September 1970 / Volume 18 / Number 9

EEE

EXCLUSIVELY FOR DESIGN DECISIONS

Walt Hirschberg of ACDC Speaks Out On What's Wrong With Miniature-Power-Supply Specs

Designer's Guide: D/A Converters

MOS FET Biasing Techniques

Wideband Op Amps

Intech plays the game without spikes.

If you've had uncertain feelings about chopper op amps, you've had just cause.

The Op Amp Boys have been making noise about chopper performances when the amplifiers they offered were only useful with elaborate filters.

Sometimes you were "spiked." But good.

Intech's got the quiet answer to your historically noisy problem: the A-240 series chopper operational amplifiers. These uniquely designed units virtually eliminate chopper spikes. This feature alone makes the A-240 series the first choppers to be use in wideband applications without the use of special filters.

In fact, the engineers who have evaluated the A-240 series can't even distinguish the chopper frequency.

While the Op Amp Boys drift from one performance spec to another, the Intech A-241 holds its own at **.05μV/°C.** maximum. Yes, that's right! **.05μV/°C maximum.** Low frequency input noise voltage stands at **1.0μV** p-p maximum.

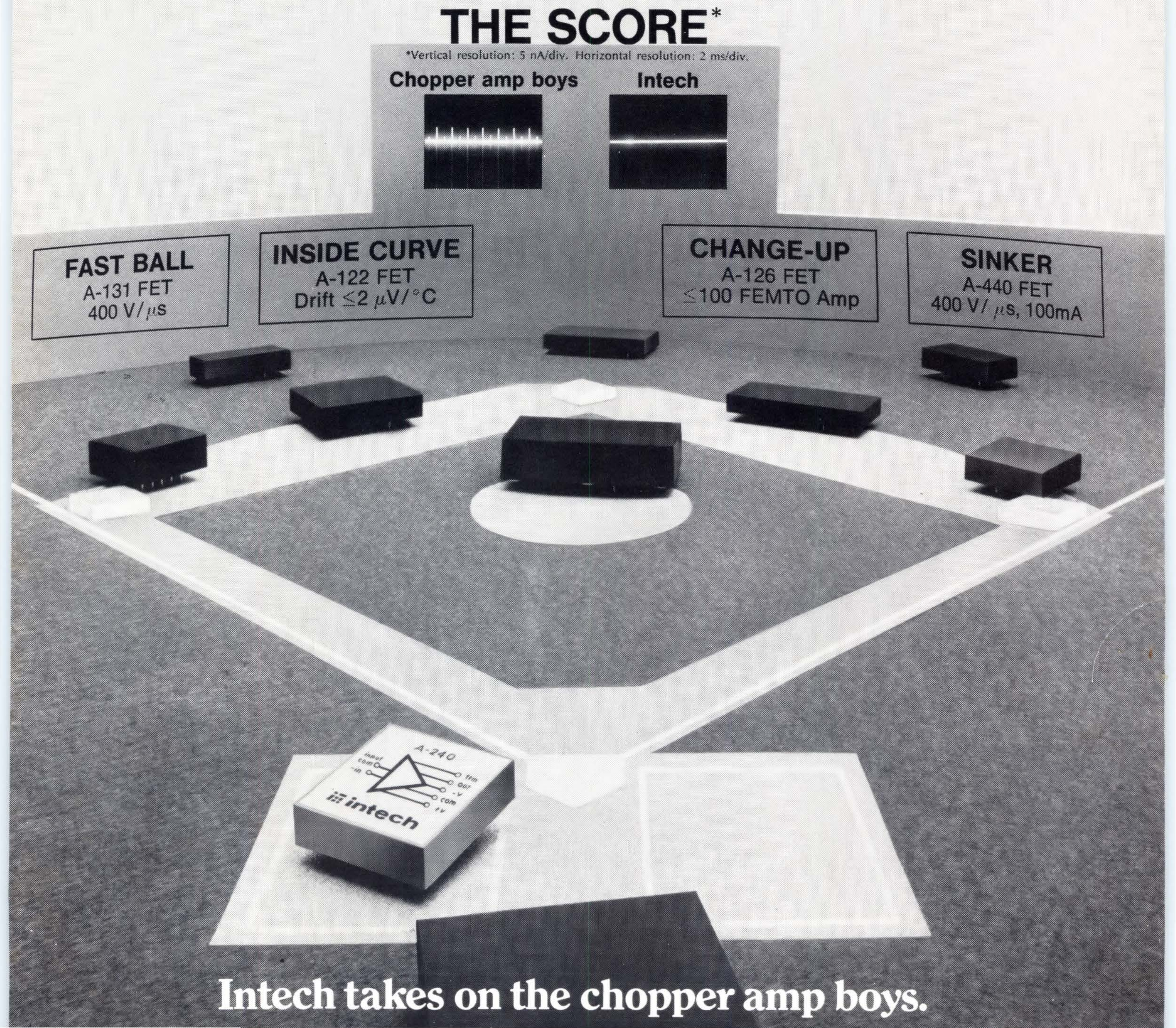
Compare that to the "old" chopper amplifier specifications.

Intech does not make idle claims. Try the A-240 on a trial basis. You'll experience what we're proclaiming. The units, packaged in 1.5" x 1.5" x .5" modules, are $91.00 each (quantity discounts available) and are available from factory and distributor stock.

If you want to get back into the ballgame, contact your local Intech representative, or write us directly using this publication's reader service card, for more information and comparison studies on the A-240 series.

Intech Incorporated, 1220 Coleman Avenue, Santa Clara, California 95050.
Phone: (408) 244-0500.

intech



Intech takes on the chopper amp boys.

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EEE
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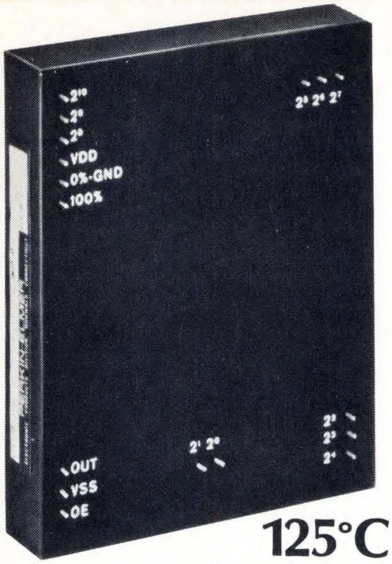
Photo by
Nils Ljunquist
Story on page 36

PROGRESS . . . in Design and Research

FEATURES

CIRCUIT DESIGN AWARD PROGRAM

DEPARTMENTS



125°C doesn't bother our D/A Converters a bit.

(not even half a bit)

Over the range of −55°C to +125°C you maintain half bit accuracy, *as well as 11 or 12 bit resolution* — a stability which spans a full 180°C. This high performance level of Perkin-Elmer precision digital to analog converters is based on the utilization of our patented principal of vernier transformer windings. There is no drift or degradation over the life of the unit.

Each D/A unit is encapsulated in a rugged package containing a series of windings switched by MOSFET IC's. The logic input lines can be used directly with 5.0 V levels and units compatible with 0.4 V and 2.4 V logic levels for TTL are available.

These precision converters have wide applications in synchro and servo controls, interfacing digital and analog systems, for shipborne or air data computers, fire control systems and drivers for analog display.

Numerous applications in the machine tool and process control industries are also possible since the frequency range is not limited to 400 Hz. For information on standard models, including bipolar or custom units for a specific application, just write or call: Electronic Products Department, Industrial Products Division, The Perkin-Elmer Corporation, 131 Danbury Road, Wilton, Conn. 06897. (203) 762-6574. Vernistat® AC pots, Scott T's and other toroidal transformers are specialties of ours too.

PERKIN-ELMER

Circle 101 on Inquiry Card

EEE

EXCLUSIVELY FOR DESIGN DECISIONS

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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:

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- 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.

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who back it up:

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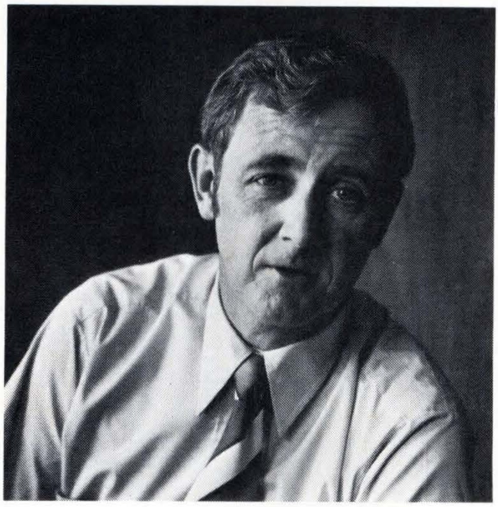


"If I told you Signetics really delivers MSI, you'd tell me to prove it.

"So–effective Sept. 15 to Oct. 15– Signetics makes this challenge:

"If you order MSI from stock– and we don't ship them to you within ten working days– you get up to 100 units free.

"I guarantee it. Personally."

