn't really need isolation. But when he checked the complete circuit he realized that his unisolated triac circuit was controlled by a reed relay (the isolator), driven from TTL logic.

In this case, the SSR could replace, not only the triac, but also the reed relay and a hybrid relay driver. And it could provide zero-voltage switching as well, so it could easily be justified economically.

In all cases we must determine the true cost of ownership. As another example, consider the engineer who wanted to use an EMR in an office copier because an SSR costs more to purchase. But the SSR gave lamps in the copier considerably longer life because of the lack of contact bounce and zero-voltage switching. And the cost of EMR and lamp replacement over the life of the equipment wiped out the initial price advantage of the EMR.

There are many examples where the apparent price advantage of the EMR must bow before the overall advantages of the SSR. I'll cite just one more example. For a military-aircraft system, the advantages of an EMR and mechanical circuit-breaker system were compared with those of a system of solid-state power controllers and solid-state circuit breakers in one small package. The solid-state package offered 45% weight reduction, 45% volume reduction and 80% maintenance reduction. But its full advantages would have been missed in a simple part-for-part cost comparison.

The conclusion is clear. We must compare devices on the basis of complete cost of ownership. We must clearly understand what we need and what we're getting.

Mil specs can be a great help in clearing up confusion if they cover basic characteristics like pole-to-pole isolation, break-before-make switching, and zero-voltage switching.

But most remedies lie in the hands of relay manufacturers. We need truth in advertising. If they're offering a hybrid device, they should say so—clearly and unambiguously. If it does not have total input-output isolation, they should say so. Finally, they should help educate the engineering community on the when, where and how of solid-state relays. **EEE**

Who is Roy Mankovitz

Surprisingly, perhaps, Roy Mankovitz never feels out of place designing solid-state circuitry at Teledyne Relays, a company that made its name when it pioneered the TO-5 electromechanical relay eight years ago. As program manager for all solid-state relay development, applications and production, Roy is most enthusiastic about all-solid-state relays, but he also directs Teledyne's program for using ICs in TO-5 cases with tiny electromechanical relays.

Before joining Teledyne, Roy was on the technical staff of JPL, where he directed the design of many elements of the attitude-control system for the Voyager Mars spacecraft. Prior to that he was with Rocketdyne, where he developed control-system electronics for the Apollo LEM descent engine.

He has designed many advanced circuits and authored many technical papers, four of them for NASA. Like many Californians, Roy is a transplant from the East, having taken his BSEE and post-grad courses in control theory at Columbia.

In his spare time, Roy likes to swim, play tennis and beat all comers at Black Jack. He and his wife Sharon are slaving over their new home in the hills of Tarzana while they try to keep their children, Jill, 6, and Alan, 3, out of trouble.

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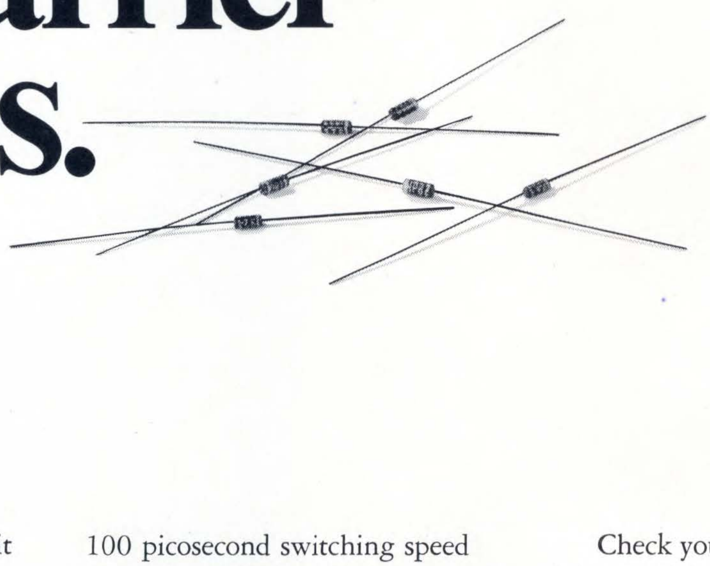

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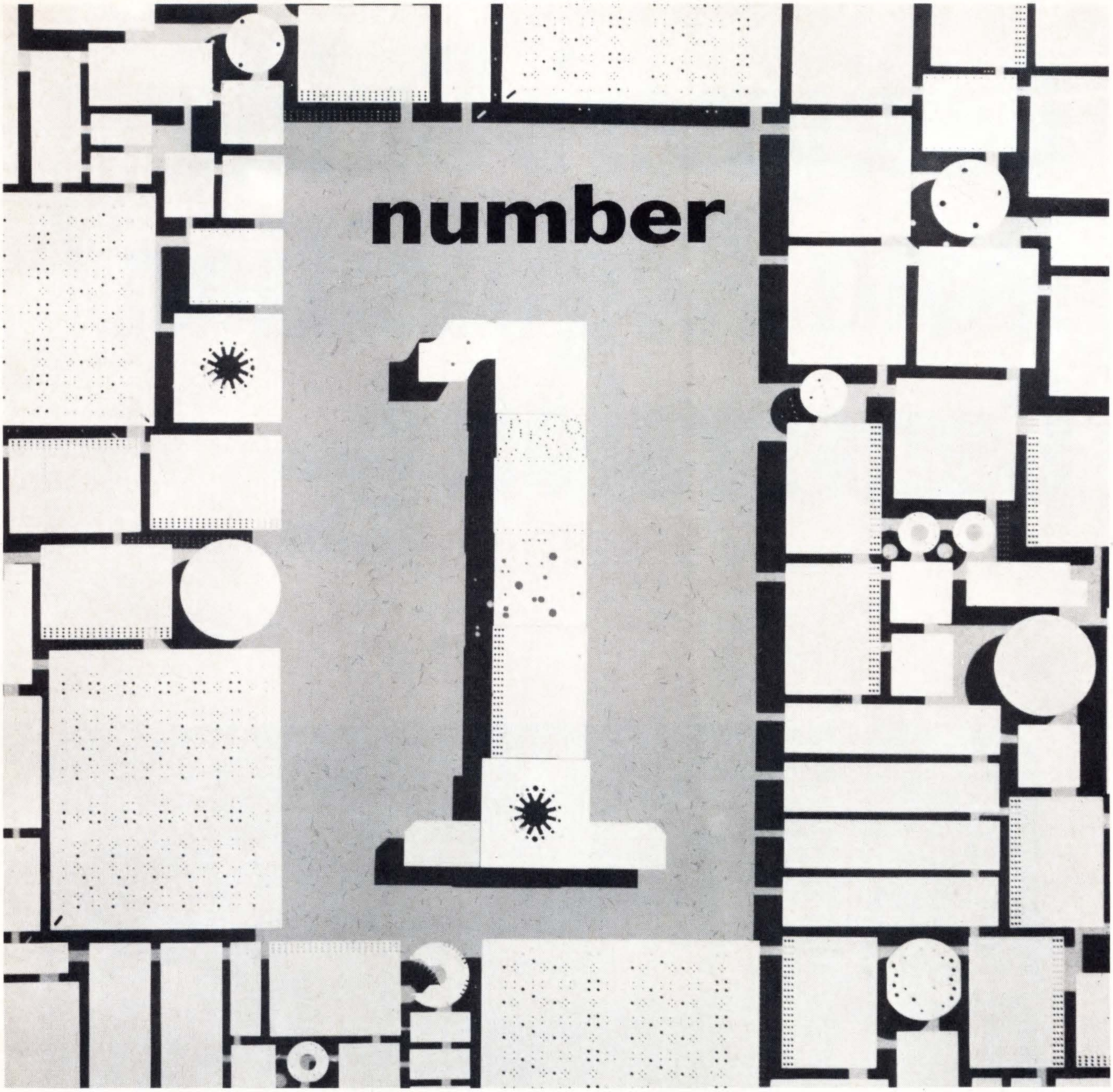

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Designer's Guide: Data Acquisition/ Conversion

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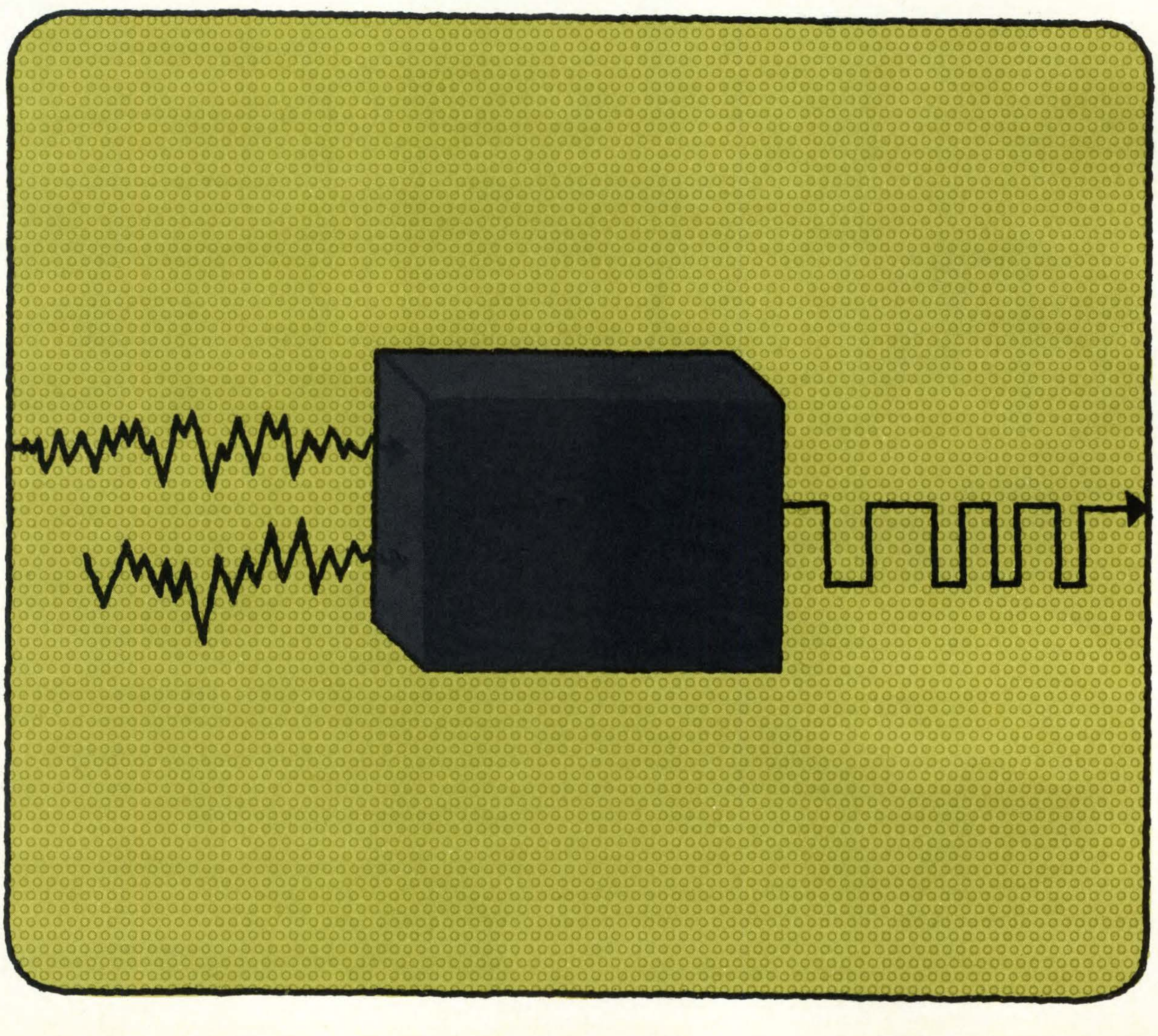

Acquisition of Shaft-Angle Data

By Jack Heaviside

The systems engineer concerned with acquiring digital angle and velocity information from rotating shafts probably has a broader array of transducers to choose from than in any other type of analog-to-digital interface system. He can select from among three basic transducer categories: shaft angle encoders, synchros, and precision potentiometers. And within each of these three broad categories there are many possible variations of transducer and interface circuitry.

The breadth of transducer choice is narrowed, however, if one specifies a particular range of industrial performance. Thus, a typical data-acquisition accuracy specification will lie in the 12-bit region, because this is about the accuracy of most of today's electromechanical systems. That is, a modern gear train or servo system will operate with an accuracy in the region of one through six minutes of arc, equivalent to approximately 0.005% to 0.025% of full scale, and hence, equivalent to roughly 12 to 14 bits of accuracy. If we confine the discussion to this 12-to-14 bit performance level, fewer transducer types meet all the accuracy, reliability, environmental, and other requirements.

The designer appears to have freedom of choice between potentiometers, shaft encoders, and resolvers (as well as synchros). However, as a practical matter, the potentiometer rarely has any advantage over synchros and encoders. And the other two categories of transducers have many factors that need to be carefully analyzed before a choice is made.

As this article will show, resolvers have an important economic advantage over encoders in multi-channel systems. This is because a single resolver/synchro-to-digital converter can be time shared between many resolver sources whereas, by contrast, a multi-channel system using encoder transducers requires one encoder for every shaft — and this is apt to be an expensive proposition at the 12-bit accuracy level.

The choice between the three basic types of transducer — potentiometers, encoders, and synchros — becomes more complex when we start to consider such factors as shaft velocity and requirements for random access to the data. Here, the engineer faces some subtle aspects of resolver-to-digital conversion that can pose problems. For example, there may be a discrepancy between the analog input and the digital output at high speeds. Thus, in some situations, dynamic errors may preclude the use of an otherwise satisfactory acquisition and conversion system.

Fig. 1 shows simplified diagrams of widely used transducers from within our three broad categories. Let's look now at these three specific types of transducer — the absolute shaft-angle encoder, the synchro, and the continuously rotating sine-cosine potentiometer.

Shaft-angle encoders

The systems designer has a choice between two types of shaft-angle encoders — incremental and absolute encoders. An incremental encoder provides an output that describes a *change* in shaft position, while an absolute encoder tells us the *actual position* of the shaft. Incremental encoders require auxiliary counting circuits to accumulate the number of incremental output pulses and thus indicate finite changes in shaft angle. The number of output pulses per revolution determines resolution. A 12-bit encoder's resolution is 5.27 arc minutes, for example, so a shaft rotation of 360 degrees will produce a total count of

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4096 least-significant-bit increments.

Since encoders tend to be used in the noisy, dirty, oily, and interference-prone environments of machine shops, aircraft, and ships, there is always a danger that a noise pulse will create a false count, and, hence, introduce random errors into the readout of shaft data. Consequently, our discussion of encoders will focus on the absolute types, which are substantially immune to noisy environments.

An encoder, as shown in Fig. 1a, consists essentially of a shaft-mounted disk having concentric rings of alternate transparent and opaque segments. Also there is a light source and a group of photocells that respond to the alternate blocking and passing of light as the disk rotates. A 12-bit encoder would generally use 12 concentric rings, with the outer (high resolution) ring providing 2^{12} pairs of transparent-opaque segments, and the inner ring divided into one opaque and one transparent semicircle. Thus, the inner ring would indicate whether the shaft was positioned between 0 and 180°, or between 180 and 360°; the second ring would specify (in conjunction with the first ring) the correct quadrant; while each additional ring would further improve the resolution by a factor of two. The outer (12th) ring would then define shaft position to one part in 2^{12}, or 5.27 arc minutes — which is less than 0.025% of full scale.

Though generally regarded as a digital device, the optical encoder is, in fact, basically an analog transducer with electronic circuitry to convert the smoothly-varying photocell output waveforms into steep-fronted "digital" pulses. Consequently, a 12-bit shaft encoder would use 12 pairs of photocells and crossover detectors to produce a square output waveform from the photocells' quasi-sinusoidal signal.

One might argue that an electromechanical sliding-brush encoder would provide a closer approximation to a true digital transducer. This is true, in principle, but we have rejected the brush-type encoder from our discussion because of its poor reliability at the 12-bit accuracy level. Also, even a brush encoder requires additional electronic circuits to preserve true and meaningful output as the brushes change from one set of contacts to another. While a Gray-code converter (either optical or contact type) produces no ambiguity when changing codes, the straight binary converter has many bits changing simultaneously at some of the major carry points (like going from 100000000000 to 011111111111 or vice-versa). Therefore if one used a brush-type encoder to produce a straight binary code, mechanical imperfections could prevent all the bits from changing simultaneously.

Admittedly, one can overcome many of the limitations of encoders by adding electronic circuits to sort out the various delays between each bit's changeover, and to transmit pulses that have all bits changing in unison. But the addition of complex logic and pulse shaping circuits will inevitably cause worsened reliability and serviceability.

Resolvers and synchros

The resolver and its close cousin the synchro (Fig. 1b) are among the industry's most reliable and widely-used rotary transducers. These devices have benefited from more than a quarter-century of continuous development and refinement, and they have a proven performance record.

Both devices are essentially rotary transformers (with all the reliability and immunity to aging and temperature variation that this implies) with combinations of rotating and fixed windings. The secondaries are usually wound on the stator's magnetic core, such that they give the effect of individual windings located at 90° intervals (for the resolver) or 120° intervals (for the synchro), around the stator. The primary is wound on the rotor and it sets up a rotating pattern of magnetic coupling as the shaft turns.

Rotation of the shaft and its primary winding induces variable signals into the multiple secondaries, leading to shaft angle being accurately defined in terms of the ratio of secondary instantaneous voltages. For the resolver with just two secondaries, shaft angle θ is $\tan^{-1}(V_1/V_2)$, where V_1 and V_2 are the instantaneous secondary values. Synchro transducers are interrogated in a similar way, but usually their output data is converted by Scott-Tee or equivalent networks into resolver form for ease in subsequent digitizing.

Because the resolver/synchro family develops analog output information, (and ac signals at that) fairly complex electronic equipment is required to convert the analog data into equivalent digital values.

Precision potentiometers

The simplest precision pot is the multi-turn high-resolution type. Unfortunately, this device is rather limited for general-purpose shaft-angle-readout applications. It can turn only through 3600 degrees, or less, before running into the mechanical stops. Thus, continuously-rotating pots are necessary for most readout applications.

There still remain, however, a remarkable number of pots to choose from, even though we have ruled out the multi-turn variety. Among the types available are the following: capacitively-coupled types that can offer very low friction; magnetic versions that can also offer low friction; and sine-cosine pots that can eliminate position and direction ambiguity.