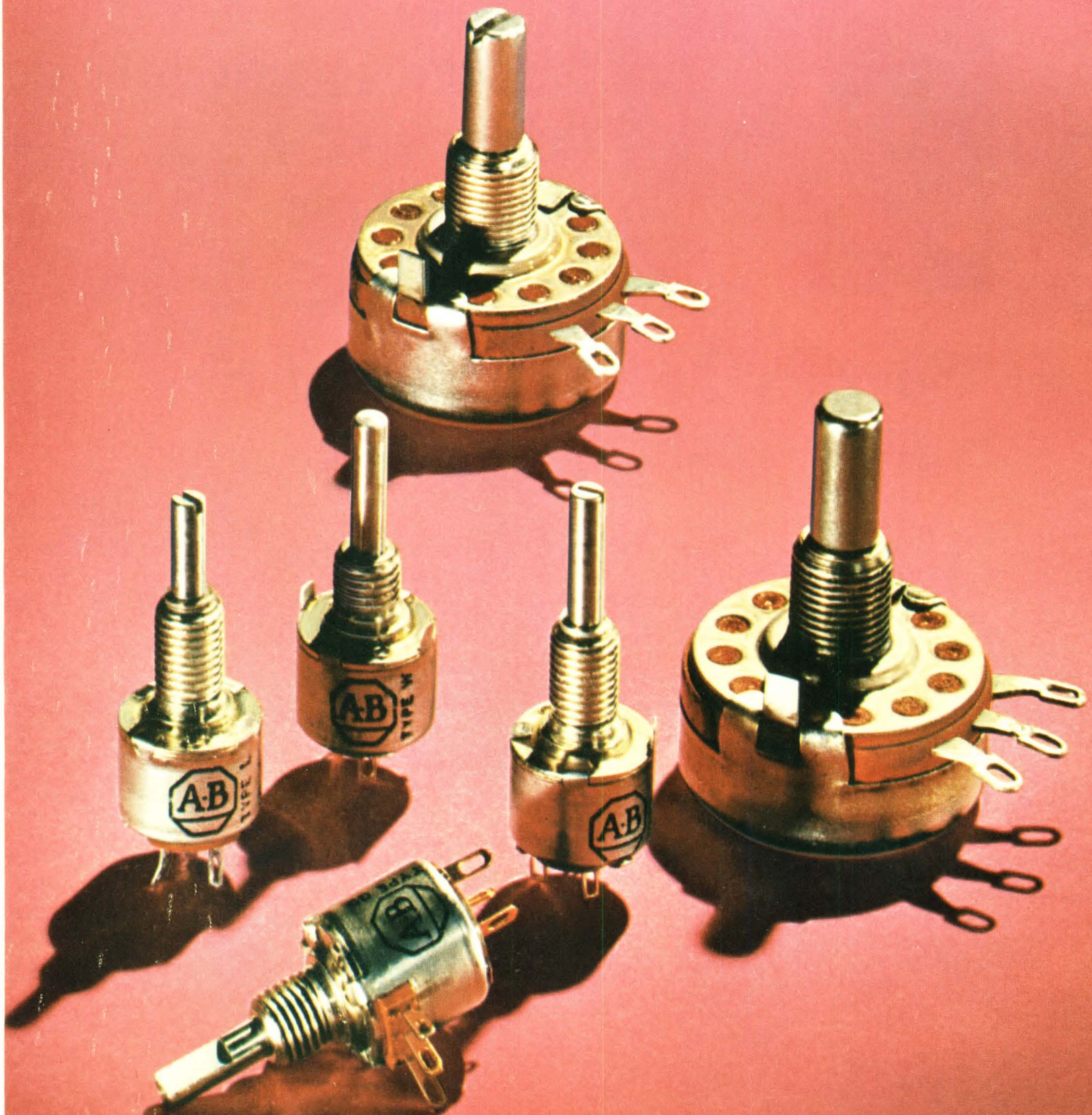
Jim Riley

James F. Riley
President
Signetics Corporation

The Signetics Guarantee. We guarantee shipment of MSI from stock within ten (10) working days ARO, or customer will receive, without charge, the first 100 units or the quantity ordered, whichever is less, of each delinquent device type. This guarantee applies to all new single orders placed between September 15 and October 15, 1970 with Signetics' distributors for immediate shipment of quantities up to 4,999 of N8200 and N8T00 products in silicone DIP. Void if order is cancelled or reduced. Signetics Corporation, 811 East Arques Avenue, Sunnyvale, California 94086 / A subsidiary of Corning Glass Works

Circle 102 on Inquiry Card

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.

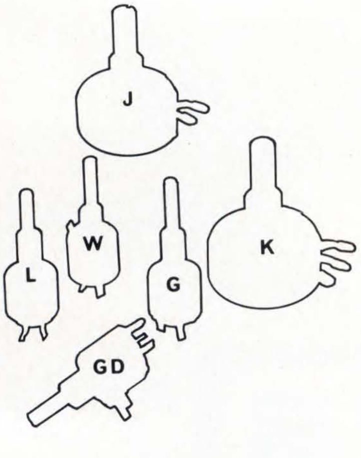
This important Allen-Bradley difference means better short-time overload capacity and a long operating life. Control is smooth, resolution almost infinite. These variable resistors are ideal for high frequency circuits. Why should you trust the performance of your designs or your reputation to anything 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.

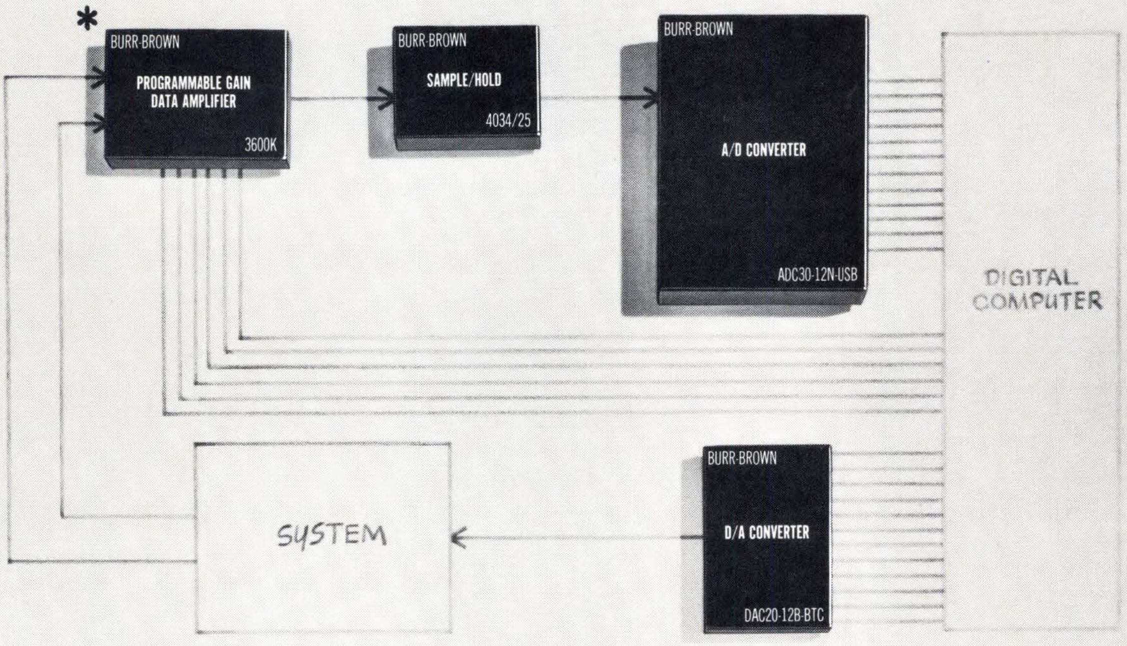
ALLEN-BRADLEY



NEW DIMENSION ELECTRONICS

Circle 103 on Inquiry Card

We've added a little something to the Burr-Brown line of computer interface and data acquisition modules



*a small, programmable gain data amplifier

Our new Model 3600K programmable gain data amplifier has a distinct advantage over its big, rack-mount counterparts in high-performance data acquisition applications. The low price (just $245) coupled with the small size (3.0" x 2.1" x 0.4") makes it feasible to assign amplifiers to smaller groups of signals and locate them closer to the signal source for better resolution. Designed to operate on multiplexed low-level signals under computer control, the 3600K rejects common mode noise and provides proper scaling prior to A/D conversion. Naturally, it's compatible with Burr-Brown's other interface and data acquisition modules.

For help with your Analog/Digital conversion and interface problems phone (602) 294-1431, collect, and ask for your Regional Applications Engineer.

PROGRAMMABLE GAIN DATA AMPLIFIER Model 3600K Size: 3.0" x 2.1" x 0.4" Price (1 to 9 units): $245	Gain accuracy: Linearity: Common mode rejection: Voltage drift: Settling time:	±0.1% ±0.01% 100 dB ±1 μV/°C 500 μsec
A/D CONVERTERS Size: 3.4" x 4.4" x 0.8" Price (1 to 9 units): 8-bit $195.00 10-bit $225.00 12-bit $295.00	High speed: Low drift: Optional input buffer amplifier. Four popular digital codes	30 μsec* 20 ppm/°C* *10-bit unit.
D/A CONVERTERS Size: 3.0" x 2.1" x 0.4" Price (1 to 9 units): 8-bit $ 95.00 10-bit $125.00 12-bit $155.00	High speed: Low drift: Four popular input codes	1.5 μsec* 20 ppm/°C* *10-bit unit.
SAMPLE/HOLD Model 4034/25 Size: 2.4" x 1.8" x .60" Price (1 to 9 units): $110.00	Gain accuracy: Input impedance:	50 MΩ ±0.01% **Three other catalog units also available.**

BURR-BROWN
RESEARCH CORPORATION
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Operational Amplifiers
Instrumentation Amplifiers
Active Filters
Multiplier / Dividers
A/D-D/A Converters

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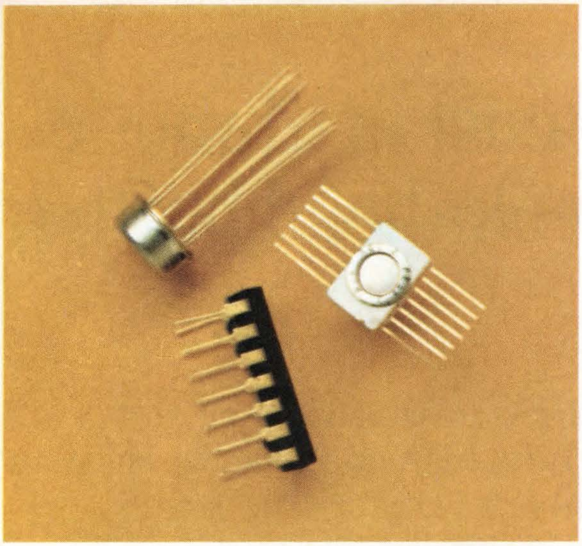
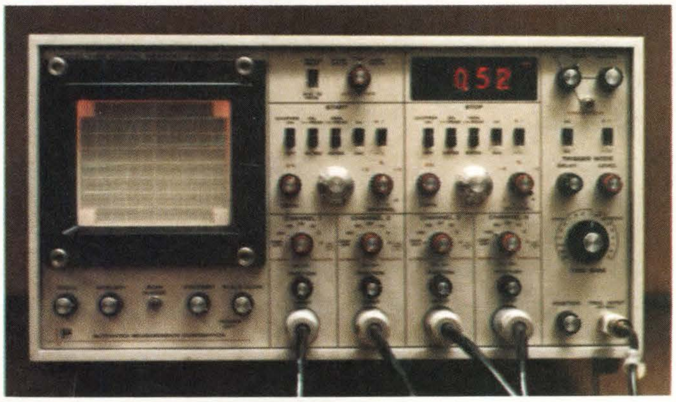
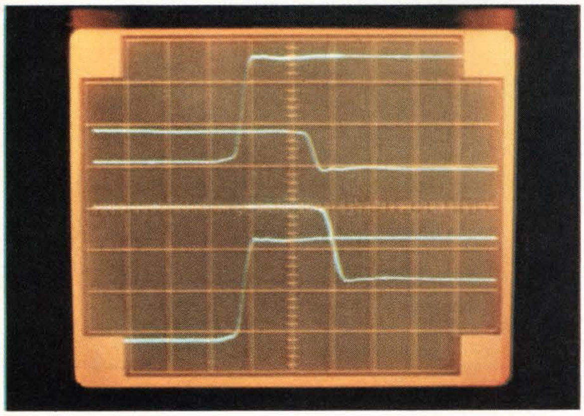






E-H
the simple solution

If you want to simplify your testing operations to the point where a relatively untrained technician can make sophisticated tests with complete confidence and accuracy, E-H Research Laboratories, Inc., and its subsidiary, Automated Measurements Corporation, offer the simple solution.

First, take a look at the **AMC Model 1100 Digital Readout Oscilloscope.** It's the only four-channel, four-trace digital readout oscilloscope on the market. It was developed for the most versatile laboratory and benchtop applications, using remote sampling units to give you greater freedom in your testing operations. It has the capability for simultaneous viewing of four waveforms. And the digital display can show time accuracy to 1% f.s. and voltage accuracy to 1% f.s.

The ideal driver for the AMC Model 1100 is the **E-H 135 Pulse Generator.** It's fondly called the Universal Pulser because of its great versatility and capability of handling just about any pulser requirement you might have today and for some time to come. The E-H 135 is the only 50 MHz pulser available that has unattenuated baseline offset to ±5V into 50 ohms. It also features rise and fall times of from 3 ns to greater than 8 ms.

The two instruments mentioned above are just a sample of a complete line of E-H and AMC equipment available. So no matter how complex your testing problems are, get to the simple solution fast. Contact your E-H representative today.

E-H RESEARCH LABORATORIES, INC.

515 Eleventh Street · Box 1289, Oakland, California 94604 · Phone: (415) 834-3030 · TWX 910-366-7258
In Europe: E-H Research Laboratories (Ned) N.V., Box 1018, Eindhoven, The Netherlands, Telex 51116
In Japan: Iwatsu Electric Company, Ltd., 7-41, 1-Chome Kugayama Suginami-Ku, Tokyo 167, Japan

Circle 105 on Inquiry Card

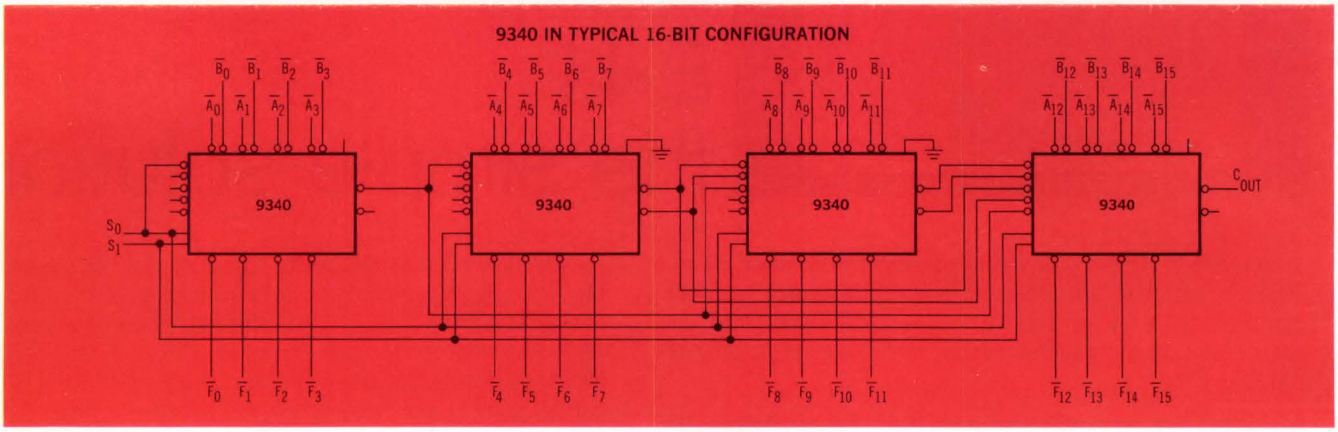
To make the lowest-cost arithmetic logic unit with carry lookahead built-in,

Fairchild's new 9340 is the perfect arithmetic logic unit for almost every application. It's a high-speed device that can perform two arithmetic operations (ADD or SUBTRACT) and any of six logic operations on two 4-bit binary words in parallel. To handle 16 bits, just hook up four 9340s. And nothing else.

The 9340 can ADD two 4-bit words in 28ns and SUBTRACT two 4-bit words in 33ns. The addition of two 16-bit words takes only 42ns.

The new ALU has full internal carry lookahead, and provides either a ripple carry output or carry lookahead outputs. The speed and flexibility of the 9340 make it ideal for other applications like multipliers, dividers and comparators.

Input clamp diodes are used on all inputs to limit high speed termination effects in the 9340. Input/output characteristics provide easy interfacing with all Fairchild DTμL, TTμL and MSI families.



9340 IN TYPICAL 16-BIT CONFIGURATION

To order the 9340, call your Fairchild Distributor and ask for:

PART NUMBER	PACKAGE	TEMPERATURE RANGE		PRICE	
			(1-24)	(25-99)	(100-999)
U6N934059X	DIP	0°C to + 75°C	$20.90	$16.70	$14.00
U6N934051X	DIP	−55°C to +125°C	41.80	33.40	28.00
U4M934059X	Flat	0°C to + 75°C	23.00	18.40	15.40
U4M934051X	Flat	−55°C to +125°C	46.00	36.80	30.80

you have to get serious about MSI family planning.

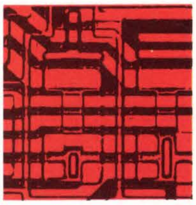
We put together a family plan by taking systems apart. All kinds of digital systems. Thousands of them.

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.

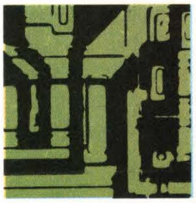
Inside each of the seven categories, we sifted by application. We wanted to design the minimum number of devices that could do the maximum number of things. That's why, for example, Fairchild MSI registers can be used in storage, in shifting, in counting and in conversion applications. And you'll find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

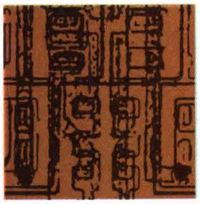
The Fairchild MSI family plan. A new approach to MSI that's as old as the industrial revolution. It started with functional simplicity, extended through multi-use component parts, and concluded with a sharp reduction in add-ons. Simplicity. Versatility. Compatibility. Available now. In military or industrial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



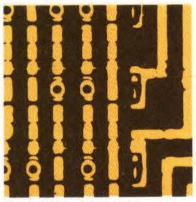
OPERATORS
9304 – Dual Full Adder/Parity Generator
9340 – Arithmetic Logic Unit



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

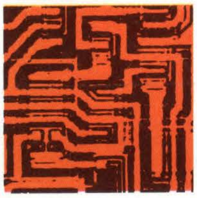


REGISTERS
9300 – 4-Bit Shift Register
9328 – Dual 8-Bit Shift Register

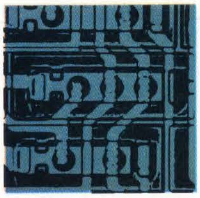


MULTIPLEXERS
9309—Dual 4 Input Digital Multiplexer
9312—8-Input Digital Multiplexer
9322—Quad 2-Input Digital Multiplexer

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

Circle 106 on Inquiry Card

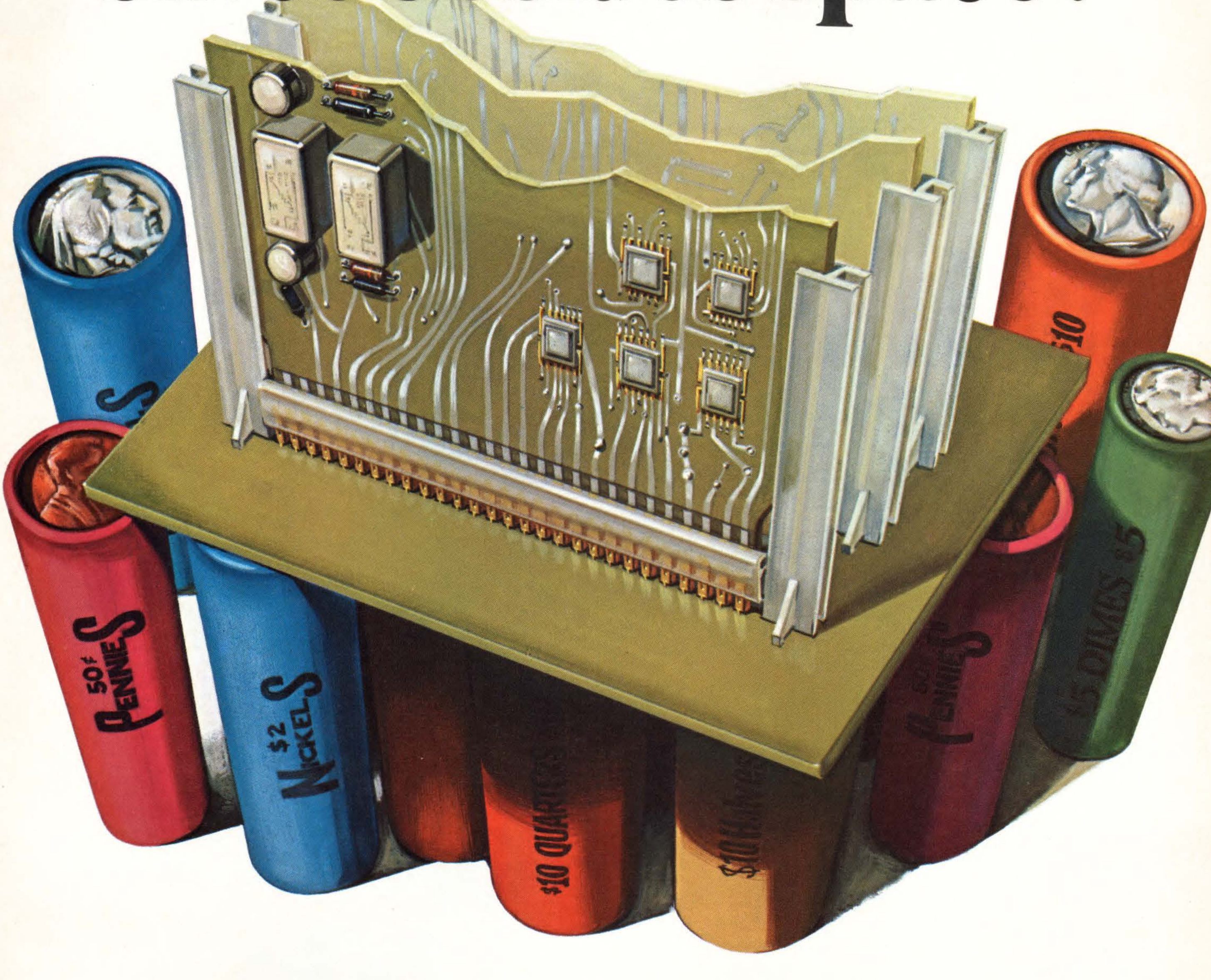
helps you keep a low profile

It's small. Only 3⅜ x 2⅝ x 1⅛ in. Yet it's capable of 80 watts output, 50 watts internal dissipation at 90°C case temperature. Its high open-loop gain and low distortion make it an ideal choice for driving DC torque motors, servo motors, Sonar transducers and other applications where maximum performance and minimum space requirements are essential.