One fairly popular type of precision pot is illustrated in Fig. 1c — namely the sine/cosine potentiometer. This device can be regarded as a dc analog of the resolver transducer, and it is widely used for many of the

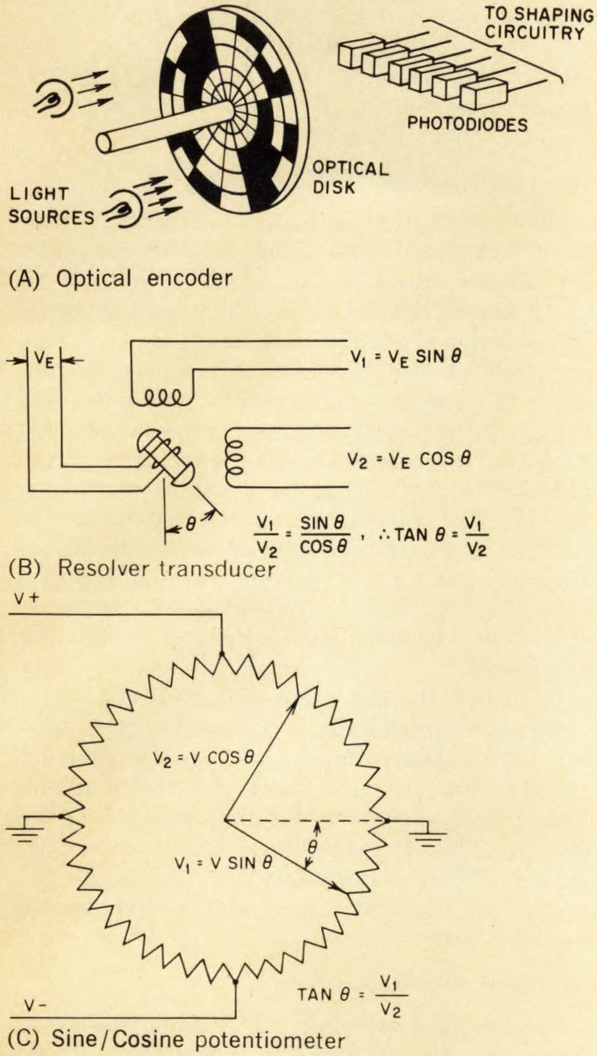


Fig. 1. Three popular types of transducers for shaft-angle measurement.

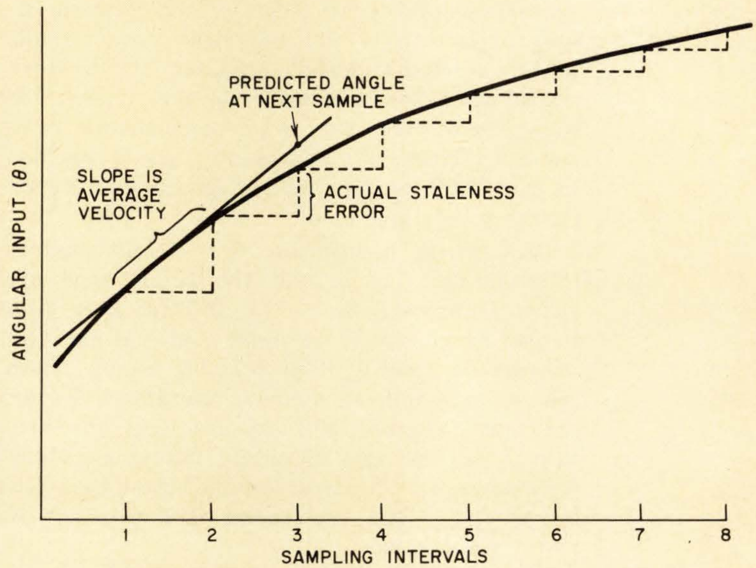


Fig. 2. The apparent staleness error of a sampling-type converter can be decreased by using prediction techniques. Circuits compute shaft angle by extrapolating from the average velocity of the previous two sampled readings. Accuracy can be further improved by using historical acceleration data to modify the prediction.

same reasons as the resolver. For example, it provides direction sensitivity, and is considerably less costly than either the capacitively or magnetically-coupled alternatives. On the other hand, it offers considerably more resistance to motion than do any of the other rotary transducers considered here.

Performance comparisons

We've already looked at some of the basic advantages and disadvantages of each type of transducer. Let's now review the performance and cost of each type in a practical digital data-acquisition system. In other words, we must consider the resolver used in conjunction with a resolver/synchro-to-digital converter; and, likewise, we must examine the performance of precision potentiometers used with an appropriate digitizer.

Introduction of the necessary external conversion circuitry (entirely separate from the basic transducer in the case of the resolver/synchro and potentiometer categories) brings with it another set of advantages and disadvantages, as we shall see.

Speed capability

The shaft-angle encoder inherently provides better dynamic performance than either its synchro or precision-potentiometer rivals. This is because the absolute encoder's digital output is read directly from the shaft-mounted multi-ring disk. By contrast, both the resolver/synchro and potentiometer families produce digital output readings by processing the transducer's analog data. Consequently, a certain "staleness" or lag exists between actual shaft angle and the converted digital value.

All converters take a finite time to digitize analog data, so one can expect some deterioration in up-to-dateness as potentiometer or resolver shaft speed increases. (A fixed conversion period implies an increasing percentage error as shaft speed rises.)

Resolution

Resolution of a shaft-angle encoder is established by its basic mechanical design — that is, by the number of opaque-transparent segments in the outer high-resolution disk. With a potentiometer, resolution is also fixed — this time by the resistance wire diameter, or wire-to-wire spacing.

The resolver, however, is virtually an infinite resolution device — resolution of its digital output data depends upon the conversion electronics, rather than on the transducer itself. Consequently, systems using resolver or synchro transducers can be upgraded by improving the conversion equipment, instead of by altering the basic transducer.

Static accuracy

Static accuracy, in terms of the relation between shaft angle and electrical output, tends to be a definite design property of all three transducer types (whereas resolution is not). For the purposes of the price/performance comparison table in this article, accuracy is specified in the 12-bit region, where definite price comparisons are available.

It is worth mentioning that potentiometers offering accuracy beyond the 12-bit level are virtually unavailable — or at least they tend to get so costly as to make some alternative transducer type a more sensible choice. Both the encoder and the synchro families however, are manufactured with accuracy in the arc-second region, and magnetic inductosyns can provide resolution considerably better than one arc-second. (One arc-second is equivalent to 20-bit resolution).

Mechanical reliability

Owing to wear of its sliding contacts, the precision potentiometer is definitely the least reliable of the three basic transducer types considered here. Even if the device doesn't fail catastrophically, the high (and variable) contact resistance that results from wear can create erroneous angle readings.

The synchro, too, relies on slip rings for its primary excitation (except in modern versions that use magnetic coupling to excite the primary winding). But slip-ring wear, has never been a cause of serious malfunction. This is primarily because the resolver or synchro's electrical output is defined by the *ratio* of its independent secondary voltages, not by any absolute output value that could be distorted by slip-ring resistance. Testimony to the reliability of conventional synchros — with rotor-excitation slip rings — is provided by the infrequency with which magnetically-excited synchros or resolvers are used.

To a certain extent, the synchro or resolver's highly inductive nature contributes to self repair of the slip rings. Any intermittent fault or open circuit tends to be cleaned by the sparking action that it produces.

Encoders have historically proven unreliable owing to the relatively short life of their light sources. If the lamp is easily replaced, this may not be serious. However, mechanical transducers tend to be used in precisely those applications where maintenance is difficult.

Modern encoder designs based on solid-state light sources can solve the lamp replacement problem — albeit at rather high cost. But modern encoders still have complex circuitry, which remains in its inaccessible location within the encoder housing.

Electronics reliability

The electronic equipment associated with resolver/synchro and precision potentiometer transducers can be conveniently located in an air-conditioned room, and it is usually housed in easily accessible equipment racks. Thus, any failures can be easily corrected. By contrast, the encoder's conversion electronics are usually housed within the transducer casing to minimize the distance over which the weak photocell signals must be transmitted. Consequently, the encoder's electronic circuitry is exposed to an arduous span of environment and climate, ranging from the oil and cutting fluid of a machine shop to the salt-spray, humidity, and wide temperature range of shipborne equipment.

In future, the use of medium and large-scale integration of electronic circuits (MSI & LSI) can be expected to favor the use of resolvers and synchros, over shaft encoders, since servicing of the conversion circuitry will be carried out on a throw-away basis. Encoders are an entirely different proposition — throwaway circuitry won't help if the encoder is inaccessible to begin with.

Installation complexities

An absolute encoder with 12-bit resolution needs at least 13 wires to convey the digital data from the rotating member to the digital acquisition equipment. And, since the circuitry and light sources inside the encoder draw power, at least one extra wire is required.

Potentiometers and resolver synchro families operate with considerably fewer cables. And the number of wires — usually 5 or 6 — does not depend on resolution. This can be an important factor if slip rings are interposed in the signal path (as occurs with radar azimuth and bearing antennas, for example).

In fact, the cost of multiple-channel coaxial cables for high-speed encoder data, plus the cost of installing these cables, can exceed the cost of the encoder itself. Synchro and potentiometer wiring is less demanding, firstly because fewer conductors (and slip-rings) are involved, and, secondly, because the nature of the data doesn't require high-quality cable. That is, ordinary shielded conductors will suffice for synchro data, compared with high-quality coaxial cable for a 12-bit encoder.

Transmission errors

A resistive sine/cosine potentiometer is inherently a variable-impedance signal source. Typically the impedance lies in the range 5,000 to 50,000 ohms. This range results from com-

Tracking-type resolver-to-digital converters

A tracking converter updates its digital output whenever the analog input changes by one LSB. Therefore, this type of converter normally introduces only minimal delays in the updating process.

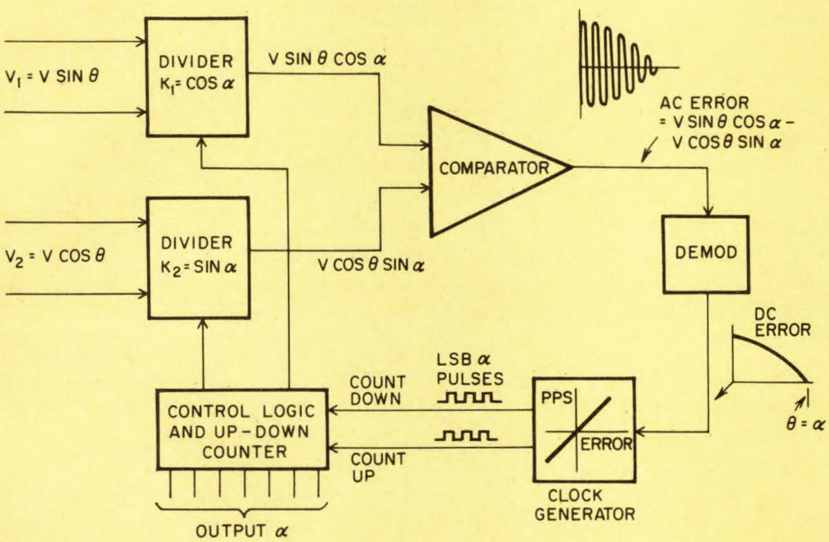
In operation, the converter automatically adjusts a pair of trigonometrically-tapped dividers so that a null is eventually achieved. Until the outputs from the dividers become equal, the resulting error signal continuously updates a clock generator which, in turn, moves the dividers towards a balance. Thus ratios K_1 and K_2 are updated to make $K_1V \sin \theta$ equal to $K_2V \cos \theta$ (where $K_1 = \cos \alpha$ and $K_2 = \sin \alpha$). Then, at null,

$$\frac{\sin \alpha}{\cos \alpha} = \frac{\sin \theta}{\cos \theta}$$

therefore, $\alpha = \theta$

If the converter is designed for a resolution of 0.01 degrees, then a 180-degree input step will require 180 × 100 LSB updating pulses to adjust the divider circuits to a new null. This is why tracking converters have initial requisition times of around 10 to 30 milliseconds. However, once the converter has locked onto the input data, updating occurs within a few microseconds following an LSB change in input data.

At high data velocities, the digital output will lag the analog input by an error amount that continuously updates the divider ratios. The faster the dividers must update, the longer the error voltage will be. With good commercially available tracking converters, however, the velocity lag is negligible at moderate speeds. The error (shaft velocity/velocity constant) is only 0.0005 degrees for 100 degree/second data, with a velocity constant k_v of 200,000, which is typical of today's tracking converters.



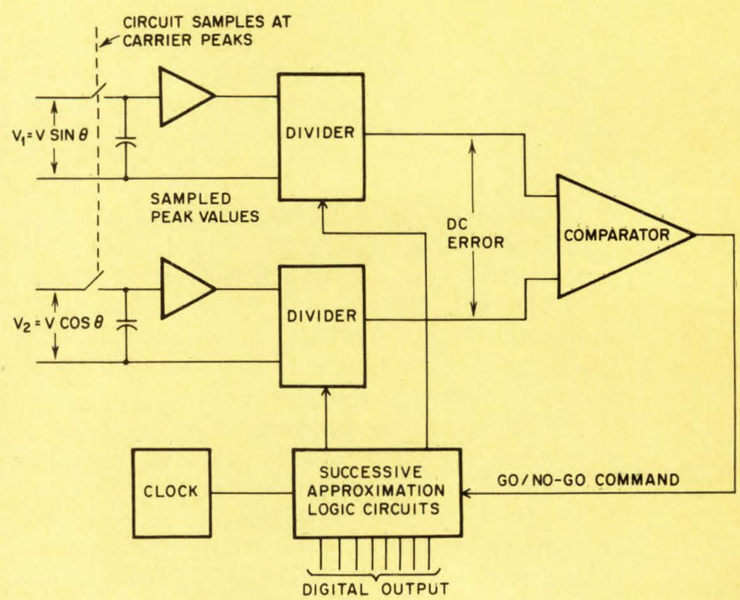
Sampling-type resolver-to-digital converters

A sampling converter must wait for peak values of the resolver ac carrier before it can sample V_1 and V_2. But, once the samples are acquired, the converter operates on a dc (rather than ac) basis, allowing rapid conversion.

Typically, this type of converter can complete its successive-approximation conversions, starting at the MSB and working down, within about 50 microseconds. This contrasts with tracking-type converters which update by only one LSB increment at a time.

Sampling converters, however, are vulnerable to errors caused by noise and harmonics on the data lines, hence they cannot attain the accuracy levels provided by tracking converters—whose demodulation circuits automatically reject noise and harmonics. In spite of their noise susceptibility, however, it is possible to achieve up to 12-bit accuracy with sampling-type converters.

With sampling converters, data staleness is the major factor limiting accuracy in multi-channel systems. But it is possible to include prediction circuits that process earlier data samples to estimate the shaft angle at the next sample. This method, especially if acceleration is computed together with velocity, can often reduce the effects of data-staleness errors and make sampling converters competitive with tracking converters in real-time systems.



promises in mechanical design, involving turn-to-turn resolution and wear-resistance of the resistance wire. As the potentiometer's wiper turns, the output resistance varies with it — from zero resistance at either extreme of the winding, to maximum halfway between the stops. Thus, accuracy of the output data will depend upon the actual shaft position, and the degree of error will depend, also, on the input circuit of the converter.

Resolvers and synchros have inherently low output resistance because of their transformer action, so they don't produce angle-dependent errors. The digital shaft encoder's output impedance is actually defined by its built-in electronic circuitry; but, in any event, accuracy of the output digital data is largely independent of output impedance.

An ordinary (not sine-cosine) potentiometer's output accuracy depends, also, upon stability of its dc excitation. This situation doesn't occur with the synchro family or with sine/cosine potentiometers because information is conveyed by the ratio of outputs, not *absolute* output. Hence these devices are relatively unaffected by line-voltage variations. The encoder, too, is relatively immune to supply voltage variations — except that variations may affect the electronic circuitry's ability to switch accurately at zero-crossing values of photocell output signal.

Noise on the analog data lines from resolver/synchro and potentiometer transducers can be removed by filters at the converter input. Or one can use phase-sensitive detection and similar methods to minimize noise. The absolute encoder's output is, similarly, immune to noise. However, the incremental encoder is particularly vulnerable to noise spikes, since, for example, firing of heavy-current SCR devices could create false pulse counts that create erroneous digital totals.

Conversion time

With dc transducers, such as precision pots, one normally uses a conventional analog-to-digital converter to produce a digital output. Commercially-available A/D converters can complete a 12-bit conversion within 50 microseconds.

Optical encoders are usually extremely fast, and, of course, they don't need external A/D converters. The conversion time of an optical encoder delivering parallel data might typically be nanoseconds — with some allowance for the storage circuits that hold data until all "bits" can be changed simultaneously.

With synchros and resolvers, however, it becomes more difficult to figure out the time delays that will occur during conversion of the analog signals to digital form. Basically, there are two approaches to resolver/synchro-to-digital conversion — namely, sampling and tracking. Each of these two methods produces different types of dynamic errors.

Sampling systems require the data to be digitized only at the positive or negative peaks of the ac-carrier waveform (for maximum accuracy and rejection of quadrature) thus incurring "waiting time" or staleness between successive peaks. Once the next carrier peak voltage occurs, however, the actual conversion process can be carried out in a matter of 50 microseconds or so.

Tracking-type synchro-to-digital converters digitize the analog data continuously, so that there is no "staleness" error, but merely a small dynamic lag at high speed caused by the circuit's need for a finite error between analog input and digital output. Though the tracking converter incurs a minimal updating time of about 5 microseconds, it does initially require 10 to 30 milliseconds to acquire the data.

Staleness considerations

It is worth considering the sampling converter's staleness error in some detail, since, by understanding this deficiency, the techniques for minimizing it can be appreciated. The problem arises because, for example, a 400-hertz resolver excitation provides only two voltage peaks per cycle, or a maximum sampling rate of 800 samples/second. Thus, if the shaft happens to be turning rapidly, the latest data soon becomes increasingly stale.

For example, consider a shaft turning at 100 degrees per second (18-1/3 rev/min), and generating 400-hertz resolver data. Since the data can only be sampled once every 1/800 seconds, the shaft will turn through $100° \times 1/800 = 0.125°$ between samples. Thus there is a discrepancy of 7.5 minutes of arc between the actual shaft position and the position represented by the digital output. This error is larger than the least significant bit of a 12-bit conversion system (5.28 arc seconds). Consequently, it is easy to see why there are velocity-versus-accuracy tradeoffs involved in digitizing resolver/synchro data with sampling-type converters.

Tracking technique

Because a tracking converter follows the analog data continuously, updating within about 5 microseconds for every LSB change in input angle, there is negligible staleness between analog input and digital output. Actual discrepancy will depend upon the converter's inherent accuracy, rather than upon the problem of waiting for the next carrier half-cycle.