You won't even need a heat sink if you're operating short term high peak periods with moderate average power levels. Give Inland a call for all your amplifier requirements. But think of us first at the early design stages, when we can help you eliminate interface problems because of our systems capabilities through our affiliated divisions.

INLAND
CONTROLS
A DIVISION OF
KOLLMORGEN

Guess what our new TWIN-LEAF* connector saves besides space?



That's right. This new connector takes up very little space. For very little money.

You can choose from four different centerline spacings. Two of them—.100″ and .125″—nobody else makes. And the other two—.150″ and .156″ with *bifurcated* contacts—are the same spacings as anyone else's.

But that's all that's the same. You can get from 6 to 100 contacts (by 2's) per connector. Contacts are phosphor bronze with gold over nickel plating on contact area, and bright tin plated solder posts. Our card guides can handle two adjacent cards at the same time. There's also the unique stand-off feature of the connector housing. It exposes the contacts so you can make electrical continuity probes without damaging the contact area.

This pre-loaded TWIN-LEAF★ connector has proven to be adaptable to every mother-daughter board application known. And its future applications wait only for your imagination.

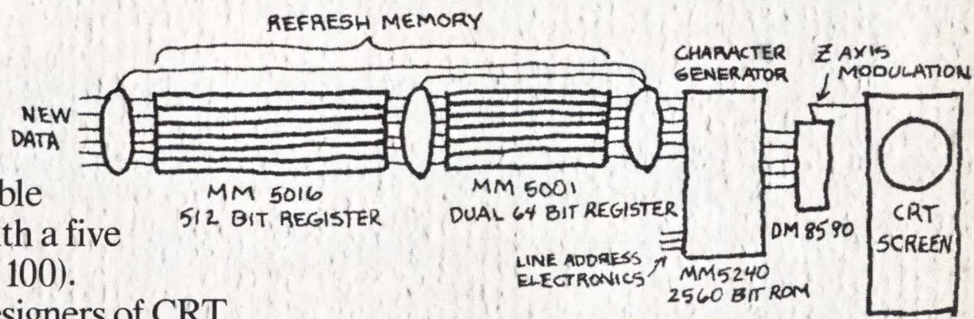
For more information on how you can save money and space on all your mother-daughter board applications write to **Industrial Division, AMP Incorporated, Harrisburg, Pa. 17105.**

AMP
INCORPORATED

National sells MOS than Fairch TI and Signetics

Guess which one is selling shift registers at a penny a bit.

more
ild, Motorola,
combined.



Who else?

National just came out with the MM5016, a bipolar compatible 512-bit dynamic shift register with a five dollar price tag (in quantities of 100). The MM5016 should interest designers of CRT refresh memories, radar delay lines or fast access drum memories. And engineers looking for a small and stable replacement for glass and magnetostrictive delay lines.

Now guess who's selling 600ns ROM's.

National again. We just introduced the MM5240, a bipolar compatible, 2560 bit character generator that offers you off-the-shelf standard fonts in addition to its blazing speed. We've priced the MM5240 at $30.00 (in quantities of 100) and now await orders from people involved in character generation, random logic synthesis, micro-programming and table look-up.

What else?

Well, National recently introduced still another MOS, the MM5001. The MM5001 is a dual, 64-bit dynamic shift register. Like the MM5016 and the MM5240, it's bipolar compatible. It costs just $10.80 (in quantities of 100), and you'll find the MM5001 handy in a variety of data handling and computer type applications.

All three of National's new MOS products have application in CRT refresh memories. We've written an application brief to give you all the details. The brief awaits you now at your National distributor. So do the products.

National Semiconductor Corporation,
2900 Semiconductor Drive, Santa Clara,
California 95051/Phone (408) 732-5000,
TWX (910) 339-9240.

National

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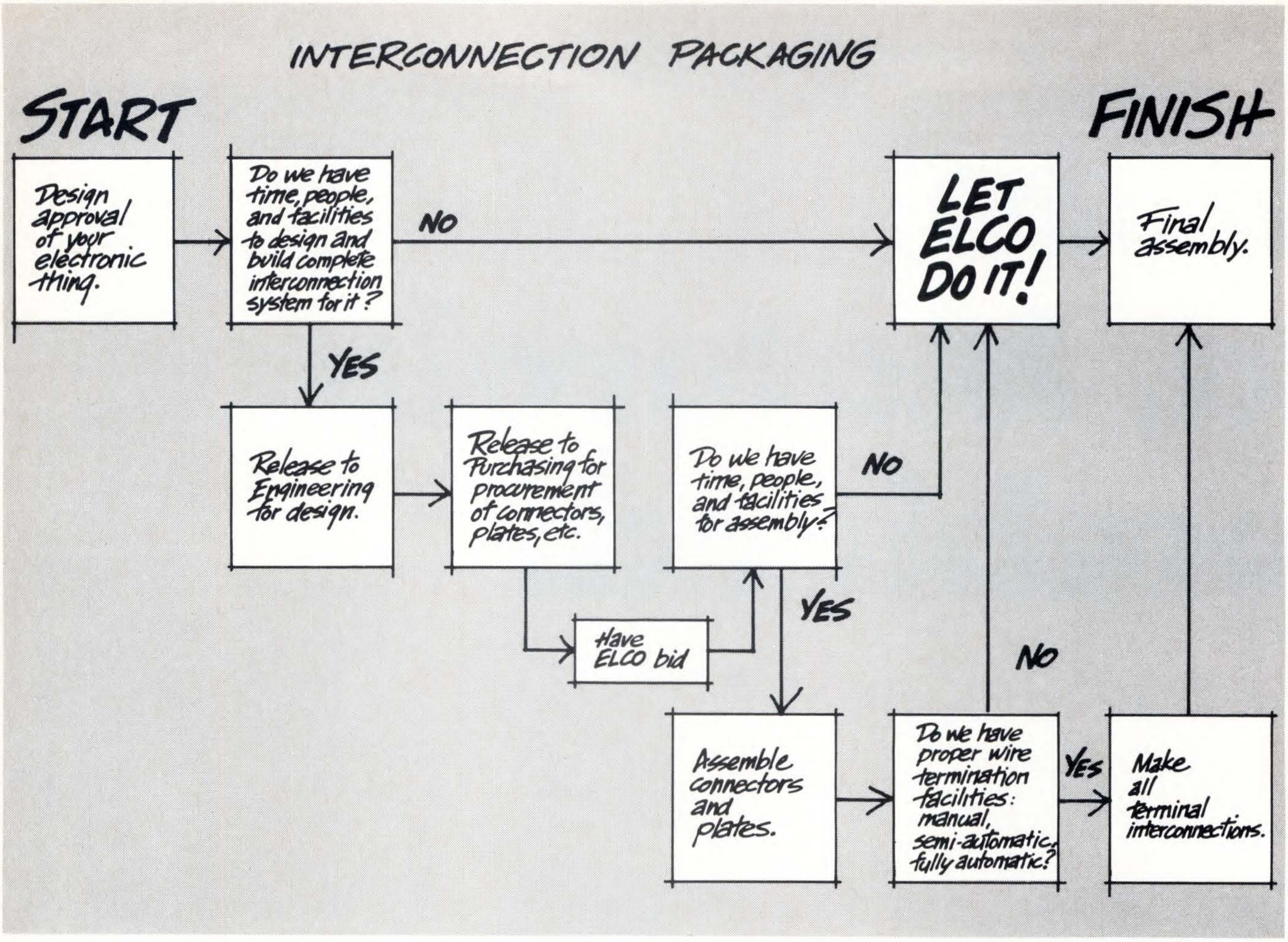


The sooner you say no, the more time and money you save.

Take the high road all the way, and you'll be done in six weeks.

The high road is our "Total Packaging Service": complete interconnection system packaging from design to wire termination.

It's saved a lot of our customers a lot of time and money. (And helped make us the largest manufacturer of metal-plate back-panel interconnection systems.)

But maybe that's more than you need.

All right.

Start at the last decision point, for instance: Should you have your production people making terminal interconnections, when they could be making something more profitable?

We think not.

Send us your back panels and wire list. We'll tie everything together for you. By hand, semi-automatically, or automatically with our Gardner-Denver think-and-do machines. You'll get an accurate job, with minimum wire lengths and densities.

Or start back a little further in the process—at the point where you have to get and assemble your connectors and back plates. We'll save you some time and money there, too.

Because.

We've got several hundred thousand standard connectors to work with. For square or offset grids. On .100", .125", .150", or .200" centers. And the plates to assemble them on. And the people to assemble them with. You can buy from us either way. With savings, either way.

But what if your requirements are definitely not standard?

Ah.

That brings us back to the beginning. Where our designers can (a) help you avoid non-standard connectors or (b) design, quickly, those that can't be avoided. Big savings there.

Whichever decision (crisis?) you're facing, between design and production, give Elco a call. Call Jim Scaminaci direct: he's our interconnections man. You can reach him at (213) 675-3311, Ext. 235. Collect. Or call, write, or TWX Joe Roos, Product Manager at Elco Corporation, Willow Grove, Pa. 19090. (215) 659-7000. TWX 510-665-5573.

ELCO Interconnection Systems

Circle 110 on Inquiry Card

Editorial

Letter from a concerned reader

Dear EEE:

I was pleased to read your editorial, "Watchful Waiting," in the July 1970 issue of EEE. You are finally showing some concern for the state of the electronics industry. But what the hell about the scientists and engineers who are being threatened with layoffs? Your total lack of concern for the welfare of your readers leads me to believe you really can't care. I will only support those magazines and groups which serve the welfare of American Science and its dedicated scientists. Please cancel my subscription to EEE.

I urge all EEs to cease their support to those elements which work against our interests, that are uninvolved or just couldn't give a damn about us.

Paul G. Snigier
Raynham, Mass.
July 18, 1970

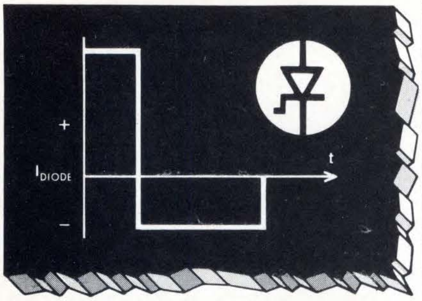
We regret that the concern expressed by our July editorial for the survival of new, struggling electronics companies could be interpreted as a lack of concern for the *EEE* reader. This conclusion does not necessarily follow.

Yes, we expressed the hope that new small companies endangered by the recession would be able to hold on until conditions improve. Many pioneering efforts in the electronics industry are now being carried out by such companies and if they're not around when the recovery comes, the industry will be the worse for it.

But certainly the plight of today's unemployed engineer is the most serious of any of the problems troubling our industry. Mr. Snigier, in his letter, expresses only concern for those individuals whose jobs are in jeopardy—does this mean that he doesn't care about the unemployed? This conclusion would be just as unfair as the one made by Mr. Snigier.

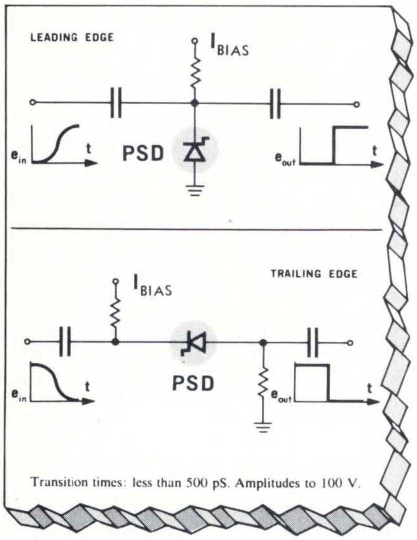
Jerry Eimbinder

Jerry Eimbinder
Editor



PULSE
SNAP
DIODE

Problem: You need to sharpen a high amplitude pulse to picosecond speeds.
Solution: The Siliconix PSD. Here's a typical application, a pulse sharpener:



Transition times: less than 500 pS. Amplitudes to 100 V.

Use the PSD for pulse squaring, delaying, area limiting and other applications, too.

Write for instant data and applications information.

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ACROSS THE Editor's Desk

Connector terminology

Dear EEE:
Your May, 1970 issue had interesting historical notes on rf connectors.

However, I disagree with the statement on page 40 that the letters "RG/U" and "UG" do not mean anything. The following explanation appeared in the July 1966 issue of "73" magazine: "The familiar 'RG'-/U, derived from 'radio guide,' was designated for rf transmission lines, both coaxial and wave-guide. The 'UG'-/U system, derived from 'union guide,' was assigned to rf connectors and adapters used with these lines. The suffix 'U' was used to indicate a 'universal' system of numbering."

Raymond F. Elsner
ITT Research Institute
Chicago, Illinois

Dear EEE:
There seems to be some room for argument over the statements made on page 40 of the May issue under "Coax cables and connectors: How they got their names." Volume II of the MIT Radiation Lab series, Technique of Microwave Measurements states in Section 1-4, ". . .the joint Army-Navy Radio Frequency Cable Coordinating Committee (ANRFCCC) was active during the war and established specifications for cables, connectors, and adapters for transmission lines of all types, including waveguides." Later-on they state "Lines are described by a number such as RG-9/U (radio guide-9/universal), and fittings by UG-21/U (union guide-21/universal)." In regard to the BNC connector the following statement is made ". . .the low frequency connector shown in Fig. 1.5 is a small connector similar to a type N connector designated as a BNC or 'baby type N' connector."

Herbert E. Dawson
Supervisory Engineer
Page Communications Engineers, Inc.
Washington, D.C.

Analog Signals

Dear EEE:
I would like to comment on two statements in Bernard Gordon's article "Digital Sampling and Recovery of Analog Signals" (*EEE,* May, 1970, pp. 65-75) and then propose an alter-

(Continued on page 20)

NEWEST
POWER SUPPLIES
FROM
ARNOLD
MAGNETICS

MULTIPLE OUTPUT DC-DC CONVERTER
FOR TTL, OP AMP, MOS, AND DISPLAY POWER
Size: 1⅝ x 3½ x 3⅝
Input: 26-30 VDC
Regulation: 2%
Ripple: .2%
Operating Temp: —55 to +85°C

Model	Outputs (Volts DC)	Price (1 pc)
SHU 200/.05-5/2	5 @ 2 Amps	$250.00
	200 @ .05 Amp	
SHU 30CT/.5-5/2	5 @ 2 Amps	275.00
	+15 @ .5 Amp	
	—15 @ .5 Amp	

Delivery: Stock — 4 weeks ARO

MULTIPLE OUTPUT AC-DC CONVERTER
FOR TTL, OP AMP, MOS, AND DISPLAY POWER
Size: 1⅝ x 3½ x 3⅝
Input: 108-130 VRMS 50-500 Hz
Regulation: 2%
Ripple: .2%
Operating Temp: —55 to +85°C

Model	Outputs (Volts DC)	Price (1 pc)
PHU 200/.05-5/2	5 @ 2 Amps	$322.00
	200 @ .05 Amp	
PHU 30CT/.5-5/2	5 @ 2 Amps	365.00
	+15 @ .5 Amp	
	—15 @ .5 Amp	

Delivery: Stock to 4 weeks ARO

100 WATT DC-SINE WAVE INVERTER
Size: 5 x 4 x 2½
Weight: 56 oz
Input: 24-30 VDC
Output: 100 Watts @ .8 PF
Closely Regulated at 400 Hz. 4%
Total Harmonic Distortion (other frequencies available to 10 KHz)
Operating Temp: —55 to +71°C

Model	Output (VRMS @ 400 Hz)	Price (1 pc)
SKD - 28-28-400-100	28	$479.00
SKD - 28-115-400-100	115	479.00

Delivery: Stock — 4 weeks ARO
Other inverters available from 12 Watts to 200 Watts

PRINTED CIRCUIT STYLE POWER SUPPLY
Hermetic Sealed Steel Case
Flexible Lead Spacing
Small Size: 2½ x 2½ x .9
.05% Regulation
115 VAC, 50-500 Hz Input
3 to 30 VDC Single or Dual Outputs

Application	Model Number	Output	Price (1 pc)
Logic	PCA-5/500	5VDC @ 500MA	$84.00
OP Amp	PCA-30CT/100	+15VDC @ 100MA —15VDC @ 100MA	99.00
MOS	PCA-28/60-14/40	—28VDC @ 60MA —14VDC @ 40MA	99.00

Delivery: Stock to 5 weeks ARO
Other models available with inputs of 28 VDC and 5 VDC.

11264 Playa Court, Culver City, Calif. 90230
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ARNOLD MAGNETICS

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Circle 200 on Inquiry Card for Sealectro demographic insert →

What's a 500 kHz plug-in doing in a 100 MHz mainframe?

Increasing its versatility, that's what!

When you need 100 μV sensitivity, rather than 100 MHz bandwidth, HP's new dual-channel 1806A plug-in lets your 180 Scope System do the job. With the 1806A, the versatile 180 Mini-Giant becomes a powerful tool for measuring and analyzing low-level signals up to 500 kHz.

A 100 μV/div deflection factor lets you see beyond the surface of a signal – to detect ripples, discontinuities and harmonics invisible at less sensitive levels. To get the most out of the 100 μV sensitivity, drift is typically <50 μV/hr, CMRR is 100 dB, noise is <20 μV tangential at full BW–and a pushbutton lets you limit bandwidth to 50 kHz, when you need to. Yet the price of the 1806A is only $675.

For applications where you need high-bandwidth capabilities, there are a host of other plug-ins for the versatile 180 System. There's a 50 MHz, 5 mV/div plug-in for only $695. 100 MHz with 10 mV/div and 50Ω input, $1200 (10 MΩ active probe, $95 extra).

Other available plug-ins include: a differential/dc-offset amplifier, a 4-channel amplifier, and a 35 ps time-domain reflectometer that doubles as a 12.4 GHz sampler.

Today, oscilloscope technology is at a crossroads. The HP direction points to getting the best, now, at a low price–with assurance of increased measurement capabilities down the road, using existing mainframes. The new 1806A plug-in is the latest example of this approach at work.

To see the 180 System, call your local HP field engineer. Or, write to Hewlett-Packard, Palo Alto, California 94304. In Europe: 1217 Meyrin-Geneva, Switzerland.

080/15

HEWLETT hp PACKARD

OSCILLOSCOPE SYSTEMS

Circle 112 on Inquiry Card

nate design approach to the problem. First, he states on Page 70: "If it is understood that the original signal is multiplied by the sampling signal having an amplitude of 0 to 1, then a knowledge of transform relationships makes it clear that the original spectrum is being multiplied by the spectrum of the sampling theorem," I suspect an editing error occurred in this case since Fig. 8 does show quite clearly that the original spectrum is being convolved by the spectrum of the sampling signal.

On page 72, however, the statement "This is the theorem yielding Nyquist's results — i.e. equi-spaced data, with two or more points per cycle of highest frequency, allows reconstruction of band-limited functions" is at best a misleading statement of Nyquist's results even for the unrealistic supposition of an ideal low-pass filter. It would be correct, although misleading, to say "with more than two points per cycle of highest frequency, etc." Nyquist's sampling theorem says that the sampled frequency spectrum amplitude must be *zero* for frequencies at and above the frequency where two samples per cycle are taken; a subtle but most important difference.

In the realizable case, then, one should choose the sampling frequency as being twice the frequency, f_{zero}, at and above which the sampled spectrum amplitude can be considered zero, that is, below the system resolution capability. Keeping in mind that f_{zero} is higher than the highest frequency of interest, f_{int}, the design question amounts to: what is the transition band characteristic needed between f_{int} and f_{zero}? One approach since f_{int} is known, is to choose f_{zero} and the sampling rate $2_{f(zero)}$ at the intersection of the attenuation characteristic of the (natural or designed) alias filter and a point approximately 6 dB below the system resolution capability. Thus, if the system had a dynamic range of, say 42dB — then f_{zero} would be chosen where the alias filter response was down 48 dB.

If we now choose the recovery filter to have the same attenuation characteristics as the alias filter, but with its corner frequency at f_{zero}, we are guaranteed two things during recovery by the symmetry of the sampled data spectrum about f_{zero}: (1) the frequencies above f_{zero} corresponding to the convolved spectrum of the original input signal can increase in amplitude at most at the rate they are attenuated by the recovery filter, which for our purpose gets rid of them. (2) The frequencies symmetrical about f_{zero} corresponding to the aliased frequencies (due to the realizable case that the original sampled input spectrum amplitude cannot be zero at f_{zero}) are not detectable by the system since the spectrum amplitude at f_{zero} was already 6 dB (approximately a factor of two) below the system resolution capability. Hence, the aliasing effect is negligible.