At higher data velocity, however, we encounter a new kind of lag between the analog input and digitally-converted output of tracking-type converters. This lag is caused by the converter's need for an internal error voltage (proportional to the input-output difference) to drive the conversion circuitry. Usually, this "velocity lag" is expressed in terms of a velocity constant, k_v, which describes the velocity lag as $\Delta\theta =$ data velocity$/k_v$. For modern con-

Price/performance comparisons for various shaft-data acquisition systems

(Prices and sizes are ballpark values only. Cost of multiplexing hardware is not included. Systems are compared at 12-bit accuracy level)

TRANSDUCER TYPE	TRANSDUCER SIZE	TRANSDUCER COST	CONVERTER COST	SINGLE-CHANNEL COST	TEN-CHANNEL COST	CABLES REQUIRED	ERROR SOURCES	RELIABILITY & MAINTAINABILITY
POTENTIOMETER								
0.025% continuous rotation	1-in. dia. 2-in. long	$100	$750 (scaled analog-to-digits)	$850	$1,750 (multiplexed)	3	line drop, contact wear, variable source resistance.	poor
0.025% sine/cosine	4-in. dia. 2-in. long	$200	$1500 (scaled analog-to-digits)	$1700	$3,500 (multiplexed)	4 to 6	contact wear, variable source resistance.	poor
SYNCHRO/RESOLVER								
5 arc-min synchro	1-in. dia. 2-in. long	$25	$1200 (synchro-to-digits)	$1,250	$1,450 (multiplexed) $12,250 (non-multi-plexed)	5 to 6	harmonics, quadrature.	good
SHAFT ENCODER								
12-bit incremental	4-in. dia. 2-in. long	$300	$400 (up-down counter)	$700	$3,400 (multiplexed)	3 to 4	noise spikes.	fair
12-bit	4-in. dia.	$1200	none (may require gray-to-binary converter)	$1,200	$12,000 (multiplexed)	14 to 15	excellent error immunity.	fair

verters (with k_v = 100,000 to 1,000,000) this source of error is negligible. For example, the lag between digital output and analog input for a tracking converter with $k_v = 200{,}000$, and handling input data of 100° per second, would be $100°/200{,}000 = 0.0005°$.

In short, the tracking converter's dynamic performance virtually matches that of the shaft-angle encoder, with the exception that the tracking converter requires an initial 10 to 30 milliseconds to acquire the input data.

Conversion auxiliaries

Often, the acquisition system's specific function will require the data to be manipulated in a variety of ways, above and beyond the mere production of digital values.

Because the digital output code developed by a resolver/syncho-to-digital converter can be designed for whatever the application demands, this data-acquisition method is extremely versatile. The same is generally true of potentiometer-to-digital conversion, although dc sine/cosine-to-digital conversion hardware is manufactured by very few firms, and, hence, tends to be costly.

With the shaft-angle encoder, however, the output code is fixed. Therefore, this type of transducer frequently requires an auxiliary electronic "stunt box" to change its digital output into the format required by a given acquisition system. For example, a BCD format might be required for visual display, while offset binary code might be required for data processing. Thus, the encoder is not always the self-contained digital transducer that it appears to be. And, of course, cost of the code-conversion unit must be added to the encoder cost.

But by contrast, a resolver/synchro-to-digital or potentiometer-to-digital converter can quite routinely be custom-modified to provide a variety of output options.

Single channel cost

As shown in the price/performance comparison table, resolvers and synchros are by far the least-costly basic transducers. Potentiometers are relatively expensive because 12-bit (0.025% accuracy) pushes the state of the potentiometer art. Shaft encoders are most costly of all, owing to their complex construction and built-in pulse-shaping electronics.

If one considers the overall system (still adhering to 12-bit single-channel operation) then the table shows that potentiometers are the most costly and least effective acquisition method. Shaft encoders, and resolver/synchro conversion systems, fall into a common price ballpark, because the required conversion equipment raises overall resolver/synchro channel price to the encoder price level.

Multi-channel interfacing

Owing to the relatively high cost of multiple encoders, it is often considerably more economical to use synchro transducers to generate basic shaft-position data from a multi-axis machine, and then to multiplex the various analog sources into a single resolver/synchro-to-digital converter.

However, multiplexing is not universally applicable. For example, if a system designer is confronted with an installation involving an array of synchro sources, it may be that his accuracy requirements (say 14-bit) demand a synchro-to-digital converter for every channel. This is obviously more costly than a single common multiplexed converter.

Multiplexing with sampling converters

The sampling converter is potentially the most economical method for digitizing shaft data from several sources. However, to exploit the basic economies of the technique, the system designer needs considerable skill. This is because the sampling converter suffers from data-staleness errors, and subtle design techniques are required to overcome this limitation.

Earlier, we saw that a sampling converter handling a 400-hertz source (i.e., 800 samples per second), produces a 7.5 arc-minute data staleness error when digitizing 100°/second shaft data. Now we must examine the techniques used to minimize this seemingly inescapable error.

Multiplexing worsens the overall staleness errors in a sampling-converter system by reducing the rate at which samples can be acquired. For example, in a 10-channel multiplexed sampling system, each resolver interface must wait for ten half cycles (instead of one), before it is re-sampled and its digital value updated. Staleness for a 100° per-second system excited at 400 hertz now rises to $100°/80 = 1.25°$. This corresponds to an accuracy level of 8 to 9 bits. If 8 to 9 bits accuracy is acceptable, then no further complications arise. And, of course, if the system involves ten shafts travelling no faster than 10°/second (as might occur in a nuclear-reactor's rod-positioning system) staleness errors drop tenfold, elevating accuracy proportionately.

It is possible, however, to raise the accuracy of a multiplexed sampling system by using sample-and-hold circuits for every data channel (rather than a single sample-and-hold that acquires data from different sources in succession) to cut down the waiting time. In this arrangement, all sampling circuits acquire data from their associated sources once per carrier peak. Then a high-speed converter switches sequentially between the different sets of stored data. A high-speed arrangement like this can digitize ten sets of sampled data every carrier peak, instead of waiting for ten carrier peaks. With this arrangement, data staleness for the multi-channel system is the same as for the single-channel digitizing arrangement.

Another method of decreasing the staleness error is the prediction technique illustrated in Fig. 2. This scheme involves computation circuits that continuously estimate the shaft angle, based on past history of the shaft's velocity. Thus, the two previous readings give an indication of average shaft velocity between the sampled intervals, enabling the system to estimate where the shaft will be when the next sample is obtained. If the prediction circuitry also takes shaft acceleration or deceleration into account, accuracy is further enhanced. Fig. 2 shows how simple velocity averaging leads to a predicted shaft angle with an error less than the staleness that arises without the prediction. In this way ,the computer or other equipment can be kept informed of the shaft's approximate position between samples.

Multi-channel tracking

As we saw earlier, the speed and accuracy requirements of a multi-channel interface system may make multiplexing of a single converter undesirable. And the staleness errors of sampling converters may be unacceptable. For high-accuracy applications, then, the system designer may be forced to choose between using individual shaft encoders or a tracking converter for each shaft. Use of several independent tracking converters isn't necessarily as expensive as it sounds, however. For example, it is possible to share some of the multi-channel tracking converter's circuitry between several signal sources, thereby reducing hardware cost.

Because of the subtlety of some of the trade-offs involved in an accurate multi-channel system, the system designer is urged to discuss his problem with manufacturers of encoders and converters before making any irrevocable decisions. **EEE**

Low-Level Multiplexing for Data-Acquisition Systems

by David C. Yoder

Today's high-speed industrial processes and space-related programs require very precise techniques for monitoring and controlling the many parameters involved. Digital computers can provide the precision required to perform the data reduction if the acquired data is digital in nature. However, the most common type of input data signal is a voltage analog of some physical phenomenon — temperature, stress, strain, force, etc. The range of this type of analog signal tends to be quite low, from around 5 millivolts full scale to an upper limit of approximately 500 millivolts full scale.

Low-level signal handling generally requires differential-input equipment — with high input impedance to preserve the integrity of the input signal, and good common-mode rejection to cope with the electrical noise commonly associated with typical installations. Cabling, from signal-producing transducer to the instrumentation equipment, requires careful installation, and is usually shielded.

The system component most commonly used for acquiring analog data from transducers is the low-level multiplexer. A low-level multiplexer can be defined as a signal-scanning unit in which the low-level input signals are sequentially switched into a common amplifier that performs several functions. The amplifier converts the input signal from differential to single-ended, provides the gain required to establish the desired output level, and provides a low-impedance output to drive the equipment that follows — usually an analog-to-digital converter. (Note that multiplexers with individual preamplifiers on each input channel are fundamentally different from the low-level multiplexers discussed here.)

Historical overview

A brief historical discussion of the instrumentation field may provide a better understanding of the need for low-level multiplexing techniques and of the various methods currently being implemented.

In the late 1940's and early 1950's most instrumentation systems used some form of graphic recording. Strip chart recorders and oscillographs were commonly used, and data reduction was frequently accomplished by inspection. Rulers and planimeters were common data-reduction tools.

In the late 1950's, digital computers became widely available for data reduction. Computers made it possible to rapidly reduce data in vast quantities that would have been impossible with the earlier hand methods.

To prepare raw data for computer entry, many digitizing methods were developed. Some of these methods still used graphic recorders as the recording media, with subsequent mechanical (or manual) digitizing. But these techniques soon became too cumbersome for the volume of data being handled, and efforts to directly acquire instrumentation data in digital form received a great deal of attention from both government and industry. This was the birth of the market for data-acquisition systems.

Let's look now at some of the requirements of data-gathering systems. First we will examine the quality of signals that we must deal with. Many widely used transducers generate extremely feeble electrical signals.

For accurate physical measurements, we can obviously use a high-quality amplifier on each input channel, thus preserving and protecting the integrity of the measured variable. This approach was used in most early data acquisition systems, but because the input amplifiers were difficult to design, they tended to be very expensive.

Since a digital computer can handle only one operation at a time, multiple inputs must be time-shared. But the high cost of instrumentation amplifiers makes it very attractive to also time-share a single amplifier instead of using individual amplifiers for each transducer — hence the need for low-level multiplexers.

Older multiplexing methods

For those applications where measurements

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need to be made only at very low rates, mechanical multiplexing methods have been explored and have proven quite successful. Crossbar scanners, relays and specially constructed mechanical choppers have all been used with excellent results in low-frequency systems.

The design of a satisfactory electronic low-level switch has proved more difficult however. Diode bridges, early alloy transistors, photo resistors, and even neon lamps were all tried in the early days of data-acquisition systems. For various reasons each of these approaches was found to be unsatisfactory.

One circuit that showed early promise was the Bright switch. And, in fact, this approach was used in some of the first truly successful attempts to multiplex low-level wideband signals. In the late 1950's, availability of bipolar transistors with closely matched base-emitter voltage temperature coefficients finally allowed the design of low-level multiplexers that could rival the performance of medium-priced instrumentation amplifiers. As a result of government sponsorship, most of the early electronic multiplexers appeared in instrumentation related to the missile and space programs.

Typical instrumentation problem

To illustrate some of the problems involved in data acquisition, let's examine a fairly typical instrumentation requirement as illustrated in Fig. 1. The temperature of the liquid in the tank is the variable to be measured. A thermocouple is used as the transducer. The temperature of the liquid ranges from 0°C to 100°C, resulting in a total output voltage change from the transducer of about 5 millivolts, or approximately 50 microvolts/degree C.

To insure intimate connection of the thermocouple to the liquid, the transducer is welded to the tank. Use of thin thermocouple wire insures that no significant thermal sink is generated by its attachment. The reference junction (which provides the transition from the thermocouple metals to copper wire, and establishes the temperature reference point) is located centrally and the shielded thermocouple lead wires are routed to this central location.

Let's assume for the moment that we have a perfect measurement system and that we need consider only the errors produced by the source and its environment. The system shown in Fig. 1 is assumed to measure perfectly the voltage between the two lines without any effect on the lines. The reference junction is assumed to be completely isolated.

With a constant temperature in the tank, the value of E_s is fixed. Note that no dc error can exist since, with the hypothetically perfect measurement system, no path exists for dc current to flow. In a practical installation, some leakage may exist, causing small errors, but these errors are normally negligible. If there were no fields present to cause induced voltages on the signal lines, and if no difference of potential existed between earth-ground *1* and earth-ground *2*, the illustrated measurement would be nearly perfect.

Common-mode noise

The real world, however, is saturated with electrical fields, and large currents flow within the earth itself. If these impinging fields cause induced voltages that are exactly equal in each signal line, or if a voltage exists between earth-ground *1* and earth-ground *2*, a common-mode or longitudinal stray is said to be present. These factors in themselves, however, will not cause errors in our hypothetically perfect system, since all such induced errors will completely cancel out.

Unfortunately, several mechanisms exist for the conversion of common-mode voltages into differential voltages (transverse strays). Each common-mode generator will cause current to flow down its line, through the source impedance, and back through the earth. These currents (unless some remarkable coincidence intervenes) will cause voltage drops in the source impedance that do not perfectly cancel. The result is a noise signal superimposed on E_s. In practical installations, this noise signal may be many times the amplitude of E_s.

Fortunately, common-mode noise signals are usually widely separated in the frequency domain. Except in unusual cases, the impinging fields, and the voltage drops in the earth, are generally concentrated at local power-line frequencies and harmonically related higher frequencies. If very-low-frequency data are being acquired, noise frequencies can be removed quite nicely by filtering or averaging. Averaging techniques do, however, place some additional demands on the dynamic range of the system.

Another error source can occur if the two sides of the signal lines are allowed to become separated, even slightly. This will result in an induced differential voltage. The use of twisted pair originates from this fact, though the twisting is far less important than keeping the signal lines close together. Again, this type of error can be eliminated by filtering or averaging, if the data bandwidth permits.

Shielding and guarding

If the data bandwidth is high, the "guard-shield" approach to error reduction has much merit. This approach involves shielding the input and driving the shield from some point that causes no current flow in the unbalanced source impedance. Fig. 2 illustrates a typical method used. Since the shield is "driven" from the common-mode voltage, the designer's primary concern is to reduce the "unguarded" capacity that results from imperfect shielding.

With our hypothetically perfect measurement system, and with a perfectly guarded input line, no common-mode to differential conversion would occur. Therefore, the differential signal would be without error. But perfect measure-

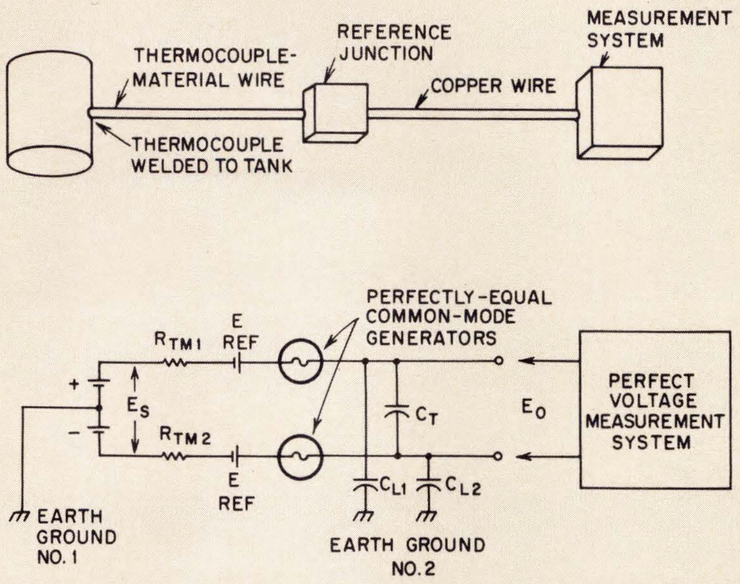

Fig. 1. Schematic (top) and equivalent circuit (below) of a hypothetically perfect temperature-measurement system using a welded thermocouple.

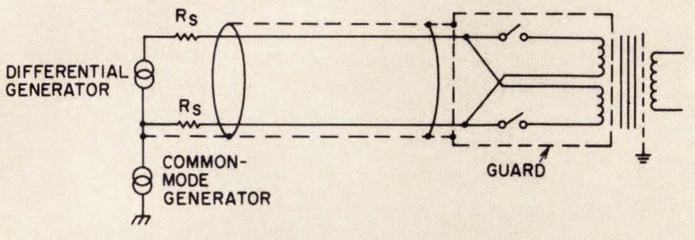

Fig. 2. Guard-shield approach for minimizing common-mode noise.

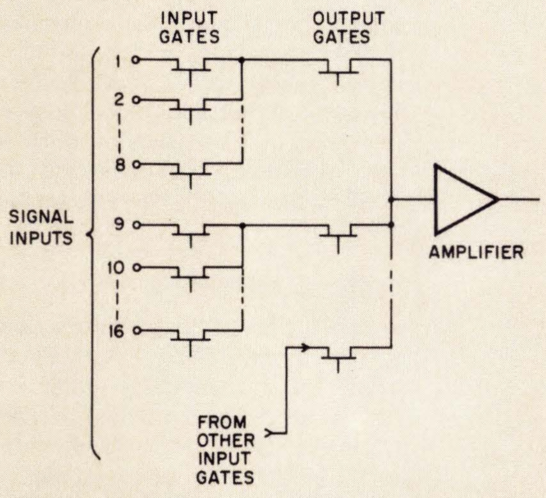

Fig. 3. Simplified schematic of direct-coupled multiplexer.

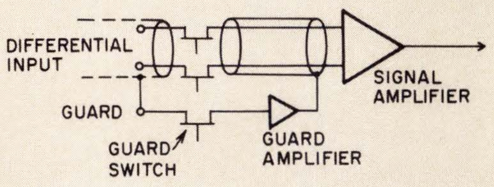

Fig. 4. Switched guard shield for direct-coupled multiplexer.

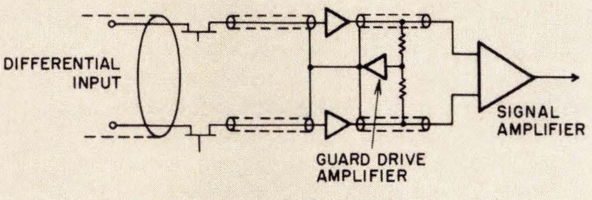

Fig. 5. Guard signal derived from signal lines.

TABLE 1. State-of-the-art performance of low-level multiplexers

Error Source	Specification
noise	5-μV pk at three sigma
zero drift	random: less than 5 μV/day tempco: less than 0.2 μV/°C
common-mode rejection	better than 120 dB (1 million:1 rejection ratio) from dc to 60 Hz with 1000-Ω source unbalance
input loading	less than 0.01% with 1000-Ω source at normal sample rates
feedback current	less than 10 nA at normal sample rates

ment systems do not exist, and it is very difficult to maintain low unguarded capacity. The input to the system is not normally perfectly shielded and floating. The guard-shield configuration at the system end normally does not degrade the input signal more than the unguarded capacity outside the system.

As an example, note that 3 picofarads of unguarded capacity on each line, coupled with a 1000-ohm unbalance in the source, would cause 1 microvolt of differential error signal per volt of 60-hertz common mode voltage. This results in a system that can boast 120-db common-mode rejection with a 1000-ohm unbalance. (Note, however, that common-mode rejection specifications are meaningless without the source-unbalance value specified, and in many cases are not a real indication of the relative errors that may be experienced in a practical installation.)

Our discussion, so far, should have provided some insight into typical problems involved in low-level signal handling. We've considered only one type of transducer, but though the details are different, the problems associated with other types of transducers are of similar magnitude.

Modern multiplexing methods

There are really just two basically different low-level multiplexing methods that are widely used. The two methods differ primarily in the degree of isolation that is provided between channels. The first method will be referred to as "direct-coupled multiplexing" since the input channels are switched directly to an output bus. The second method uses a floating-input arrangement and will be referred to as "transformer-coupled multiplexing."

The direct-coupled multiplexer is shown in simplified form in Fig. 3. Several input channels (usually 8 or 16) are switched onto a common output bus, which is then connected by an output switch to the amplifier input. The output switch reduces the number of "off" switches connected together and, thus, reduces the leakage current that they can contribute to an individual output. This technique also reduces the total capacitance across the output bus, thus minimizing loading effects on the source.

In some direct-coupled multiplexers, the shield (or guard) may be switched by a separate guard switch associated with each input channel as shown in Fig. 4. In others, the guard signal is derived from the signal lines as illustrated in Fig. 5. Regardless of the specific technique employed, the unguarded capacity must be kept low to achieve satisfactory common-mode rejection. Note, however, that switching the guard results in the common-mode voltage being chopped into higher-frequency components. This can cause problems, and usually does.

The amplifier and gate-drive logic in the direct-coupled multiplexer is frequently "floated" and driven by the guard amplifier. This reduces the common-mode voltage seen by the

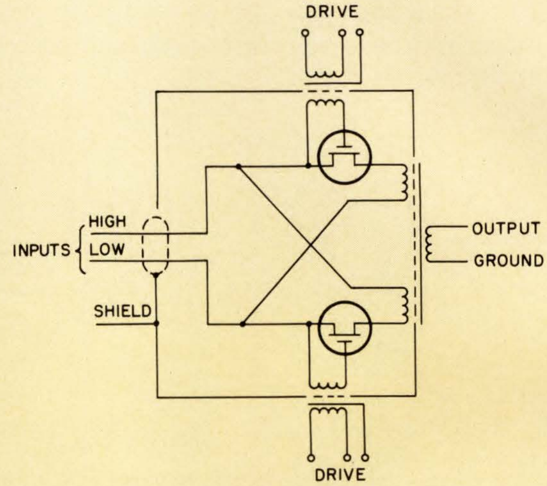

Fig. 6. Low-level switch for transformer-coupled multiplexer.

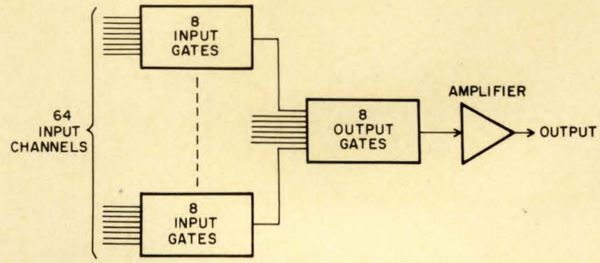

Fig. 7. Output gating used with 64-channel multiplexer.

amplifier and prevents the common-mode voltage from modulating the switch resistances.

Transformer-coupled multiplexers provide individually floating input channels, each of which behaves very much like a chopper-input amplifier with an individually guard-shielded input transformer. Fig. 6 shows the schematic of a typical switch and input transformer. For each input channel, a solid-state switch chops the input signal into an ac waveform which can be transformer coupled. The individual guard shield of each transformer provides excellent common-mode rejection and the circuit accommodates common-mode voltages up to several hundred volts. Since there is no direct interconnection between channels, no cumulative leakage currents flow in the source. (However, though the system is transformer-coupled, it handles dc signals as well as ac signals. Each chopped dc signal is converted back to dc by the demodulation process that follows the ac amplifier.)

The transformer-coupled multiplexer enjoys many advantages over the direct-coupled multiplexer. One minor disadvantage, however, is that it's slightly more expensive to manufacture.

We've looked briefly at the two most widely used methods of low-level multiplexing. Let's look now in more detail at the advantages and disadvantages of each method. Only with a full understanding of their relative merits can a system designer choose the best approach for a given application.

Advantages of transformer coupling

A major advantage of transformer-coupled multiplexers is that they can handle high common-mode voltages, limited only by the dielectric capabilities of the transformers. The common-mode voltage isn't chopped, so the multiplexer doesn't generate high-frequency components of common-mode noise. Common-mode rejection is achieved by the guarding technique described previously, and common-mode rejection at higher frequencies is determined by the completeness of the shielding. Since electrostatic shielding can be made a hundred-percent effective, almost perfect common-mode rejection can be achieved by careful design.

With transformer-coupled multiplexers, the switching transistors can work with low gate and substrate biases as the input circuits are fully floating and isolated. A substrate bias equal to twice the input signal level is all that is required. The threshold gate voltage of MOS switching transistors can provide sufficient "hold-off" bias to handle up to one volt of input signal without the need for fixed bias. Substrate bias can be generated by rectification of the gate-drive signal. As explained earlier, the transformer isolation ensures that leakage currents are not cumulative on the common output bus.

Another overall system benefit of transformer-coupled multiplexers is that the design of the instrumentation amplifier is simplified because it need not provide common-mode rejection. And the amplifier can be designed for lower noise operation because dc drift is unimportant and the amplifier needs only one transistor in its input stage.

In well designed transformer-coupled multiplexers, the dc component of the input signal is completely removed by the input circuits and restored after amplification. A "double-chop" technique generates a single cycle of ac (a doublet pulse) with amplitude proportional to the value of the input signal. The phase of this single cycle depends on the polarity of the input signal. Essentially, it is a suppressed-carrier, amplitude-modulated, waveform. The double-chop technique allows the flux energy stored in the input-transformer core to be zero at the end of the second chop period. Current is pulled from the input filter during the first chop and returned to the filter during the second chop (minus core losses, which are quite small).

The use of ac signal amplification, together with synchronous demodulation, removes drift and flicker noise without increasing higher frequency peak-to-peak noise.

Disadvantages of transformer coupling

The major disadvantage of transformer-coupled low-level multiplexers is that they tend to be fairly expensive because of the need for carefully-designed shielded transformers. Care must be exercised in the selection of the coupling transformers because their turns ratios must be carefully controlled to insure gain uniformity betwen channels. This disadvantage is partially offset by the fact that guard-driver amplifiers and complicated guard-driving techniques are not required.

Successful design and manufacture of a high-accuracy, moderate cost, transformer-coupled multiplexer generally requires high levels of skill. The techniques involved require very conscientious quality control.

The physical size and weight of transformer-coupled multiplexers are generally greater than with direct-coupled systems. For this reason, transformer-coupled multiplexers are rarely considered for airborne instrumentation equipment.

Also, transformer-coupled multiplexers tend to be less rugged than dc-coupled types. Performance may be affected by mechanical vibration. Because of the mechanical nature of the transformer assembly, transformer-coupled multiplexers should not be used in environments that are subjected to high levels of shock of vibration.

Advantages of direct coupling

Because direct-coupled multiplexers don't need expensive transformers, the cost per channel should be lower with direct coupling than with transformer coupling.

Another advantage of direct-coupled techniques is that an input channel can be held "on" continuously if required. This may be a useful feature in some applications.

Direct-coupled multiplexers require fewer drive circuits than are needed in transformer-coupled systems. With direct coupling, drive circuits can be arranged in a matrix configuration that, for example, would require only 16 driver circuits for a 64-channel unit.

Disadvantages of direct coupling

One serious disadvantage of direct-coupled systems is that the cumulative current from a large number of "off" switches can leak into the common output bus.

The problem is compounded by the high "off" bias voltage required on the gates (and substrates if MOS switches are used). For example, assume that a multiplexer is designed to handle ±10 volts of common-mode voltage and ±10 volts of maximum input signal, and assume, also, that the "on" channel has ±10 volts of common mode voltage when the input signal is also 10 volts. Then one input line will have the sum of the two voltages (unbalance source) or 20 volts peak which is also connected through the "on" switch to the common bus. Now, if one of the "off" switches has −10 volts of common-mode voltage and also 10 volts of input signal, then one input line of the "off" switch will have −10 volts (unbalance source) of signal which will add to the common-mode signal to produce a total of −20 volts. Therefore, the "off" switch could have a total stress of 40 volts.

The designer's problem is that the "off" bias must then be at least equal to 40 volts to assure that the "off" switch remains off. If junction FETs are used as switches we must also add pinch-off voltage to this value. If enhancement MOS switches are used, the voltage requirement is reduced by the threshold voltage on the gate, which is made higher by substrate biasing. But the substrate bias must also be equal to twice the common-mode voltage plus twice the signal voltage. So, in any event, approximately 40 volts of gate and substrate biasing are required, and leakages can become quite high since, in the MOS switch, this leakage is from the substrate to drain or source, and, in the junction FET, leakage is from gate to source or drain. And, of course, both types of devices are semiconductor junctions in which leakage doubles every 10°C.

Fortunately, the leakage currents can be reduced by output switching. Fig. 7 shows a typical 64-channel arrangement using output gate switching. The leakages are static and they add to the dynamic feedback currents (pump-out current) caused by synchronous rectification of gate-drive signals.

With direct-coupled multiplexers, therefore, the maximum common-mode voltage that can be handled is limited by the avalanche rating of the semiconductor used and the dynamic-swing limitations of the guard amplifiers. And, with direct coupling, there is an increased possibility that a failure of one channel will damage many other channels.

Another circuit design problem that occurs with direct coupling is that drive circuits must be bootstrapped with the common-mode voltage in an attempt to meet common-mode rejection specifications. This method is necessary because the gate capacitances of the "off" channels are cumulative on the output bus; thus effective unguarded capacities in the 1- to 5-picofarad range are necessary to approach a 120-db common-mode rejection at 60 hertz. If MOS devices are used in the multiplexer, the substrate bias supply must also be bootstrapped since the substrate to source/drain capacitance is also cumulative on the output bus. This bootstrapping requires floating power supplies with shielded and guarded power transformers.

Yet another disadvantage of direct coupling is that high-frequency components of the common-mode voltage are generated because the guard is switched each time a channel is turned on. Since the amplifiers used to drive the guard shield have finite rise times, there is a short interval before the common-mode signal can pass through the common-mode amplifier. During this brief interval, the effective common-mode input impedance of the signal amplifier will be quite low, and currents can flow in the input lines due to common-mode voltage.

Generally, direct-coupled signal amplifiers are used with direct-coupled multiplexers. These amplifiers must use differential input transistors. This means that two noise sources are present at the amplifier input (they are noncoherent and increase the noise voltage by $\sqrt{2}$). Also any dc drift in the amplifier adds to drift due to the input gates. In some cases synchronous demodulation can be used if a shunt clamp is used on the common bus which supplies a shorted reference between channels. This technique can eliminate flicker noise and zero drift in the amplifier, but it will double the higher-frequency noise.

Performance possibilities

The performance that can be achieved by today's low-level multiplexers is summarized in Table 1.

Total error limits of 0.1% f.s. ±10 microvolts are being achieved regularly. Errors can be reduced to about ±0.03% of f.s., ±3 microvolts, if the requirement justifies considerable additional expense and bother, and if the required data bandwidth permits some on-line averaging and calibration.

Several manufacturers sell packaged low-level multiplexers. Direct-coupled multiplexers are more widely available than transformer-coupled multiplexers. Currently, there are only two vendors of the latter type. Prices vary with the manufacturers but, typically, they run under $100 per channel when substantial numbers of channels are involved. **EEE**

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Products Of The Month

Semiconductors

Boldface numbers following each product refer to those you can circle on the reader inquiry card for further information.

Negative voltage regulators, MC1563R, MC1463R, complement available positive regulators. (Virtually identical to MC1569R.) MC1563R and MC1569R can be used to build 3-wire (common-input ground) dual polarity supplies to 40 V. Output impedance, 20 mΩ; diss., 9W; load current, 500 mA. 9-pin TO-66. $6.95. MOTOROLA. **564**

Op-amp IC, 741D, fully compensated. Replacement for Fairchild introduced IC. Offset voltage, 5 mV; offset current, 200 nA. Low-profile 8-lead TO-99 version also available. $1.30 (100-999). AMELCO. **562**

Dual high-gain op amp, 749, with 140-dB channel separation. Max offset voltage, 3 mV. Outputs can be OR wired as dual comparator. DIP, flat pack and TO-99. $11.99 (100-999). AMELCO. **563**

FET-input op amp, H50, with provision to externally trim offset voltage to zero. CMRR of 10,000 to 1 (80 dB) at ±10 V inputs. Initial offset, 2 mV max; voltage drift, 5 μV/°C max; initial bias current, 5 pA max.; full output frequency, 130 kHz min. $60 (1-9). DATA DEVICE. **565**

Linear ICs, second-source line, equivalent to Fairchild, National Semiconductor devices. Line includes 101, 748, 107, 741, 715, 733, 723 op amps, voltage regulators, video/sense amplifiers. 723, 748, 101, $3.25 (100 up, mixed); 733, 107, $3.95 (100 up, mixed). ADVANCED MICRO DEVICES. **566**

Interface-IC family, MC1580-4L, for driving and receiving digital data via coaxial or twisted-pair transmission lines. Driver and receiver provided for interfacing with standard digital logic families. MC1580L, dual line driver/receiver, for ECL, RTL; MC1581L, dual line receiver, for ECL; MC1582L, dual line driver, for DTL, TTL, RTL; MC1583L, dual saturated logic receiver (open collector), for DTL, TTL, RTL; MC1584L, dual DTL/TTL receiver (active pullup), for DTL, TTL. 14-pin DIP. $7.50 to $8.75 (100 up). MOTOROLA. **567**

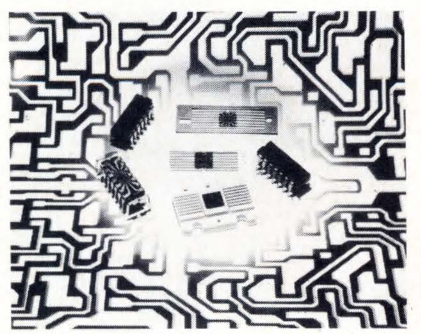
Interface IC, SN75451P, costs 97¢. Provides two independent channels for use as dual lamp or relay drivers, high-speed logic buffers, power drivers, MOS drivers, and memory drivers. Turn-on, turn-off delay times, 12 ns typ. $0.97 (100 up). TEXAS INSTRUMENTS. **568**

Dual line drivers, line receivers, QC-9614,5, for interfacing. Driver has single 5-V supply, input and output diode clamps, output short-circuit protection, and uncommitted pull-up/pull-down outputs for "NAND" or "AND" operation. Receiver has single 5-V supply, high common-mode voltage range (±15 V), frequency response control, output gate with strobe, and uncommitted, active pull-up/pull-down. Driver, $4.50; receiver, $5.50 (100 up). QUALIDYNE. **569**

Interface ICs SS334-345, for operation in high-noise environments. Series consists of quad logic-level driver for transmission of digital signals and two types of receivers. One receiver is quad single-ended device, other is dual differential receiver. Interface between standard TTL or DTL. TO-85 14-lead flat pack. $5.90 to $12.45 (100 up). SYLVANIA. **570**

DTL ICs, 13 new devices, swells 15830 DTL series to 33 ICs. Pin for pin replacements for Motorola devices. Inverters, NAND and NOR gates, power gates. 75¢ to 85¢ (100 up). TEXAS INSTRUMENTS. **571**

DTL ICs, additions to SW770 series, compatible with 930 ICs. NAND, OR,



NOR, exclusive OR gates and quad latch. Type numbers: 1802, 5, 6, 8, 10, 12, 14. Military and commercial temp-range versions. STEWART-WARNER. **572**

Four-bit binary full adder, DM7283/8283 similar to Texas Instruments' SN5483/7483. Ripple time, 12 ns. Equivalent to 30 gates. Can also be used as dual single-bit full adder. Accepts four A and four B inputs plus carry input. 16-lead DIP. $8.02 (100-999). NATIONAL SEMICONDUCTOR. **573**

High threshold logic ICs, SG393-5, for high noise environments. SG393 is

This Month's ICs

General-purpose op amp, $1.30. AMELCO. **562**
Dual high-gain op amp, $11.95. AMELCO. **563**
Negative voltage regulator, $6.95. MOTOROLA. **564**
FET-input op amp, $60.00. DDC. **565**
Second-source linear line, $3.25. ADVANCED MICRO DEVICES. **566**
Driver, receiver interface ICs, $7.50. MOTOROLA. **567**
Low-cost interface IC, $0.97. TEXAS INSTRUMENTS. **568**
Line drivers, receivers, $4.50. QUALIDYNE. **569**
High-noise-environment interface ICs, $5.90. SYLVANIA. **570**
DTL industrial DIP line, $0.75. TEXAS INSTRUMENTS. **571**
DTL 930-series gates. STEWART-WARNER. **572**
TTL 4-bit adder, $8.02. NATIONAL SEMICONDUCTOR. **573**
High threshold logic, $2.75. SYLVANIA. **574**
LSI multi-function array. SYLVANIA. **575**
Schottky-clamped TTL, $2.65. TEXAS INSTRUMENTS. **576**
J-K master-slave flip-flop, $1.50. NATIONAL SEMICONDUCTOR. **577**
Monostable multivibrator. RAYTHEON. **578**
MOS array family, $22.50. ELECTRONIC ARRAYS. **579**
MOS test wafer, $100.00. CARTESIAN. **580**
Sound-system IC. RCA. **581**

This Month's Transistors and Diodes

High-frequency overlay transistor: RCA: **582**
Matched dual FETs, $4.35. SILICONIX. **583**
High-speed switches, $0.30. FAIRCHILD. **584**
Single-diffused power transistors. SOLITRON. **585**
MESA power transistors, $0.84. POWER PHYSICS. **586**
Power switching transistors, $29.00. UNITRODE. **587**
Plastic SCRs, $0.55. TRANSITRON. **602**
High-voltage rectifiers, $1.09. RECTIFIER COMPONENTS. **603**

quad two-input NAND gate, SG394 and SG395 are dual four-input NAND gates. Latter has open collector output, can drive relay coils. Dc noise immunity is 15 times that of standard TTL circuits. Power supply 11.4 to 12.6 V. 14-lead DIP. $2.75 (100-999). SYLVANIA. **574**