If the recovery filter were followed by a phase equalization filter based on the original alias filter, the recovery process would be the same as for the ideal case as far as the system could resolve.

Phil Ward
M. I. T. Electronic Systems Lab
Cambridge, Mass.

Author's reply

Mr. Ward's comment that the phrase, "the original spectrum is being multiplied by the spectrum of the sampling theorem" should read "is being convolved by the spectrum of the sampling signal" is correct.

With respect to the statement, "This is the theorem yielding Nyquist's results, etc." it does seem to me that making a point out of the difference between the phrases, "two or more" and "more than two" is cutting it a bit too fine except for the very purest of mathematicians. For example, R. B. Blackman and J. W. Tukey in their excellent reference book, "The Measurement of Power Spectra From the Point of View of Communications Engineering" define (on page 175) "sampling theorem" as, "Nyquist's result that equi-spaced data, with two or more points per cycle of highest frequency, allows reconstruction of band-limited function." I suspect that if this definition is good enough for them it ought to be good enough for most practicing engineers.

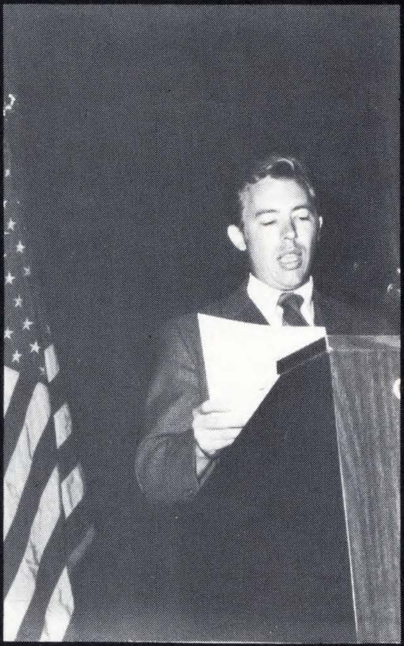
Mr. Ward's suggestion regarding an approach to developing the characteristics of a recovery filter is a useful contribution. However, one of the main points that I attempted to make in my article was that very frequently the specific judgment decisions made by a systems engineer will relate to the exact nature of what that system is trying to accomplish and that the various judgment decisions will vary considerably depending on the end result. That is, in many real systems there will exist no practical real frequency at which the spectrum amplitude can be considered zero and the system designer must deliberately decide what errors he can afford to tolerate.

Also, I would like to comment that my *EEE* article can, at best, be considered a starting point for the engineer who must seriously tackle the problems considered.

Bernard M. Gordon
Gordon Engineering Co.
Wakefield, Mass.

Dear EEE:
I think I have never read such a clear article about such a sophisticated problem. Thank you, Mr. Gordon.

J. P. Poindersault
Physio Au Fac Sciences
Poitiers, France


Mike Markkula
of Fairchild Semiconductor

This engineering/engineering management seminar will cover the positive aspects of designing with standard ICs. It'll analyze the degrees of flexibility that different standard ICs provide the circuit/system designer and it'll survey what can be accomplished with existing digital and linear ICs including bipolar and MOS MSI/LSI. The seminar's main goals are to show the IC user the ranges of capability offered by standard devices and the best ways from technical and economical viewpoints, to take advantage of these capabilities.

As with previous EEE Seminars, this Boston seminar permits key applications engineers at leading IC manufacturers to interface as a group with IC users. This helps attendees gauge the opinions of several leading IC engineers on each topic discussed.

PROGRAM:
Session One
Key innovators from leading digital/linear IC manufacturers will discuss groundrules for making standard available-off-the shelf ICs fit the requirements of various circuits and systems.

Session Two
The controversies concerning which

EEE Seminars Announces an Important New IC Seminar For Engineers and Engineering Management:

"Designing With Commercially Available Integrated Circuits"

of competing IC approaches is best for various systems will be examined.

Session Three
The present range of capabilities of most types of ICs (LSI/MSI, RAMs, ROMs, op amps, regulators, comparators, etc.) will be explored.

Date/Place

Friday, November 6
Holiday Inn (Charles River)
5 Blossom St. at Cambridge St.
Boston, Mass. (zip: 02114)
(During NEREM week)

8:45-9:15	Coffee/Danish
9:15-11:45	Morning Session
11:45-1:00	Luncheon
1:00-3:00	First Afternoon Session
3:00-3:15	Coffee/Coke Break
3:15-4:30	Second Afternoon Session

Registration Fee
Advance registration is $35 ($40 at the door if seats are available). Registration includes detailed program, materials, luncheon, coffee breaks. Fee is tax deductible. Cancellations honored one day before seminar.

To register, use the form below.

Make your check payable to
EEE Seminars
820 Second Avenue
New York, New York 10017

Please register me for

Seminar on "Designing With Commercially Available Integrated Circuits," Friday, Nov. 6, 1970, Holiday Inn, Boston, Mass. Fee: $35.

☐ **My purchase order or check is enclosed, or**
☐ **Bill me, or** ☐ **Bill my company.**

Name____________________ Title____________________

Company______________________________________

Address______________________________________
(Street) (City)

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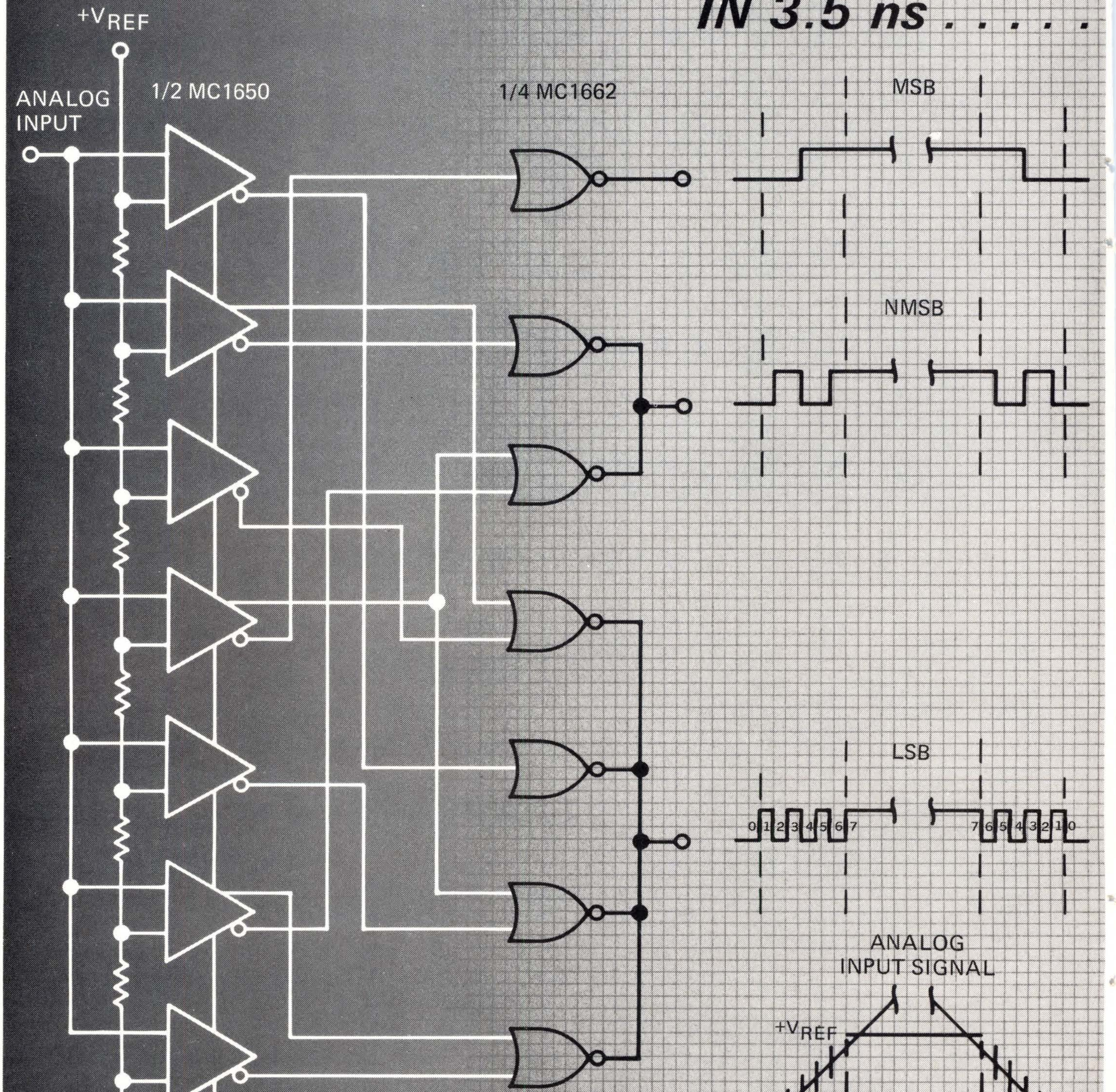
Your ticket will be mailed to you.

FROM ANALOG-TO-DIGITAL IN 3.5 ns . . . . .



3-BIT A/D CONVERTER

. . . . MECL III MAKES IT HAPPEN

In this computer world of rapidly accumulating data it is imperative to develop new high-speed techniques for analog-to-digital data conversion. To meet these demands Motorola now offers the MC1650 A/D Comparator, a digital integrated circuit providing faster conversion rates than any comparable IC system available today — at no increase in cost!

Basically, the MC1650 compares an analog signal to a reference voltage when the gate is in the logic "1" state. When the analog level is greater than the reference, the output (Q) of the comparator goes to a logic "1". When the analog signal is less than the reference voltage, the comparator output voltage goes to a logic "0".

The comparator will accept analog signals with slew rates up to 340 V/μs and provides digital information at rates up to 200 megabits per second, at the least significant bit (LSB). And the MC1650 features a built-in memory whereby the gate input, when taken to a logic "0" level, will cause all bits of digital information to remain in the present state, regardless of a change at the analog input. The MC1650 incorporates two comparators in one package and operates at MECL III logic levels. Other features include a typical delay of 3.5 ns and complementary outputs which increase flexibility of design.

In the 3-bit A/D converter illustrated, the analog signal is represented as a straight line, but may assume any form as long as the maximum slew rate is not exceeded. The incremental steps are determined by the bias values supplied by resistors between $+V_{REF}$ and $-V_{REF}$. Equal values for all resistors (assumed here) will break the analog sensitivity of the system into equal increments, while different values result in unequal increments.