Adaptive digital array, SM400, combines eight logic functions on single chip. Functions: clear, store, load X, shift left, shift right, count up, count down, complement. IC has 80 TTL gates with three levels of metalization. Contains basic 4 flip-flop configuration. Operates from 5-V power supply, clock frequency, 15 MHz. 28-lead flat pack. SYLVANIA. **575**

Schottky-clamped TTL, SN74S00 series, uses Schottky diodes to clamp active transistors. Line includes SN74S00 quadruple 2-input positive NAND gate, SN74S20 dual 4-input positive NAND gate, and SN74S112, a 100-MHz dual negative edge-triggered J-K flip-flop (with preset and clear). 5-V supply. Compatible with TTL standard logic. Delay time, 3 ns; fan out, 10; noise margin, 300-700 mV. $2.65 (100-999). TEXAS INSTRUMENTS. **576**

J-K master-slave flip-flop, similar to Texas Instruments SN5472/7472. Three J inputs and three K inputs. User can provide AND gating on inputs. Asynchronous PRESET and CLEAR inputs are provided, which override other inputs. 14-lead DIP $1.50 (100-999). NATIONAL SEMICONDUCTOR. **577**

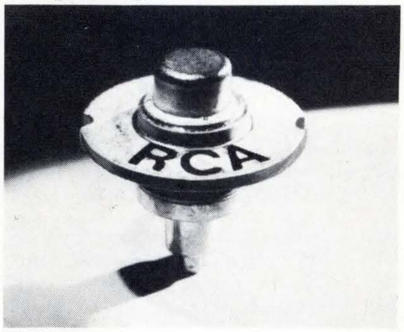
Retriggerable monostable multivibrator, RF8601, with optional retriggering lockout capability. Replaces Fairchild 9601. Output pulse width can be predetermined from 50 ns to infinity by external resistor and capacitor. Four Dc-level-sensitive inputs; two are active-level high, two are active-level low. Compatible with DTL and TTL logic. 14-lead flat pack or DIP. RAYTHEON. **578**

Complex arrays, EA1800-3, universal logic array, control array, register array, carry array. Dissipation, 180-200 mW; delay time, 150-500 ns; supply voltage, 24-28 V. EA1800 consists of six networks, has 32 options, user programmable. 40-pin DIP. $22 (100, mixed). ELECTRONIC ARRAYS. **579**

MOS/LSI evaluation wafer, TC01, consists of separate 32-bit shift registers of ratioless two-phase design. Includes MOS FETs, diffused resistors, MOS capacitors. Can be used as design tool, to determine tolerances for electrical characteristics. $100 each. CARTESIAN. **580**

Sound-system IC, CA3065, includes multistage i-f amplifier/limiter, fm differential peak detector, electronic attenuator, zener-diode regulated power supply, and audio amplifier/driver. Volume control action is accomplished when bias levels in attenuator are changed by variable resistor which replaces conventional potentiometer control. Attenuation in excess of 60 dB. Shielded leads for volume control eliminated. Plastic case. RCA. **581**

Silicon npn overlay transistor, 2N5921, for power amplification and frequency multiplication. Output, 5 W with 7-dB min power gain at 2 GHz and 10-



watt output with 11-dB typ gain at 1.2 GHz. Beryllium-oxide ceramic path between collector stud and base flange. Ceramic-metal package. RCA. **582**

Matched dual n-channel FETs, 2N-5902-9, available in packages or as chips. 2N5902-5 have max I_G of 3 pA; 2N5902 and 2N5906 have 5-mV max offset with 5 μV/°C differential drift. Differential gate current at 125°C is 2 nA max for 2N5902-5, 0.2 nA max for 2N5906-9. Min transconductance is 70 μmho with minimum matching ratios from 0.95 to 1 depending on device. $4.35, per pair of matched chips, $7.05 packaged (100-999). SILICONIX. **583**

30¢ plastic pnp transistors, 2N4257A, 2N4258A, 2N5910, with 12, 15, 20 ns storage time constants. 2N4257A operates from LV_{CEO} of 6 V at 3 mA, 2N4258A operates from 12 V, 2N5910 from 20 V. Saturation voltage, 0.5 V max over 10 to 50 mA. Turn-on time, 15 ns; capacitance, 3.0 pF max; beta, 30 to 120. Epoxy TO-106 packages. 2N4257A, $0.30 (1000 up), 2N4258A and 2N5910, $0.36 (1000 up). FAIRCHILD. **584**

Single-diffused power transistors, 2N-3055/1, 2N3055/10 replace 2N3055 standard devices. Voltages, 20 to 120 V; h_{FE}, 10 to 70 at 3-4A. Tin plated TO-3 cases. SOLITRON. **585**

Diffused mesa silicon npn transistors, 2N3054 series, 84¢. Line includes TO-

66 packages, power ratings to 30 W. Voltages to 140 V with I_C of 4 A. $0.84. POWER PHYSICS. **586**

Power switching transistors, 2N5658, 2N5659, Ratings: 20 A, 30 W. Typ failure rate of less than 0.01% per 1000 hours. TO-59 and TO-111 isolated stud packages. $29. UNITRODE. **587**

55¢ SCR, TC106, can replace GE C106. Current ratings to 4A, Voltages, 15-400 V. Peak current rating, 100 A. Turn-on gate current, 200 μA. $0.55 to $1.20 (100 up). TRANSITRON. **602**

Rectifiers, RC1731-4, versions of 1N-1731-4. Output current, 500 mA; voltages from 1500 to 5000 V, surge currents, 50 A peak. $1.09 to $2.89 (10,000 up) depending on voltage. RECTIFIER COMPONENTS CORP. **603**

Packaged Circuits

Hybrid bipolar op amp, ZA101D1, in 14-pin DIP package. Input voltage drift 15 μV/°C. CMRR 50,000:1. Unity gain frequency response 4 MHz. Full-output frequency 100 kHz. Slew rate 6 V/μs. Dc gain 5×10^4. Input bias current 50 nA. Input noise 2 μV rms (10 Hz to 10 kHz). Operating temp -25 to $+85$°C. $20 (1-9). Stock. ZELTEX. **529**

Electrometer op amps, 3336/27 and 3337/27, with varactor inputs. Need external feedback scaling resistor to generate output voltage proportional to input current. Input bias current 0.01 pA. Input noise current 0.001 pA pk-pk (0.01 to 1 Hz). Input impedance 3×10^{11} Ω. Common-mode input impedance 10^{14} Ω with shunt capacitance of 2 pF. Output ±10 V at 5 mA. Input voltage drift 10 μV/°C (3336/27) and 30 μV/°C (3337/27). Aluminum package, 2.6 × 2 × 0.7 in. $95 (3336/27 in 1-9) and $65 (3337/27 in 1-9). Stock to 4 wks. BURR-BROWN. **530**

Junction-FET op amps, A-126 and A-127, with input bias current guaranteed less than 10^{-15} A. Input impedance 10^{13} Ω. CMRR 100 dB. Input noise 2 μV rms. Voltage drift 50 μV/°C (A-126) and 25 μV/°C (A-127). Differential input, with low bias current at each input. No special shielding or decoupling required. 1.5 × 1.5 × 0.4 in. $49.50 (A-126 in 1-9) and $58.50 (A-127 in 1-9). INTECH. **531**

Low-cost analog multiplier, 4452, for 4-quadrant operation as divider or multiplier. Provides full rated output of ±10 V at frequencies to 40 kHz. Can be operated to 400 kHz with some performance tradeoffs. Input impedance 30 kΩ. Encapsulated module, 1.5 × 1.5 × 0.6 in. $29.50 (1-9). Stock. TELEDYNE PHILBRICK. **532**

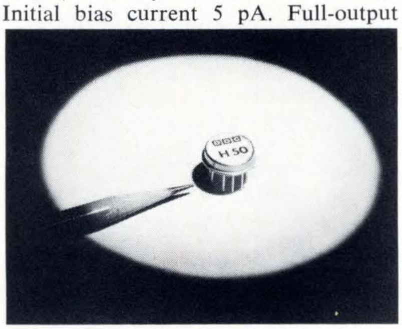
Low-cost FET amplifier, 801, with small-signal crossover frequency of 1 MHz and full-output frequency of 50 kHz. Slew rate 5 V/μs. Open-loop gain 100,000. Output ±10 V at 20 mA. Offset voltage 2 mV (adjustable to zero). Offset tempco ±70 μV/°C. Bias current ±50 pA. Input impedance 10^{11} Ω. Noise voltage 20 μV pk-pk (10 Hz to 10 kHz). Compact encapsulated module. Weight 1 oz. $17 (1-9). Stock. GPS. **524**

Inexpensive FET op amp, ZA802M1 with maximum input current of 15 pA. CMR 100,000:1. Unity-gain frequency response 4 MHz. Input voltage drift 50 μV/°C. Operating temp −25 to +85°C. Output ±10 V at 5 mA. Dc gain 10^5. Full-output freq 100 kHz. Slew rate 6 V/μs. Input impedance 10^{11}Ω. Input noise 3 μV rms (10 Hz to 10 kHz). Encapsulated package 1 × 1 × 0.4 in. $26 (1-9). Stock ZELTEX. **525**

Instrumentation amplifier, 603, to extract low-level signals from common-mode interference. FET input stage provides input impedance of 10^{12} Ω (differential and common mode). CMR 80 dB (gain >10) and 70 dB (gain <10). Linearity 0.2%. Input drifts 5 pA/°C and 15 μV/°C (low-drift version) at 25°C. Common-mode voltage range ±8 V. Gain-bandwidth product 1 MHz. Output ±10 V at 5 mA. Gain can be programmed by single external resistor. $54 (unity qty). Stock. ANALOG DEVICES. **526**

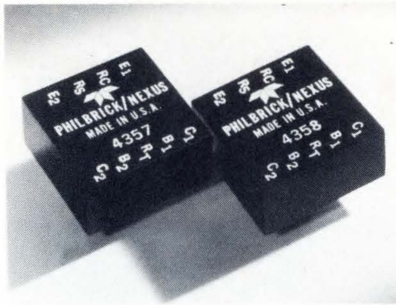
Low-cost op amp, 1024, with output current of ±20 mA. Slew rate 15 V/μs. Full-output frequency 250 kHz. Common-mode voltage range ±10 V. CMRR 20,000. Input bias current ±50 nA. Short protected. Encapsulated package, 1.125 × 1.125 × 0.59 in. $15.50 (100 up). Stock. TELEDYNE PHILBRICK. **527**

Hybrid FET op amp, H50, with CMRR of 80 dB for common-mode voltages to ±10 V. Initial offset 2 mV (externally trimmable to zero). Initial bias current 5 pA. Full-output



frequency 130 kHz. Unity-gain frequency response 4 MHz. Input impedance 10^{11} Ω. Operating temp −55 to +125°C. Sealed TO-8 can. 3 graded versions with voltage drifts of ±25 μV/°C (H50), ±10 μV/°C (HC50) and ±5 μV/°C (HB50). Prices in 1-9: $60 (H50), $70 (HC50) and $80 (HB-50). Stock to 2 wks. DDC. **528**

Low-cost log modules, 4357 and 4358, with each component graded for precise match to optimize tracking. Used with FET-input op amp to perform log operations over 4 decades of input voltage or 6 decades of input current. 4357 computes log of positive signal while 4358 is for negative signals. For rooting, exponentiation, compression, log ratio computation, multiplication,



division, or linear-to-log sweep. Encapsulated package, 1 × 1 × 0.5 in. $22 (either type in 1-9). Stock. TELEDYNE PHILBRICK. **533**

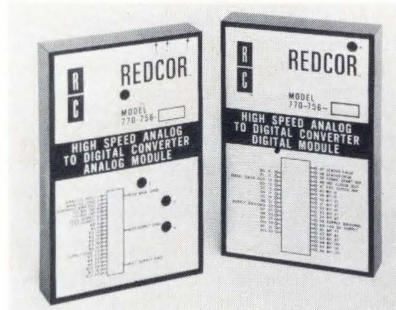
Active bandpass filter, AF6B1, with 6 poles. Multiple-negative-feedback circuit. Input impedance 100 kΩ. Available for center frequencies from 10 Hz to 25 kHz. Operates from single ±15 Vdc power supply. Bandwidth 1/3 octave. Uses metal-film resistors and polycarbonate capacitors for low noise and tempco. Encapsulated module 2.4 × 1.5 × 0.625 in. $59. Stock to 4 wks. TESTRONIC DEV. LAB. **534**

Hermetically sealed active filter, FS-60-1, similar to company's earlier FS-60 but with metal package. 0.905 × 0.56 × 0.4 in. Pin configuration compatible with 14-pin DIP sockets. Power dissipation 0.3 mW at ±2 V. Operating frequencies from dc to 10 kHz. Multiloop negative feedback provides high stability and stable Q range from 0.1 to 500. Voltage gain adjustable to 40 dB. Simultaneous bandpass, high-pass and low-pass outputs. F_c and Q can be tuned by adding external resistors. KTI. **535**

Computer-designed active filters, Type 41, for frequency range 20 Hz (0.5% bandwidth) to 20 kHz (1% bandwidth). Manufacturer's computer program provides optimized design with minimum number of components and smallest possible package. Accuracy 1% (below 100 Hz) and 1 Hz (above 100 Hz). Standard response characteristics are Butterworth, Bessel and Chebyshev. Custom transfer functions available. Size 0.5 in^3 for typical pole pair. Operating temp −40 to 85°C. Input impedance 100 kΩ. Ouput impedance 10Ω. Supply voltage ±15 to ±22 Vdc. $17 (small qty). 6 wks. KDI NAVCOR WEST. **536**

Computer-designed active filters, 700 series, for frequencies from 0.001 Hz to 20 kHz. Standard basic units can be adjusted to customer's specific cutoff frequency, using off-the-shelf resistors and capacitors. Cutoff-frequency tolerance 2%. Noise level 50 μV. Dynamic signal range 10^4:1. Full-scale output ±10 V. Package size 2.02 × 1.14 × 0.62 in. (for frequencies above 10 Hz), or 2.8 × 1.3 × 0.95 in. (for frequencies below 10 Hz). Standard versions have Butterworth response. Can also be supplied with Bessel, Chebyshev, Paynter, notch, and other responses. $34 to $99 (unit qty). 2 wks. ANALOG DEVICES. **550**

High-speed A/D converter, 770-756, packaged in pair of compact modules, each 4.5 $in.^3$ 8-, 10- or 12-bit versions. Conversion rate 330 kHz (8 bits), 250 kHz (10 bits) or 165kHz (12 bits). Accuracy ±0.025% of f.s. input. Operating temp 0 to 50°C. Tempco ±0.0015% fs/°C. Full-scale input



ranges of ±5 V, +10 V, ±10 V and +20 V available. Binary, offset binary, one's complement and two's complement output codes available. Output and control signals DTL/TTL compatible. $625 (8 bits), $650 (10 bits), $675 (12 bits). 30 days. REDCOR. **538**

Tiny crystal-controlled oscillators, MCO-F, in TO-5 cold-welded package. Consists of thin-film hybrid IC and quartz crystal. Intended as local oscillator and 2nd mixer in dual-conversion receivers. Frequencies from 5 MHz to 25 MHz. Frequency stability ±0.003% from −55 to +125°C. Frequency tolerance ±0.005% at

25°C. Operating voltage 1.8 to 5 Vdc. Output 0.35 V rms into 1 kΩ load (with 3-V supply). Stability 1 ppm with ±10% change in input voltage, and 0.1 ppm with ±20% change in load. Under $30 (100 up). TRW SEMICONDUCTOR. **544**

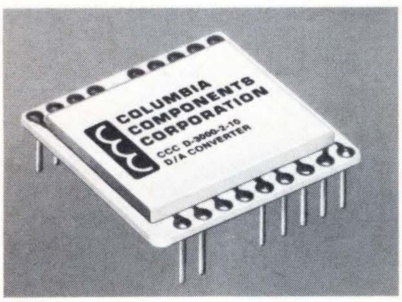
Photo-coupled isolator, MCS1, with photo SCR as detector and GaAs solid-state light source as transmitter. High current capability allows direct activation of solenoids, motors, lamps and other 120-vac loads. Functions as spst relay with no contact bounce and with response time of 1 μs. Acts as patching device in dc circuit. LED current 4 mA typ. SCR turn-on time 50 μs typ, but can be reduced to less than 2 μs by increasing LED current. $18.75 (1-9) and $11.00 (1000 up). MONSANTO. **545**

3-port circulator/isolator,, ICL-3713, in compact package, 1 1/4 × 1 1/4 × 5/8 in. Frequency range 1675 to 1875 MHz. Operating temp −54 to +70°C. Isolation 20 dB. Insertion loss 0.4 dB (from −54 to +55°C) and 0.5 dB (from +55 to +70°C). VSWR 1.2 at all ports. Connectors 3 mm female. WESTERN MICROWAVE. **547**

High-frequency balanced mixer, M2F, claimed "lowest-cost high-frequency mixer on the market." Frequency range 1 to 2.5 GHz. Midband noise figure 5.5 dB typ. Isolation 20 dB. Output bandwidth dc to 500 MHz. Built-in filters isolate "R" port. Performance guaranteed over temperature range −54 to +100°C and after environmental stressing per MIL-STD-202D. 1.8 oz. BNC, TNC or SMA connectors. Max input power 25 mW pk. $140 (1-4). Stock. RELCOM. **548**

Set-point temp controllers, 200 P (analog), 300 P (digital). Zero-voltage switching of up to 1500 W resistive (for heating) and 30 W inductive (for solenoids controlling coolant valves). Set-point acc ±3°F from 40 to 110°F. Closeness meter shows when sensor (included in price) is too hot, too cold or just right. 200P, $199. 300P, $249. VICTORY ENG. **549**

Hybrid D/A converters, D-3000 series, using cermet thick-film chip-and-wire technology. Each module contains fast slewing output amplifier, ladder network, reference element and high-speed switching circuits. 10-bit resolution. Accuracy 8 or 10 bits binary, or 12 bits BCD. Settling time 100 ns (8 bits)

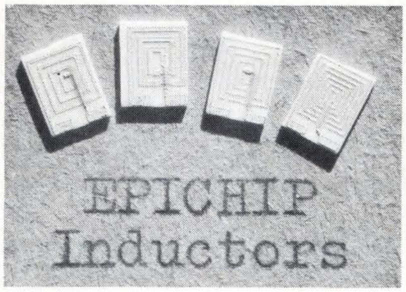


or 150 ns (10-bit binary and 12-bit BCD). Low-profile ceramic package, 1.5 × 1.5 × 0.17 in. Choice of three temp ranges: 0 to +50°C, −25 to +70°C, and −55 to +85°C. $195 (8-bit commercial temp in 1-9) and $230 (10-bit commercial temp in 1-9). Stock. COLUMBIA COMPONENTS. **540**

Semiconductor RAM, Mostak II, using monolithic MOS RAM devices. 1024 words × 8 bits. Full-cycle time 1 μs. Consists of 2 PC boards. One board contains clocking and timing system, while second board contains memory array. Direct replacement for core memory of comparable size. ELECTRONIC ARRAYS. **551**

Transformers & Inductors

Miniature chip inductors, for vhf and microwave. Inductances to 100 mH on 0.188 in. × 0.250 in. ceramic. Thick-film gold-conductor deposition gives



high Q. Solderable or bondable gold terminations. EPITEK. **558**

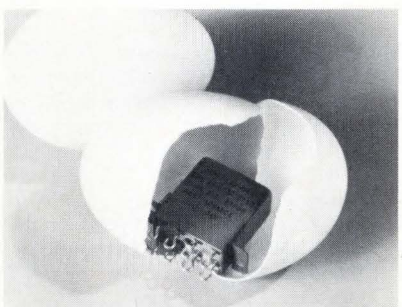
Ferrite toroids, B material, with temp stability of 15% from 10-105°C. Pulse permeability 5500 ±20%. O.D. available from 0.10 to 3.75 in. For use in pulse and wideband transformers. FERRONICS. **559**

Isolation transformer, 1109-PA, for elimination of ground-loop currents in 75 Ω coaxial, video and data lines. 140-dB attenuation against 60-Hz interference from 25 Hz to 7 MHz. Sinewave and pulse transmission. 2.9 in.^{2} × 2 in. high. BNC connectors $125. NORTH HILLS. **560**

Flat-pack transformer, with temp range −35 to +105°C. Turns ratio 1:1:1. Used to drive transistor switches. $15. PCA. **561**

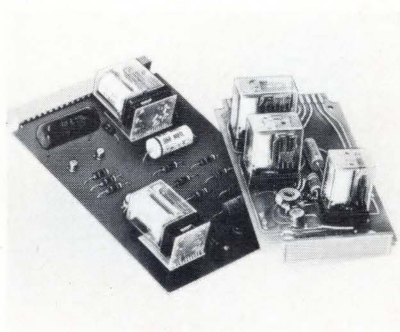
Switches & Relays

Crystal-can relay, 30 W, with dpdt gold-flashed bifurcated contacts. QPL rated to meet Mil-R-5757E for low-level loads. 50-mΩ contact resistance.



1-GΩ insulation at 125°C. 250-mW sensitivity. Various coil voltages, mounting and termination styles. HART-ADVANCE. **505**

Ultra-sensitive relay, Hi-Mag, requiring only 30mW per pole to switch 150 W.



(Continued on page 78)

To 8 form C. Patented hinge allows millions of mechanical cycles. ALLIED CONTROL. **506**

Time-delay relays, TM, for various delay modes, preset or resistance-programmed delays or intervals, 100 ms to 1 hr, with 1% repeat acc at constant temp. $12.35 to $23.53 (list). CHRONOLOGICS. **507**

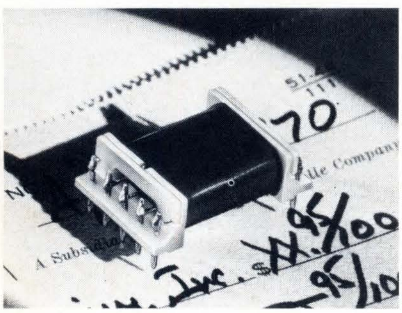
All-solid-state time-delay relay, QR, in half-size crystal can. Resistance programming of delay, 10 ms to 60 s. 20-32 Vdc operation at -55 to +100°C. Single-pole, 100-mA output. $80 (list). BRANSON. **508**

Rf matrix relay, LCM10-2191, with 10 50-Ω inputs. Mercury-film switching for 50-million bounce-free operations, regardless of mounting position. Dc -35 MHz. 0.1-dB insertion loss. 60-dB isolation. VSWR 1.15:1. Contact resistance 50 mΩ ±5 mΩ over matrix-point life. 5-ms operate/release. 7.5 cu. in. $650 (production quantities). FIFTH DIMENSION. **509**

Open-construction reed relays, CG, for PC mount. Dry-circuit to 100-W loads. Contacts: one form A, B, C; two form A, C. Terminals on 1.7-, 1.8- or 1.9-in. centers. DOUGLAS RANDALL. **510**

Open-construction reed relays, 101MPC (miniature), 102MPC (standard), for PC mount. Form A. 101MPC: 10 VA, 0.5A, 200 Vdc. $2.65 (1-24), $1.50 (1000-up). 102MPC: 15 VA, 1A, 250 Vdc. $2.50 (1-24), $1.41 (1000-up). MAGNECRAFT. **511**

Low-cost open-construction reed relays, 832, for PC mount. To six poles in combinations of form A, B, C. 3-A



carry, 0.5-A switch, 100 Vdc, 150 Vac. 150-mil pin spacing. 95¢ (OEM quantity). NEW PRODUCT ENGINEERING. **512**

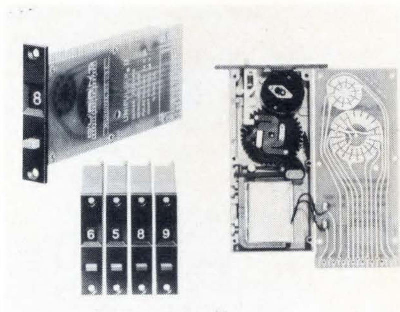
Lighted pushbutton with momentary-contact form A or B. Stationary single neon or incandescent. Single-hole mount in ⅜-in. D holes on 9/16-in. centers. DRAKE. **513**

Lighted pushbutton, 01-600, with 10-A 125/250-Vac 1- or 2-pole contacts with double break. Momentary or alternate action. Individual or matrix mount. No-tool front-replaceable T 1-¾ lamp. Snap-in housing. LICON. **514**

Matrix program board with up to 100 × 100 crosspoints, up to 6 levels. For diode-pin programming. Typ 20¢ per crosspoint. INFO-LITE. **515**

Miniature thumbwheel, H, with ⅜-in. module width, 1.3-in. hgt including integral bezel lip. Tie rods and end plates allow grouping 50 modules. No panel-mounting screws. Repeating 2 pole 2 position, 1 pole 10 or 11 position, decimal output or any BCD. Extended-board option for user-added components. INTERSWITCH. **516**

Electromechanical decade counter with count rates to 40 cps. Independent drive input, transfer, reset, 1-2-4-8 out-



put for each module. Data retained even during power failure. $23 (set model). $22 (non-settable). DURANT. **517**

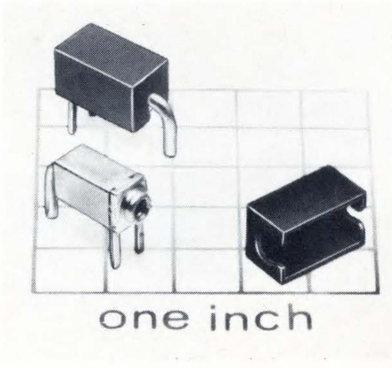
Packaging/Hardware

Rf connectors, LP, in three sizes for ¼, ⅜, ½-in. semi-flexible, air-dielectric coax cable. Replaceable TNC and N interfaces. One-tool field installation for all sizes. TIMES WIRE. **476**

Miniature round connectors, Nu-Mite 2400, with 2, 3 or 4 polarized contacts in ½-in. environment-proof shell. Cable-mount plug, chassis-mount receptacle, through-bulkhead adapter. Plug bodies of Teflon. Receptacles and adapters have glass-to-metal hermetic seals with Ni-plated brass or all-stainless bodies. 7.5-A contacts of gold-plated BeCu. CINCH-NULINE. **477**

Waterproof audio connectors, Mil-C-10544 (10 contact), Mil-C-55116 (5 contact), to resist immersion, salt spray, temp cycling, vibration per Mil specs. ELCO. **478**

Test-point jack with snap-on insulator in red, black or blue. Takes 40,000 in-



sertion/withdrawal cycles of 40-mil pin. CAMBION. **479**

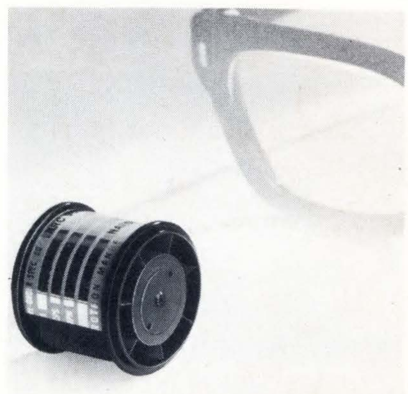
DIP jumper, for intercommunication between DIP sockets on one or two PC boards. 4- or 10-in. lengths with plug or socket ends on flexible ribbon cable. ROBINSON-NUGENT. **480**

Stackable jumpers, Hypertac, with cable lengths from 6 to 15 in. in six colors. Combination 30-mil pin and spiraled-wires socket allows stacking cable ends at PC test points. INDUSTRIAL ELECTRONIC HARDWARE. **481**

Round-conductor flat cable with individually insulated conductors, solid or stranded in AWG 32 to 12, bonded in same plane. Variety of color codes and insulating materials. Easy breakout for individual conductors. CABLE TECH. **482**

Heat sinks, UP, HP, both for TO-3 and TO-8 cans. UP allows 10-W dissipation of TO-3 at 80°C instead of 3.25 W with no heat sink. HP allows even higher dissipation. Staggered-finger aluminum construction. UP in one size with three heights; HP in two sizes, one height. (1000-up) UP 40¢, HP 51¢. IERC. **483**

Tiny fan, Nanos, for 1 cfm free air. 1-in. dia, 1-in. length. Operates from



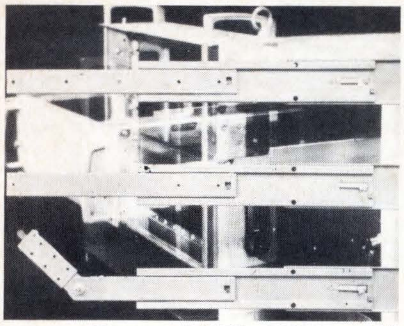
26 V 400 Hz. -55 to 100°C. 20,000 hr continuous. Also available in 1-in. cube. ROTRON. **484**

Snap-apart alumina substrates, pre-grooved to customer specs. Area down to 25 mil square, thickness down to 10 mil. 96% or 99.5% Al_2O_2. Two-wk delivery. CERMETRON. **485**

High-temp insulating epoxy, H54, for bonding and coating. Color changes from amber to red during cure, allowing easier control of time-temp cycle. 3-oz sample $15 plus postage. EPOXY TECHNOLOGY. **486**

Test clip to replace alligator. Grips AWG 32 wire as well as AWG 8 bus without scarring. Three variations: two overlapping claws; two jaws; one claw and one platform hook. OZ. **487**

Chassis slides of stainless steel. Take 150 lb/pair. 14- to 24-in. length with 3 in. extra slide extension. Non-separable, quick-disconnect or tilt-type quick-disconnect with rotation in 45° incre-



ments. -65 to +250°F. ZERO. **488**

Numerically controlled terminal locator, 14YN, for semi-automatic Wire-Wrap at installations terminating less than a million wires per year. For up to 24 × 36-in. wire area. Includes 32-tube lighted wire bin and solid-state numerical controller. GARDNER-DENVER. **489**

Power Supplies

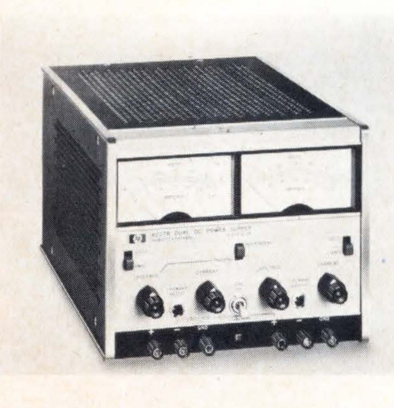
Low-cost logic supply, 517, with adj 4.5 to 5.5 Vdc at 2.5 A. Line reg 0.03%. Load reg 0.2% Ripple 5 mV pk-pk. 3.75 × 3.75 × 5.875 in. Mounting by threaded inserts. $59. RO ASSOC. **518**

Power module, W 1.2, for 400-Hz 115 V input, 5-100 Vdc at 1.2 A. Line and load reg each 0.05% or 20 mV. Ripple 0.02% or 5 mV. TC 0.03%/°C. Overload and short protected. Meets Mil-Std - 461. Hermetic sealed and encapsulated. $315. ABBOT **519**

Dual supplies, ET, with fixed output 1-28 V at 250 mA. Isolated outputs. PC mount. Trim adjust for balancing. $78. ACOPIAN. **520**

Modular supplies, LV series, with eff greater than 50% and ripple of 10 mV rms. To 170A. Fixed 3-15 Vdc. Line and load reg each 0.15% + 10 mV. TC (0.03% + 0.5 mV)/°C. Remote sensing and remote programming. Overvoltage protection and current limiting. Convection cooled. LAMBDA. **521**

Dual dc lab supply, 6227B (0-25 V at 0-2A), 6228B (0-50V at 0-1A). Isolated supplies act independently or track within 0.2% +2 mV of master. Const V or I with internal crowbar. Load reg 0.01% +1 mV for const V or 0.01% +250 μA for const I. Line reg 1 mV or 100 μA. Ripple 250 μV or 250μA rms. 0 to 55°C. $450. HP. **522**



High voltage source, AEC-1000, with cont adj 0-3000 Vdc at 0-1 mA. Operates from internal 12 V and 24 V. Reg. 0.0025%. Stability 100 ppm per day. Noise and ripple 500 μV. Source Z 10 kΩ max. Electrostatic and electromag shield. Mounts in a std NIM bin. $390. POWER DESIGN. **523**

Test Equipment

Logic probe for hands-free testing of DTL, TTL and other logic systems. Requires 60 mA at 5 V from equipment under test. Green light indicates "O" level from 0 to 0.6 V. Red light indicates logic "1" at 2.4 V and above. No-indication dead band between 1 and 2 V. Probe circuit independent of pulse shape and can indicate pulses as narrow as 30 ms at rates to 30 pps. $35. AP INC. **490**

Panel mounted resistance decades, 1312, with 0.005% accuracy and stability to 5 ppm/yr. TC 2ppm/°C. Usable to 100 MHz. Features rocker switches, set-point resolution of 0.01 Ω available over the 100,000 Ω range. $165. VISHAY. **491**

Pulse generator, 5102, from 1 Hz to 50 MHz in 7 ranges. Pulse width 0.1 μs to 100 ms. Single pulse, manual pulse, gated pulse or square wave. Normal and complement outputs 0 to

6 V. Offset 0 to 2 V. IC pulse output at a fixed +4.5 V. Amplitude and offset remotely programmed. $475. DATA DYNAMICS. **492**

Digital data generator, DG7, for system testing. Serial data, 16 bits per word "true" and "complement" simultaneously provided. RZ or NRZ format. Dc to 35 MHz. Pulse width 15 ns to 10 ms. Output 5 V into 50 ohms,

(Continued on page 80)

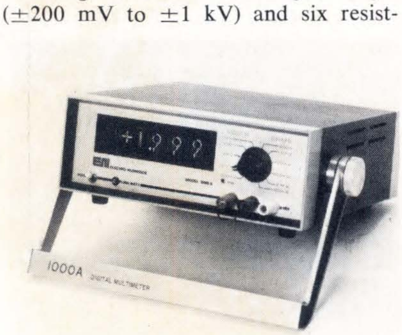
10 V into 500 ohms. $990. TAUTRON. 493

Programmable oscillator, 4130R, for sine or square wave 1Hz to 1 MHz. Manual freq selection by three decade rotary switches and a four-position multiplier. BCD remote freq programming. Freq accuracy ±0.1%. Short term amplitude stability ±0.002.% Freq response better than ±0.05 dB. Fixed 5-V pk-pk square wave. Sine wave varied by 11-position switch and vernier. $1075. KROHN-HITE. 494

Waveform generator, KW105B, with freq selection from 0.01 Hz to 100 kHz plus dc. Sine, triangle, square and positive and negative dc. Calibrated output from 1 mV to 1 V or 10 μV to 1 mV. Freq acc ±1%, drift ±0.25% for 8 hours. Amplitude acc ±1%. Freq response ±0.2 dB for 10 kHz to 100 kHz. $350. BIO-MEDICAL ELECTRONICS. 495

Pushbutton operated active filter, AF-520A (dual channel) with response characteristics of Butterworth and Time Domain. Low or high pass. Pushbutton keyboard operation for digital tuning in the 0.2 Hz to 20 kHz range. Slope of 24 dB/oct in each independent channel. Attenuation 75 dB or greater. Input Z 1 MΩ and output Z 50Ω. Gain is unity ±1dB. Also available with other response options. MULTIMETRICS. 496

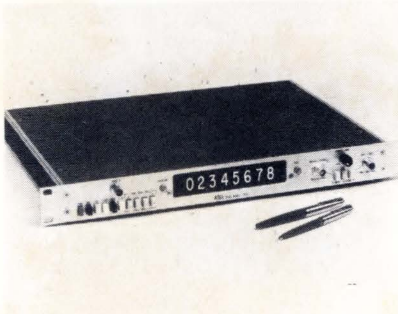
Low-cost digital multimeter, 1000A, with optional internal rechargeable sealed lead-acid battery or normal ac operation. 3 digits plus "1" for 100% overrange. Five dc voltage ranges (±200 mV to ±1 kV) and six resistance ranges (200Ω to 20 MΩ). Acc ±0.1% rdg. ±0.05% f.s.—all ranges. Complete overload protection. $295. ($360 with battery). ELECTRO-NUMERICS. 497



5-digit multimeter, 5233, with module 553 for remote command capability. 6th digit 20% overrange. 5 dc, 4 ac, 5 ohm ranges; dc/dc ratio capability; isolated remote programming; isolated and non-isolated BCD output. All functions and ranges remote programmable. All command input lines to the 553 module isolated through optical signal couplers. DANA. 498