Apply the MC1650 to instrumentation applications such as frequency measurement, high-frequency sample and hold, and peak voltage detection. In navigation and aviation use the comparator for application in altimeters, peak detectors, and electromechanical system-control interfacing. And consider the high-speed applications for computer terminals and memory translation and amplification.

For complete MC1650 specifications write to Motorola Semiconductor Products Inc., P.O. Box 20912, Phoenix, Arizona 85036. Your local Motorola distributor has evaluation devices available now. Evaluation will introduce you to the latest concept of high-speed A/D data conversion where MECL III makes things happen.

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MOTOROLA MECL
the only way to go . . . FASTER

Circle 114 on Inquiry Card

Progress in Design and Research

Two new thin-film hybrid D/A converters

PROGRESS IN MICROELECTRONICS

TINY NEW digital-to-analog converters from two companies have one common feature that may signify a new trend. Both the Micro Networks MN302 and the Precision Monolithics AIMDAC-100 are hybrid ICs with thin-film resistor networks. Thus more and more companies seem to be favoring thin-film fabrication for microelectronic D/A converters. Earlier this year, Sprague introduced a thin-film hybrid DAC (see *EEE,* February 1970, pp. 20-22) and Radiation introduced a dielectrically - isolated "monolithic" DAC with thin-film weighting network (see *EEE,* June 1970, pp. 32-36).

Thin-film resistors of course, have the important advantage that they can yield temperature drifts lower than those of most thick-film resistors. But thin films also have some disadvantages that, until recently, restricted their application in DAC modules. Costs of thin-film fabrication have tended to be higher than for the thick-film approach, but, thanks to increased knowhow and larger manufacturing volume, some companies have been able to close the cost gap. Another disadvantage of thin films is that they aren't suitable for fabrication of compact, high-value, resistors. But engineers have managed to devise some ingenious circuit tricks to eliminate the need for high-value resistors.

Though the Micro Networks and Precision Monolithics units are both compact thin-film hybrid ICs, the similarity ends there. The circuits are really intended for different applications. The Micro Networks MN302 includes an output amplifier but is intended for operation with a stable external reference source. The Precision Monolithics AIMDAC-100, on the other hand, needs an external amplifier in most applications, but it does include a precision reference-voltage regulator in the chip. Also theMN302 is an 8-bit DAC, whereas the AIMDAC-100 has a resolution of 10 bits.

Functionally adjusted

While several companies now use thin-film resistor networks for DACs, Micro Networks claims to be one of the few companies that actually trims the resistor values *after* the complete DAC has been assembled. This allows compensation for other errors within the DAC circuit, in addition to errors within the weighting network itself.

Functional trimming is more difficult with other packaging approaches. With a wholly monolithic structure it would be almost impossible to trim resistors without damaging other devices on the chip. And if the switching network and resistor network were in separate packages, it would be necessary to carefully

(Continued on page 24)

New Helipot DAC & ADC Hybrids are MOS system compatible

Model 847 DAC & Model 871 ADC offer:

- Integration of the best DAC/ADC functional elements from MOS/LSI, Bipolar and cermet thick-film technologies into *complete* hybrid converters.
- MOS system compatibility (using 3750 & 3751).
- Small, hermetic metal package & environmental specs per MIL-STD-883.

	MODEL 847 DAC			MODEL 871 ADC		
■ Resolution	10 bit			12 bit		
■ Accuracy: (Code)	D1	D2	D3	D1	D2	D3
at 25°C	±0.025%	±0.05%	±0.1%	±0.025%	±0.05%	±0.1%
−20 to 85°C	±0.05%	±0.1%	±0.2%	±0.05%	±0.1%	±0.2%
■ Price (50-99 Quantity)	$165.00	$148.75	$136.00	$252.25	$191.25	$165.00
■ Power Consumption	350mW max.			950mW max.		

Call your local Helipot Sales Engineering Representative for additional information and application assistance.

Beckman® INSTRUMENTS, INC.
HELIPOT DIVISION FULLERTON, CALIFORNIA
INTERNATIONAL SUBSIDIARIES: AMSTERDAM; CAPETOWN; GENEVA; GLENROTHES, SCOTLAND; LONDON; MEXICO CITY; MUNICH; PARIS; STOCKHOLM; TOKYO; VIENNA

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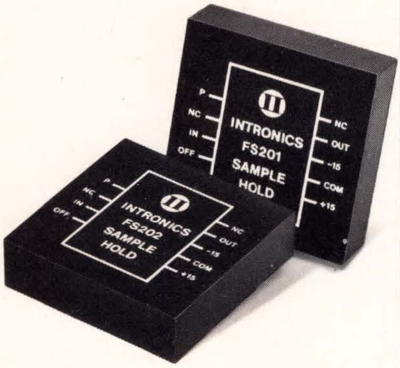
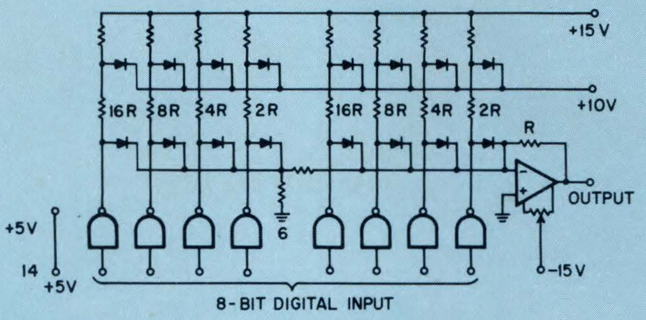
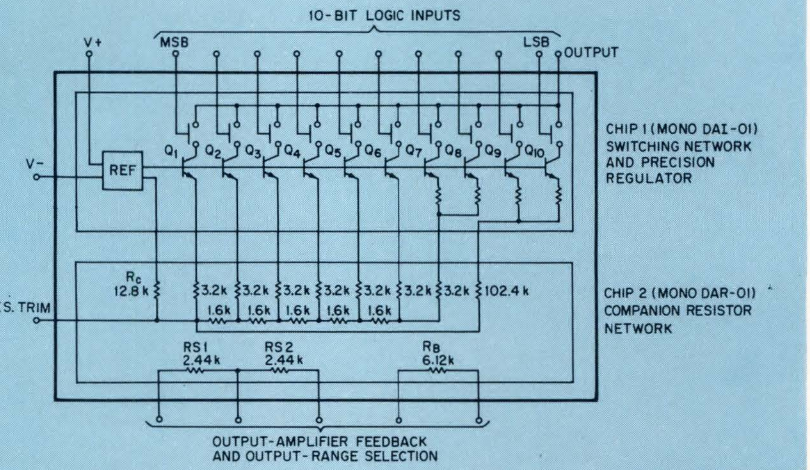




Simplified schematic of new Micro Networks thin-film hybrid DAC, type MN302. The output potentiometer shown is an internal resistor network adjusted by the manufacturer. The complete circuit comes in a 14-pin DIP-style package.



Precision Monolithic's AIMDAC-100 is a hybrid assembly consisting of a monolithic switching network and a thin-film resistor network. The simplified schematic shows how the two chips are interconnected. The complete assembly is available in either a 16-pin DIP or a 24-lead flat pack.

identify which resistors had been optimized for a given set of switches; the apparent freedom to use various ladders with a given switching network is an illusion if one needs optimized performance.

As a result of careful adjustment after assembly, the Micro Networks MN302 is able to offer accuracies comparable with discrete-component modules having similar resolution. Yet the complete hybrid circuit fits into a tiny 14-lead DIP-compatible package. The 8-bit DAC has an accuracy of ±1/2 LSB over its operating temperature range of 0 to +70°C. The temperature coefficient is a low ±10 ppm/°C.

Micro Networks does not specify settling time for the MN302. This is because the speed of response is limited by the slew rate of the output amplifier, which is 0.5 V/μs, and not by the switch settling time which is around 100 ns. Thus, though the MN302 offers better temperature

(Continued on page 27)

Robert J. Widlar
National Semiconductor

LINEAR BRIEF 12

AN IC VOLTAGE COMPARATOR FOR HIGH IMPEDANCE CIRCUITRY

The IC voltage comparators available in the past have been designed primarily for low voltage, high speed operation. As a result, these devices have high input error currents, which limit their usefulness in high impedance circuitry. An IC is described here that drastically reduces these error currents, with only a moderate decrease in speed.

This new comparator is considerably more flexible than the older devices. Not only will it drive RTL, DTL and TTL logic; but also it can interface with MOS logic and FET analog switches. It operates from standard ±15V op amp supplies and can switch 50V, 50 mA loads, making it useful as a driver for relays, lamps or light-emitting diodes. A unique output stage enables it to drive loads referred to either supply or ground and provide ground isolation between the comparator inputs and the load.

Another useful feature of the circuit is that it can be powered from a single 5V supply and drive DTL or TTL integrated circuits. This enables the designer to perform linear functions on a digital-circuit card without using extra supplies. It can, for example, be used as a low-level photodiode detector, a zero crossing detector for magnetic transducers, an interface for high-level logic or a precision multivibrator.

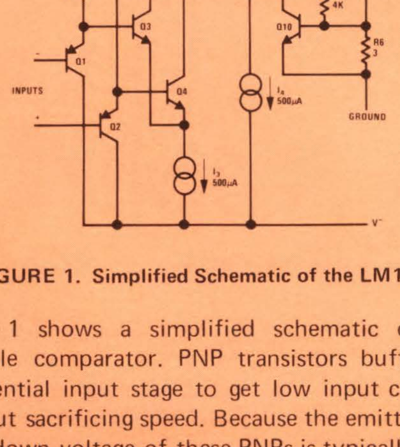


FIGURE 1. Simplified Schematic of the LM111

Figure 1 shows a simplified schematic of this versatile comparator. PNP transistors buffer the differential input stage to get low input currents without sacrificing speed. Because the emitter base breakdown voltage of these PNPs is typically 70V, they can also withstand a large differential input voltage. The PNPs drive a standard differential stage. The output of this stage is further amplified by the Q_5-Q_6 pair. This feeds a lateral PNP, Q_9, that provides additional gain and drives the output stage.

The output transistor is Q_{11} which is driven by the level shifting PNP. Current limiting is provided by R_6 and Q_{10} to protect the circuit from intermittent shorts. Both the output and the ground lead are isolated from other points within the circuit, so either can be used as the output. The V^- terminal can also be tied to ground to run the circuit from a single supply. The comparator will work in any configuration as long as the ground terminal is at a potential somewhere between the supply voltages. The output terminal, however, can go above the positive supply as long as the breakdown voltage of Q_{11} is not exceeded.