Solid-state rf millivoltmeter, 92A, with basic accuracy of 1% rdg + 1% f.s. 100 μV to 3 V from 10 kHz to 1.2 GHz in 8 ranges by pushbutton selection. True-rms response up to 30 mV. Linear dc output. $750. BOONTON. 499

Low-cost counter, 2806, with direct-measurement freq range of 10 Hz to 250 MHz. Functions include freq, totalizing and ratio. Time-base stability + 1 × 10^{-8}/day after 72 hours. Readout storage, BCD output, and remote programming of gate time, reset, storage and count gate. $1395. ATEC. 500



MOS up/down display counter, CMA, for up to 125 kHz. Counter inputs will accommodate quadrature square-waves, pulses, or pulse level. $650. DATA TECH. 501

IC card tester, ICT-100, for all digital card families. Go/no-go and qualitative testing. 20 programmable test signals. 56 programmable output loads. 56-pin card interface connector. Modes are: static, high-speed dynamic, low-speed dynamic and self test. To test, insert logic card with its IBM punched program card. DYNATRONICS. 502

Low-noise wideband preamp, 10-M, for low-level, fast risetime detection applications. Voltage gain 60 dB with 3-dB bandwidth 100 Hz—10 MHz. Rms broadband noise 10 mV/$Hz^{1/2}$. Input Z 10 MΩ. Power supply is 10 low-noise nickel-cad batteries. Triaxial input and output connectors. ADVANCED KINETICS. 503

Display Devices

3/4-in. electrostatic CRT, Y4028, with flat face. Any commercial phosphor. Single gun with defl sens of 230 Vdc/in./kV. Anode 1000 to 2000 Vdc. Overall length 3.750 in. For alphanumeric readout. GE. 553

Extra long neon, NE-211, for use as "1" in overrange position of DVMs. Also usable as a + or − display. Firing 90 Vdc. Maintaining 65 Vdc at 1.3 mA. 2000-8000 hr. PC mount 0.93 in. long. $.39. ALCO. 554

28-V incandescent, T-1, with high brightness of 0.190 mscp at 23 mA. New filament design extends life to 16,000 hr. PRECISION LAMP ENG. 555

7-segment incandescent readout, TDS 512, for BCD input. Character size 0.32 in. high × 0.19 in. wide. 500 ftL at 5 Vdc. Lamps replace from front. Meets Mil-E-5400. OPPENHEIMER. 556

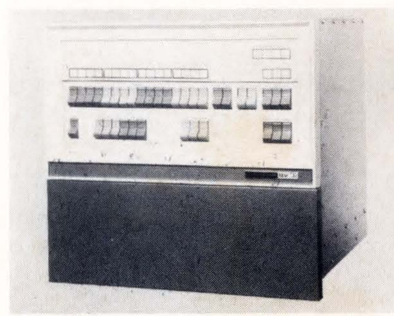
Decoder/driver display, D-4000, with bezel assembly with filter lens, decoder, driver circuitry, and replaceable 7-segment fluorescent readout tubes. Interfaces with 4-line BCD. Single-connector termination. $49.50. INTEGRATED CIRCUIT ELECTRONICS. 557

Data Handling

Price change

RAYTHEON COMPUTER has announced average price reductions of 33% for its line of conversion equipment. For example, the 12-bit Miniverter multiplexing A/D converter now costs $2,300 instead of $3,640, in a 32-channel configuration. **588**

Low-cost minicomputer, MAC Jr., with up to 8 k × 16 bits of 1-μs memory and up to 16 hardware priority interrupts. Basic version has 4-k words of memory, 4 hardware priority interrupts and integral power supply. Uses same software and peripheral devices as company's earlier MAC 16 computer. $7,900 (with 4-K memory). Available for delivery September 1970. LOCKHEED. 589



Compact digital computer, Datamate 70, in low-profile rack-mount package only 1-3/4 × 19 × 20 in. 11 registers, including four 16-bit arithmetic accumulators. 2 accumulators available as index registers. I/O index register. DMA provides 16-bit I/O transfer at 10^6 word/s. Range of optional memories include 1-μs core and semiconductor read-only and read-write versions. Instruction set includes 144 instructions in 5 classes. Up to 64 nested priority interrupts and high-speed multiply/divide available. Core memory externally expandable to 32 k. From $5,900. Available August 1970. DATAMATE. 590

Powerful small computer, Model 5, claimed to produce "more real-time programming power per dollar than any other computer available today." Privileged instructions separate supervising modes to prevent background program from destroying operating foreground. Autonomous programmable I/O channel. 114 instructions, including floating-point computation, interrupt control, operating-system linkages and list processing. 16 hardware priority-interrupt levels, expandable in blocks of 16. Real-time software including Fortran. Four basic configurations with core memory from 8 k bytes to 32 k bytes. $12,900. INTERDATA. **592**

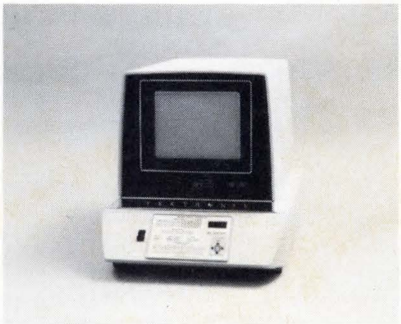
Low-cost minicomputer, MD708, claimed "lowest-priced general-purpose mini-computer available today." Instruction list includes over 100 instructions. Powerful macro-assembler. 8-bit word length. Cycle time 1.6 μs. Memory expandable to 65 k words. Supplied complete with 1024 × 8-bit core memory, power supply, control panel, and desk or rack cabinet. Weight 25 lbs. Height 3 1/2 in. I/O interfacing and all standard peripherals available. Under $3000 (qty 25). MONITOR DATA. **593**

High-speed digital computer, CSP-30, said to be "smaller and very much less expensive than computers of comparabile capability and power." 16-bit word length. Basic cycle time 100 ns. Priority-interrupt time 0.6 μs. Has 512 words of 100-ns IC memory and 4 k of 900-ns core, expandable to 32-k words. 32 accumulators. 291 basic instructions. Software includes loader, editor, debugging aid, symbolic assembler, diagnostic and maintenance programs and numerous special programs including fast-Fourier transforms and recursive digital filtering. Under $100,000. COMPUTER SIGNAL PROCESSORS. **594**

General-purpose minicomputer, 980, with 16-bit word length. Memory cycle time 1 μs, access time 400 ns. Basic memory capacity 4096 words (expandable to 65,536 words). 85 powerful

instructions including multiply and divide. Stand-alone unit comes complete and ready to use. Software includes real-time monitor, assembler, and Fortran compiler. TI. **591**

Graphic-display terminal, T4005, consisting of graphic display controller and 11-inch direct-view storage-display unit. Controller unit contains operator controls and hardware to process computer outputs into display data. Display-unit hardware performs various editing functions such as scaling, offsetting, magnifying, framing and augmenting. Controller can drive 4 separate display devices. Interfaces with most computers. Software available for



plotting, character generation and text handling. $7850. Available 3rd quarter, 1970. TEKTRONIX. **595**

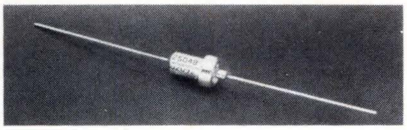
Desk-top CRT display, 2000, for use as direct replacement for Teletype equipment. Fully interactive with computer and completely compatible with existing programs and programming practices. Flicker-free display of up to 1998 characters. Split-screen capability. Flexible editing, including character and line insertion and deletion. Other features include data transfer to and from magnetic-tape cassette, instant hard copy and low-cost remote monitors. Programmable cursor. $2995 (1-24). HAZELTINE. **596**

Tape reader/interface, Mark V Data Reader, consisting of high-speed perforated tape reader and interface system for connection to PDP-8I/L series of mini-computers. Complete system costs less than half the price of equivalent DEC system. Bidirectional tape reader operates at 500 chars/s and has stop-on-character capability. Fanfold paper storage. Spooling versions available at higher cost. $1155 for complete system with interface card and cable. DATASCAN. **597**

Filter analysis/synthesis program, FILTER, for lumped-constant filter design. Designer selects filter transfer function from comprehensive program list, including Bessel, elliptic function, Butterworth-Thomson, ultraspherical, etc. Also he selects geometry and desired frequency and impedance transformations. Program then provides steady-state and transient step-and-impulse analysis of desired filter function, and provides many pertinent analysis parameters. Program available in tabulated and printer plot, TTY and CalComp, formats. SYSTEMS ASSOCIATES. **601**

Special Products

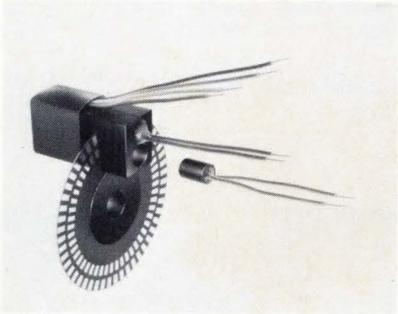
Coulometer cells, Coul Cells 589, 597 and 601, for timing circuits. Impedance and voltage drop across device changes abruptly when predetermined integral of time and current is reached. Capacity 100-3200 μA-h (589), 5350 μA-h (597) and 2700 μA-h (601).



Rugged and compact construction. Low power consumption. Operating currents from 4 μA to 225 mA depending on type. From $5 to $10 (small qty). GIBBS MFG & RESEARCH. **604**

Energy storage device, ESD Cell, with pair of pressed-powder electrode wafers separated by an electrolyte wafer. Similar characteristics to electrolytic capacitor, but with superior charge retention. Wide range of applications including standby power units, integrators and sample/hold circuits. Electrolyte conductivity less than 10^{-11} Ω^{-1} cm^{-1}. Evaluation units available with diameters of 0.5 or 1 in., and with ratings of 0.5, 5 and 50 F. $30 (prototype qty). 2 wks. GOULD IONICS. **605**

Modular photoelectric shaft encoders, Rotaswitch, with easily replaceable lamps. Available in unidirectional or bidirectional incremental versions. Output-signal configurations include single



track (model 800), single track with index (model 801) and dual track (model 802). 33 standard resolutions with from 1 to 1000 pulses/rev. Position accuracy from 5 arc-min. DISC INSTRUMENTS. **606**

Predetermining electric counter, Series 7447, with bracket for panel mounting without screws or other visible hardware. Rotary knobs permit independent presetting in either direction. Counter can be preset to any number up to 99. End count actuates spdt switch. Standard ac and dc coil voltages. Power consumption less than 3 W. VEEDER-ROOT. **607**

Programmable digital filter, 999, for control by tape reader and solid-state shift register. Real-time computer control also possible, thus providing time-varying adaptive-filter capability. Can synthesize classical filters such as Butterworth, Chebyshev and elliptic function, and special filters that are difficult to implement with analog techniques. Unit can be regarded as special-purpose digital computer with A/D converter at input and D/A converter at output. Max input freq 3.5 kHz. 7 5/8 × 19 5/8 × 18 in. Optional card reader and special software available. ELECTRONIC COMMUNICATIONS. **608**

New Literature

MOS character generators, MOS memories, ECL high-speed counters, TTL 50-MHz flip-flops and log and exponential amps in five TI app notes. **400**

Rotating components from many vendors in Electro Sales 140 pager. **401**

Capacitors, relays and other devices in Cornell-Dubilier 120-pg "Component Selector." **402**

Power-supply kits in Lambda 12 pager. **403**

Most popular op amps in Analog Devices 6-pg foldout. **404**

PM motors in Indiana General slide-rule selector. **405**

"Pitfalls of power-supply connections," in 11-pg HP article reprint. **406**

Submin connectors in Deutsch wall chart. **407**

SCRs, logic triacs and assemblies in International Rectifier 116-pg catalog. **408**

Packaged op amps and linear ICs in Fairchild 36-pg selection guide. **409**

ICs in GI 20-pg short form. **410**

Thick-film techniques in 10-pg Electro Materials manual. **411**

Panel meters in Triplett 20 pager. **412**

Glass memories in high-speed buffers in Corning app note. **413**

Logic modules and related products in Digital Equipment 448-pg "Logic Handbook" with extensive tutorial material. **414**

Hybrid power Darlingtons in 10-pg TRW app note. **415**

Power-semi applications and p-i-n diodes in GE reprints of 7 papers given at Semiconductor Applications Seminar. **416**

Precision test equipment in Keithley 70-pg catalog. **417**

Servo mechanisms in Weston-Transicoil 12 pager. **418**

TTL ICs in TI 196-pg catalog supplement. **419**

Instrument specs from many manufacturers, well organized in Leasametric data and rental catalog. **420**

Mil resistor specs in Dale identification manual. **421**

Hybrid ICs in Circuit Technology design manual. **422**

MOS ICs in handsome Electronic Arrays 12-pg brochure. **423**

SCRs for inverters in 24-pg International Rectifier brochure. **424**

Thumbwheels and pushbutton switches in 48-pg Digitran catalog. **425**

Board - to - board interconnections in Elco 16 pager. **426**

A/D and D/A conversion in Datel 14-pg jacket catalog. **427**

High-sensitivity cradle relays in Allied Control 14 pager. **428**

Quick-connect solderless terminals in Amp 32-pg catalog. **429**

Automatic impedance measurement in GR 12 pager. **430**

Magnetostrictive delay-line memories in Microsonics 8 pager. **431**

Rf test equipment, subsystems in Electro Impulse 40 pager. **432**

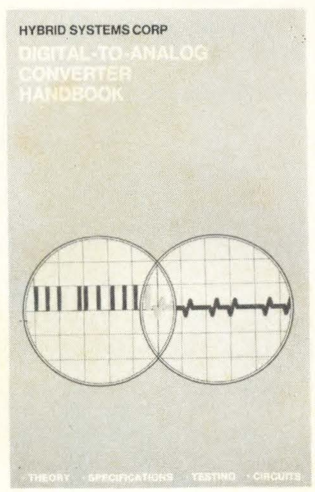
Unusual Literature

Digital-to-Analog Converter Handbook
Hybrid Systems

Here's a really fine job. It's not very useful to the man who knows everything about designing and using D/A converters, but it has a wealth of information for almost everybody else.

From the very beginning of this 92 pager, one is impressed by the logical sequence of the treatment. The author starts with a very elementary description of a very elementary DAC, then moves logically and rapidly to more complex and more real units — assisting the reader throughout with circuit diagrams, waveforms and sketches of test setups.

Throughout the presentation, he contrasts the ideal with the real and, in the process, takes a few slams at deceptive and misleading specs. He shows, for example, how the unity-gain specs of op amps can prove completely meaningless when the op amps, in fact, are to be used at a gain of nine or ten. He shows how difficult



it is to compare the specs of seemingly similar DACs. He takes the important specs (including some that are often omitted) and shows how they are influenced by deficiencies of real-life components.

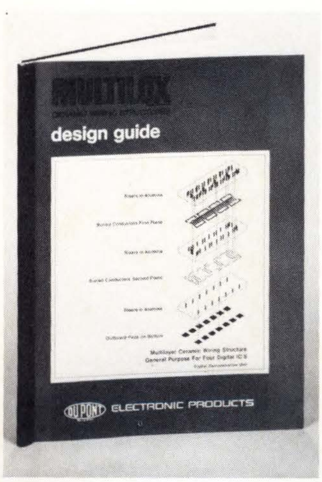
The style is refreshing, too. The author tends to stay away from a mathematical treatment except for a few places where, almost reluctantly, he offers some math "for those who revel in equations." He tries to keep the tone serious, but he breaks down at times, as when he relates the tale of the scientist, the engineer and the nude.

This is a book that will bear reading more than once. For a copy, circle **434.**

Multilox
Ceramic wiring structures
Design guide
Du Pont

Here's a description of a packaging technique that's very new, yet very reminiscent of two very old techniques, both dead. Whether DuPont knows it or not, its new multilayer-ceramic wiring system goes back philosophically to the Tinkertoy project of the Forties (which died when transistors started shoving tubes out of the picture) and to the Micromodule project of the late Fifties (which died as ICs began to take over).

DuPont's Multilox approach, detailed carefully and clearly in this 14-page brochure, differs in many important respects from the earlier ones. First, it's a packaging technique designed for a fast-growing technology — hybrid thin-film or thick-film circuitry.



Second, it extends the packaging density of components like semiconductor chips which are already tiny. Third, it can use interconnecting risers *through* the ceramic layers rather than merely around their periphery. Finally, individual layers can have buried conductor planes, so an entire multilayer circuit can be hermetically sealed.

This booklet provides design guidelines, specs and fine information on what can be accomplished easily with this packaging technique and what presents difficulties.

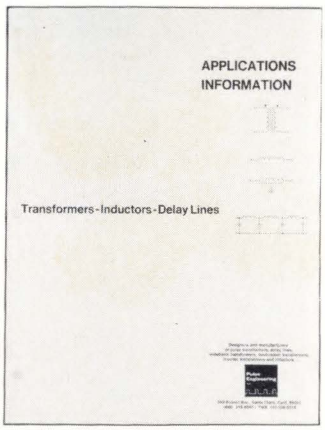
For a copy, circle **439.**

Applications Information
Transformers - Inductors - Delay Lines
Pulse Engineering

Though it could have been improved, this 36 pager is about as handy a collection of material on inductive circuits as you're likely to find. The stress is entirely practical, with almost no theoretical background.

The author starts with basic definitions and abbreviations, most of which we learned in elementary courses and many of which we've since forgotten. He then shows how to measure the basic parameters, using specific, popular test instruments, most of which you're likely to have in the lab.

He gives design procedures for the most popular coupling circuits and blocking oscillator circuits and provides two time-saving nomograms.



Finally, and here's where the presentation slips, he gives dozens of circuits, organized loosely in three different applications categories — computer applications, instrumentation applications; and control, modulation and power-supply applications.

These circuits are taken from several sources including Pulse Engineering's own engineering department, the pages of GE's SCR manual, Electronics and EEE. Unfortunately, in some cases the circuits are very old, dating back to 1959. Now, in itself, there's nothing wrong with an old circuit, but one wonders how many engineers today will design new equipment with vacuum tubes.

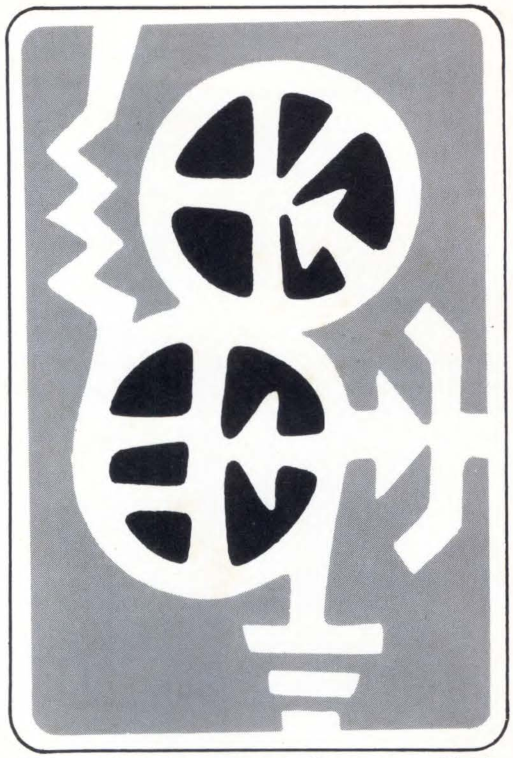
Further, though the author was careful to indicate part numbers for all transformers, inductors and delay lines, he wasn't always so rigorous in marking other components.

Despite these small deficiencies, the manual can prove to be an extremely useful backgrounder and reference. For a copy, circle **433.**

CIRCUIT DESIGN AWARD PROGRAM

UNUSUAL CIRCUITS □ Designed by EEE's readers □ For use by EEE's readers □ Voted on by EEE's readers.
Your vote determines the winner of the monthly $100 U. S. Savings Bond. All monthly winners are finalists of this year's $1000 U. S. Savings Bond grand award. All other circuits published each month win a $25 U. S. Savings Bond consolation award.

VOTE NOW . . . The ballot is on the reader inquiry card.
Submit your own circuit, too. Mail entries to Circuit Design Program Editor, EEE, Mactier Publishing Corp., 820 Second Ave., New York, N. Y. 10017.



EEE readers have voted Norman J. Webb winner of the $100 Savings Bond for May. The winning circuit design is "Low-cost 60-Hz sync." Mr. Webb is with Si-Con Signal Control in Penfield, N. Y.

Self-contained crystal tester

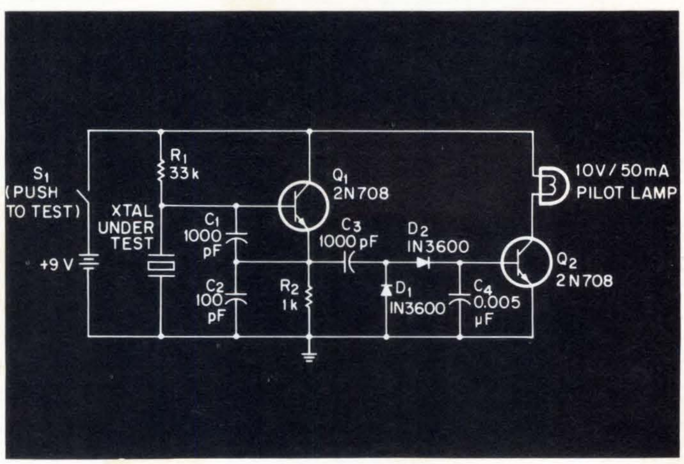
Circuit Design No. 4

by Mike Kaufman
Hughes Aircraft
Sherman Oaks, Calif.

TWO TRANSISTORS and a handful of components combine to produce a crystal tester. The crystal to be tested is inserted into a test socket and switch S_1 depressed. If the crystal is good (i.e., if it oscillates) the pilot lamp glows; if the crystal is bad the pilot lamp remains off. The entire unit can be battery operated and will fit into a 2 × 4 × 1½-in. package.

Transistor Q_1 and associated components form an untuned Colpitts oscillator which can oscillate over a wide range of crystal frequencies. When a good crystal is being tested, several volts pk-pk appear across R_2. This ac voltage is level shifted by C_3-D_1, peak detected by C_4-D_2 and the resultant dc voltage used to turn on Q_2 which turns on the pilot lamp. A non-oscillating crystal produces no drive to Q_2 and the lamp remains off.

This unit has been used to test crystals ranging from 3.5 to 90 MHz. Crystals which fail the test generally have broken leads or dirty contacts. ■



This simple go/no-go tester checks crystals over a frequency range of 3.5 MHz to 90 MHz.

Circuit of the Year 1969
Grand Prize Winner

EEE readers have chosen Albert J. Marek as winner of the annual $1000 U. S. Savings Bond for his circuit, "Simple zero-crossing solid-state switch." This circuit, which originally appeared in the December 1969 issue, was published in condensed form in March 1970.

Mr. Marek received his BSEE from Texas A&M in 1950 then, in January 1952, he went to work for LTV Aerospace. He's now Engineering Specialist in the company's Electrical and Electronic Design Group.

He has worked on many R&D studies on the use of semiconductors in flight-vehicle power switching and control, has written several articles on the subject and holds patents on components using solid-state-switching techniques. His hobbies include bowling, water-color painting and bridge.

Automatic telephone recorder

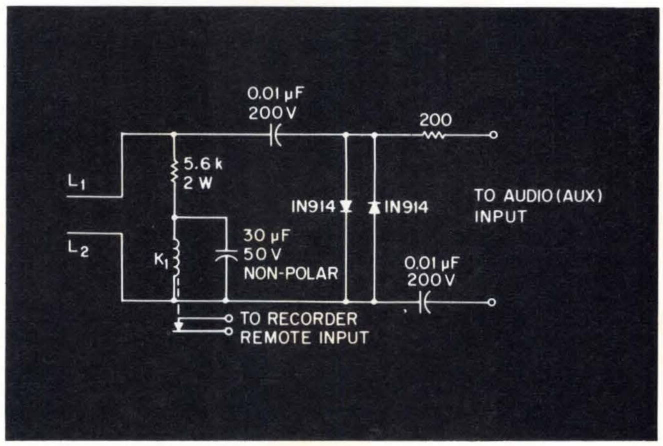
Circuit Design No. 5

by Harry Metz
Message and Transmission Systems
The Bronx, N. Y.

THIS SIMPLE CIRCUIT automatically turns on a tape recorder when a telephone receiver is lifted. Normally, there's 48 Vdc across L_1-L_2, the input wires to the telephone. That's enough to energize relay K_1, whose contacts (which go to the tape recorder's remote-switch input) are held open.

The dc resistance of K_1's coil plus the series resistor should be high enough to avoid producing an "off-hook" indication, which requires less than 2 kΩ. The ringing voltage, 90 V 20 Hz, doesn't get to the recorder's audio input because of the 1N914 diode pair, and it doesn't affect the relay coil because of the 30-μF capacitor.

When the receiver is lifted, the phone's varistor produces about 6 Vdc across L_1-L_2. That's low enough to allow K_1 to drop out; it's contacts close and start the recorder. The audio voltage across L_1-L_2 is low enough so the diode pair doesn't introduce distortion. ■



The circuit starts a tape recorder when a telephone receiver is lifted to make a call or receive one. The relay is a Sigma 65F1A —24 Vdc or equivalent.

Bipolar analog/digital interface for servos

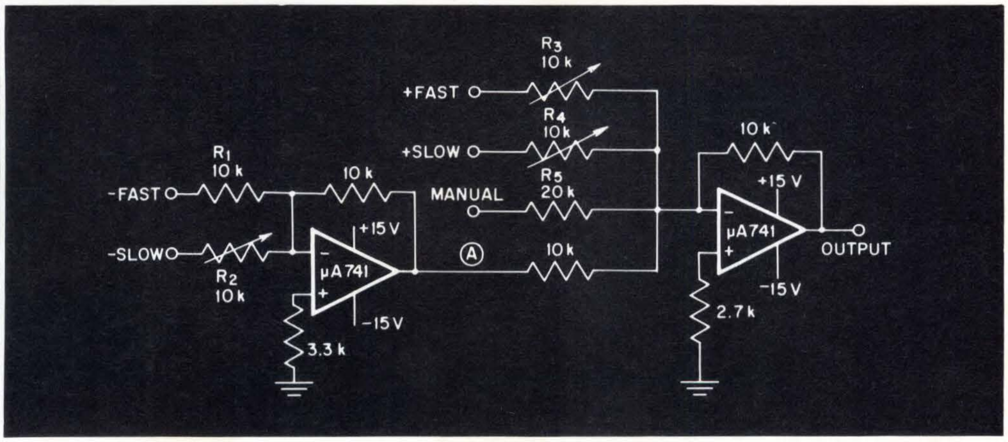
Circuit Design No. 6

by James E. McAlister
Texas Instruments
Dallas, Tex.

VELOCITY SERVOS often require a positive input voltage for drive in one direction and a negative input for motion in the opposite direction. When a system must provide bidirectional motion for both analog and digital inputs, some sort of interface must be provided.

The configuration in the

(Continued on page 86)



This circuit interfaces between digital or bipolar analog signals and a bi-directional servo.

figure accepts both bipolar manual input (from a speed control, for example) and input logic levels (+ for forward, − for reverse) from digital circuits to provide a bipolar output compatible with the servo input. Resistors R_1 to R_4 provide means for independently adjusting the gain of each channel.

The circuit accepts signals for fast or slow motion in either direction. The "Manual" input can be continuously variable from −15 V to +15 V. The other four inputs take 5-V logic.

At point A, the voltage will be zero when the "−Slow" or "−Fast" input is at 0 V. The voltage at A will be +2 V or +8 V, respectively, for "−Slow" or "−Fast" inputs of +5 V (adjustable to suit the motor being driven). The output can vary between −10 V and +10 V. ■

Optically driven pulse stretcher

Circuit Design No. 7

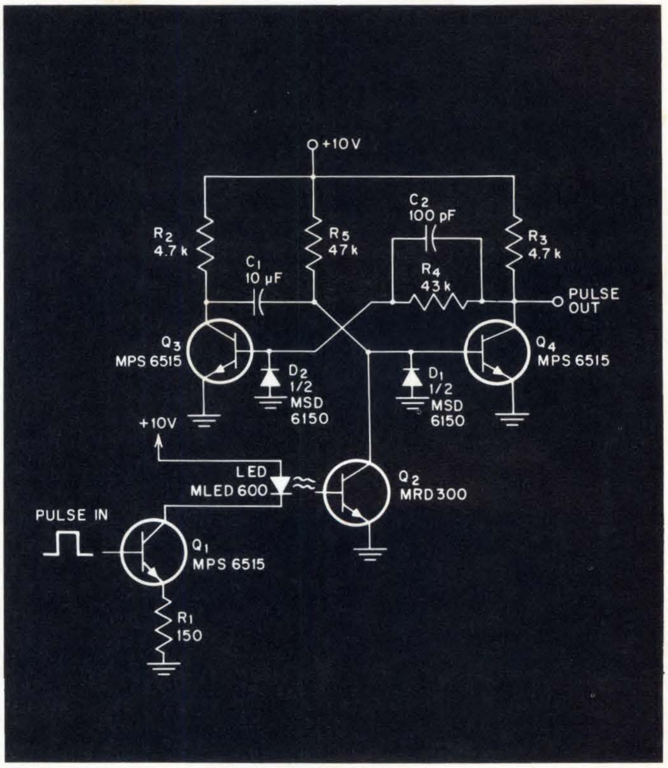
by John Bliss
Motorola Semiconductor
Phoenix, Arizona

A LIGHT-EMITTING diode and a phototransistor can be used to drive a pulse stretcher, as in Fig. 1. In this circuit, Q_4 is the normally-on transistor in a monostable multi.

When an input pulse drives the LED, phototransistor Q_2, which is photon coupled to the LED, causes Q_4 to turn off and Q_3 to turn on.

The base of Q_4 is held to $V_{CE(SAT)}$ of the phototransistor until the input pulse drops to zero. At this time C_1 begins to change toward +10 V. When the base of Q_4 reaches about 0.6 V, the circuit resets and Q_4 comes on while Q_3 goes off. The delay, or "stretch" time, after the trailing edge of the input pulse is a function of the R_5C_1 time constant, the supply voltage, the phototransistor saturation voltage and the turn-on voltage of Q_4.

For the values shown, a 3-μs input pulse creates a 55-ms output pulse with an amplitude from $V_{CE(SAT)}$ to V_{CC}. ■



A monostable multi serves as a pulse stretcher, driven by a phototransistor which is triggered by light coupled from a LED.

Crystal oscillator uses logic gates

Circuit Design No. 8

by **Stuart D. Culp**
General Electric
Aerospace Electronics Dept.
Utica, N.Y.

THE CRYSTAL OSCILLATOR in the figure is simple and stable. Since it uses no reactive-component resonators, it's physically small and easily packaged.

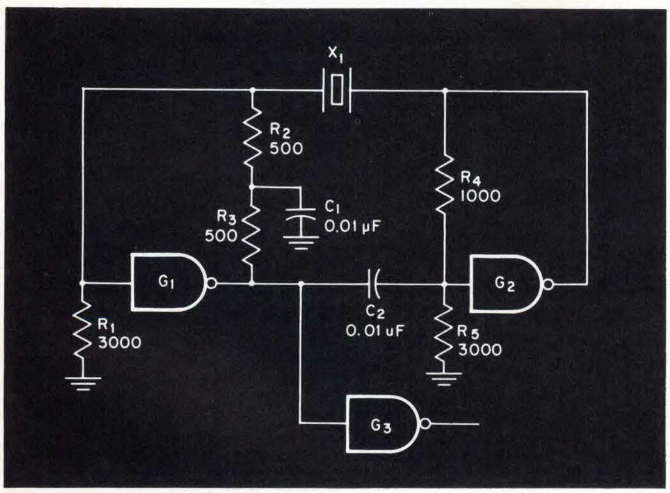
The circuit has two logic gates, G_1 and G_2, biased approximately in their linear region and connected through the crystal to form a positive-feedback loop. A third gate, G_3, buffers the loop signal and delivers the output, which is approximately a square wave with a duty cycle of about 40 percent.

Any of the DTL/TTL families can be used, but the particular gate used should be a buffer type with low output impedance in the high or low state. A 932 buffer was used in the circuit shown.

Frequency stability is essentially that of the crystal, which operates in the series mode on the fundamental frequency (1 to 3 MHz in this circuit). The circuit sees the crystal's series resistance so, at the frequency of interest, the resistance should be low compared with that at spurious frequencies.

The feedback resistors should be chosen to bias the gate input to the approximate center of its 1/0 swing. Over the voltage and temperature range that a particular logic family will see, the feedback should be chosen so that a "1" output results in a "0" input and vice versa, making certain that input-impedance effects are not neglected. The crystal should work into a relatively high impedance, but if R_1, R_2 and R_3 are too large, the gate output can no longer feed back a proper bias to its input and a "1" output can no longer drive the input to "0" or near "0."

Capacitor C_1 eliminates ac from G_1's negative-feedback path while C_2 isolates the G_1 and G_2 dc-bias loops, the ac output impedance of G_1 effectively eliminating ac feedback from G_2's input. ■



This entire crystal oscillator is powered by the nominal 5 V used by the logic gates, but it starts and runs reliably with voltages from 3.8 V to 7 V over −55 to +125°C.

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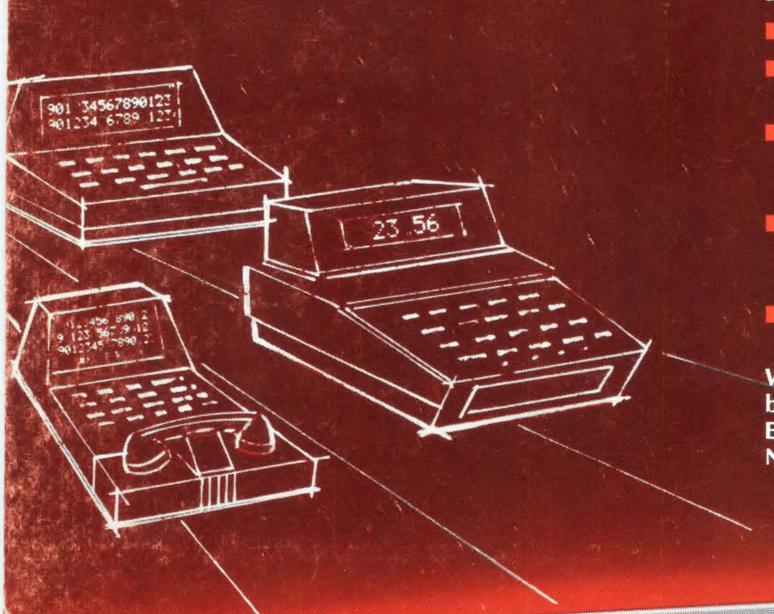

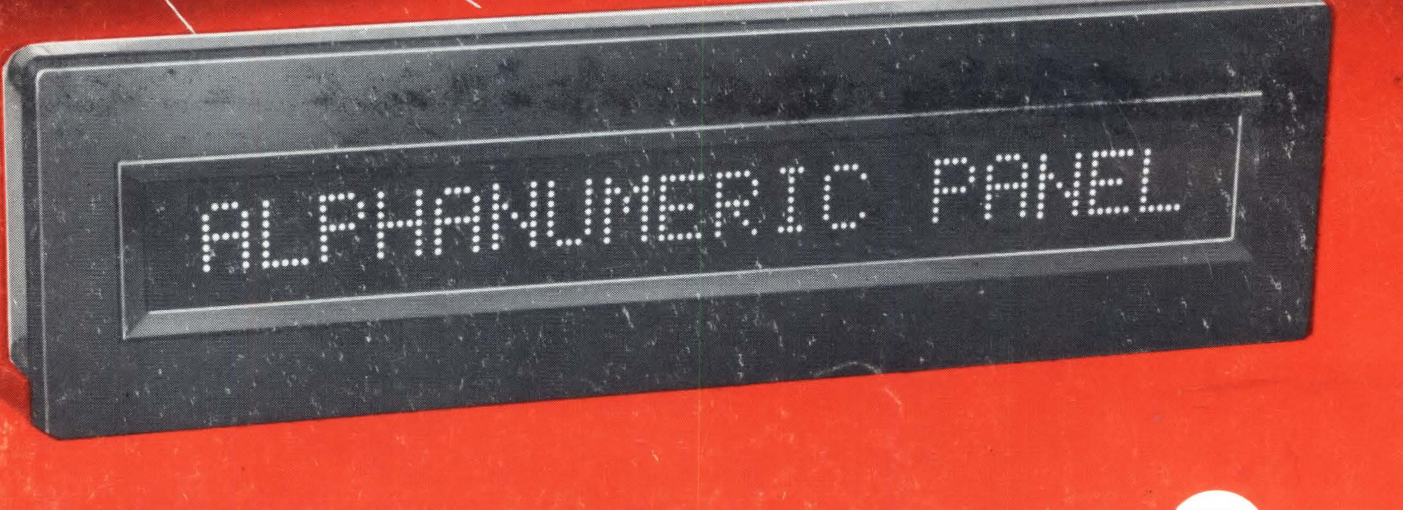

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