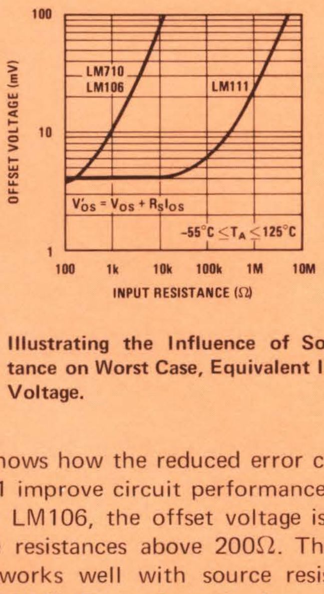


FIGURE 2. Illustrating the Influence of Source Resistance on Worst Case, Equivalent Input Offset Voltage.

Figure 2 shows how the reduced error currents of the LM111 improve circuit performance. With the LM710 or LM106, the offset voltage is degraded for source resistances above 200Ω. The LM111, however, works well with source resistances in excess of 30 kΩ. Figure 2 applies for equal source resistances on the two inputs. If they are unequal, the degradation will become pronounced at lower resistance levels.

Table I gives the important electrical characteristics of the LM111 and compares them with the specifications of older ICs.

A few, typical applications of the LM111 are illustrated in Figure 3. The first is a zero crossing detector driving a MOS analog switch. The ground terminal of the IC is connected to V^-; hence, with ±15V supplies, the signal swing delivered to the gate of Q_1 is also ±15V. This type of circuit is useful where the gain or feedback configuration of

LINEAR BRIEF 12 IC VOLTAGE COMPARATOR Write: National Semiconductor Corp., 2900 Semiconductor Drive, Santa Clara, California 95051

IC voltage comparator

LB-1

Table I. Comparing the LM111 with earlier IC comparators. Values given are worst case over a −55°C to 125°C temperature range, except as noted.

Parameter	LM111	LM106	LM710	Units
Input Offset Voltage	4	3	3	mV
Input Offset Current	0.02	7	7	μA
Input Bias Current	0.15	45	45	μA
Common Mode Range	±14	±5	±5	V
Differential Input Voltage Range	±30	±5	±5	V
Voltage Gain†	200	40	1.7	V/mV
Response Time†	200	40	40	ns
Output Drive				
Voltage	50	24	2.5	V
Current	50	100	1.6	mA
Fan Out (DTL/TTL)	8	16	1	
Power Consumption	80	145	160	mW

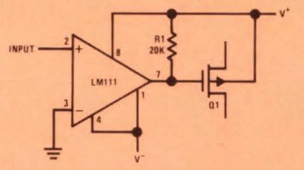
†Typical at 25°C.

an op amp circuit must be changed at some precisely-determined signal level. Incidentally, it is a simple matter to modify the circuit to work with junction FETs.

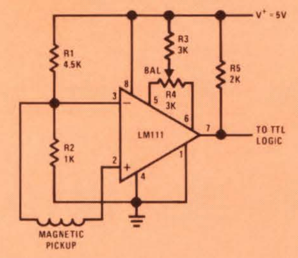
The second circuit is a zero crossing detector for a magnetic pickup such as a magnetometer or shaft-position pickoff. It delivers the output signal directly to DTL or TTL logic circuits and operates from the 5V logic supply. The resistive divider, R_1 and R_2, biases the inputs 0.5V above ground, within the common mode range of the device. An optional offset balancing circuit, R_3 and R_4, is included.

The next circuit shows a comparator for a low-level photodiode operating with MOS logic. The output changes state when the diode current reaches 1 μA. At the switching point, the voltage across the photodiode is nearly zero, so its leakage current does not cause an error. The output switches between ground and −10V, driving the data inputs of MOS logic directly.

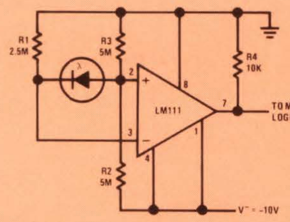
The last circuit shows how a ground-referred load is driven from the ground terminal of the LM111. The input polarity is reversed because the ground terminal is used as the output. An incandescent lamp, which is the load here, has a cold resistance eight times lower than it is during normal operation. This produces a large inrush current, when it is switched on, that can damage the switch. However, the current limiting of the LM111 holds this current to a safe value.



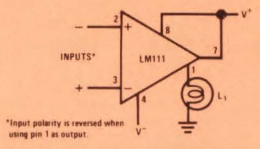
a. Zero Crossing Detector Driving Analog Switch



b. Detector for Magnetic Transducer



c. Comparator for Low Level Photodiode



d. Driving Ground–Referred Load

FIGURE 3. Typical Applications of the LM111.

The applications described above show that the output-circuit flexibility and wide supply-voltage range of the LM111 opens up new fields for IC comparators. Further, its low error currents permit its use in circuits with impedance levels above 1 kΩ. Although slower than older devices, it is more than an order of magnitude faster than op amps used as comparators.

The LM111 has the same pin configuration as the LM710 and LM106. It is interchangeable with these devices in applications where speed is not of prime concern.

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performance than most competing 8-bit converters, it doesn't match the speeds that can be attained using an external fast-settling output amplifier.

In quantities of 1-9, the MN302 costs $79. For lots of 100, the unit price falls to $53. Delivery is from stock. In addition to the binary-input MN302, Micro Networks has a BCD version designated MN303. The inputs of both versions are compatible with TTL logic.

Fast-settling hybrid

The Precision Monolithics AIMDAC-100 consists, essentially, of two monolithic chips mounted on a single substrate with simple one-to-one interconnections. The two chips are the same as those used for the company's monoDAR-01 thin-film ladder network and monoDAI-01 10-bit D/A (see *EEE,* March 1970, pp. 64-65). Thus the AIMDAC-100 is a single-package version of the earlier pair of ICs. Available package styles are 16-pin DIP or 24-lead flat pack.

Unlike the Micro-Networks circuit, the new Precision Monolithic DAC assembly does not include an output amplifier. Depending on the application, this may or may not be an advantage. One advantage is that it allows use of a high-speed external amplifier in situations where fast settling is required. The AIMDAC-100 itself has a settling time of 350 ns to within ±0.1% of full scale. In some applications, of course, the unit's full-scale current of around 2 mA will be adequate and an external amplifier won't be needed.

Precision Monolithics offers the AIMDAC-100 in a wide selection of graded versions. Thus the device is truly universal. To some users it may provide a low-cost solution, while to others it may provide a high-performance solution within a tight space.

All versions of the AIMDAC-100 will operate over the full military temperature range of −55 to +125°C. Depending on the specific version chosen, accuracy (at 25°C) ranges from 0.05% to 0.3%, while tempcos range from 12 ppm/°C to 150 ppm/°C including internal reference drift. In quantities of 1-9, the price can be as low as $42 or as high as $200. In large quantities, the prices of low-performance versions drop below $25.

Other options for the AIMDAC-100 include a choice of package styles (DIP or flat pack) a choice of pin-outs (to replace the μA722 and other ICs) and a choice of output voltage ranges (0 to +10 V and ±5 V, or 0 to +5 V and ±2.5 V). The required input levels are compatible with DTL/TTL logic. ■

For more information on the Micro Networks MN302 circle 646.
For more information on the Precision Monolithics AIMDAC-100, circle 647.

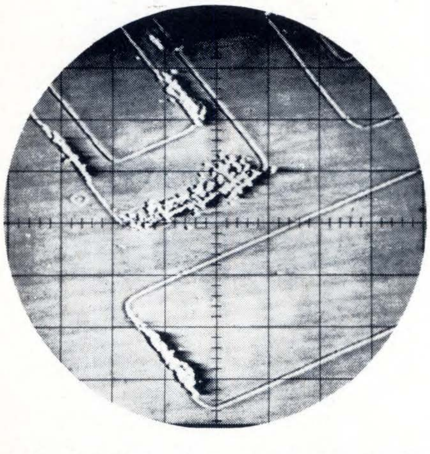
Differential FET op amp slews at 1000 V/μs

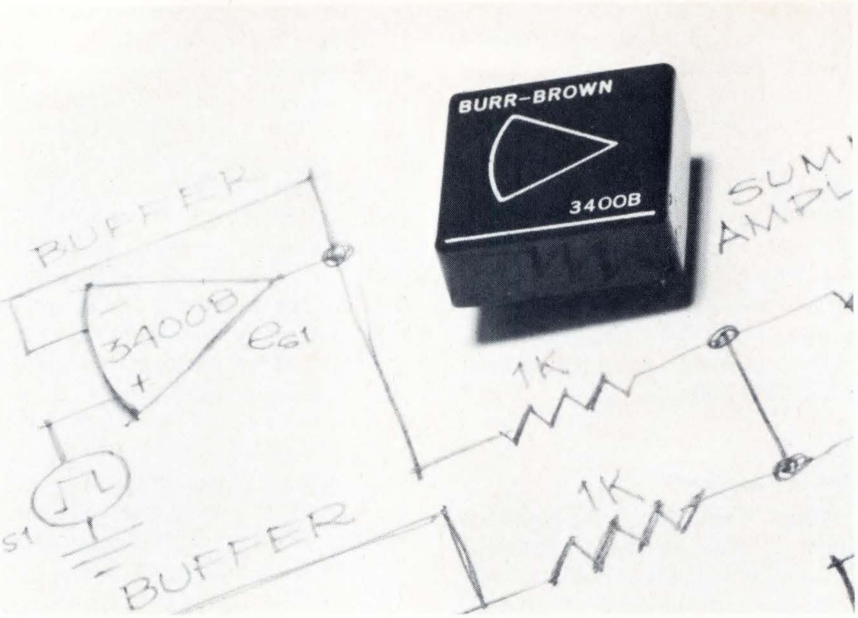
PROGRESS IN PACKAGED CIRCUITS

UNLIKE OTHER ultra-wideband op amps, a new module from Burr-Brown has differential inputs—it's not restricted to inverting-only applications. And the high-frequency performance of the new amplifier, type 3400B, equals or exceeds that of its single-ended competitors. With a large-signal slew rate of 1000 V/μs, a small-signal bandwidth of 100 MHz, and a unit-quantity price of only $65, the 3400B should provide some tough competition for older inverting-only designs.

Another important feature of the 3400B is its FET input circuitry. Most competing high-speed op amps use bipolar transistors in the input stage. But, because of the relatively large first-stage collector currents needed to achieve wide bandwidth, the base current (input bias current) also tends to be large. With the FET-input 3400B, however, the maximum bias current is only 100 pA—three orders of magnitude better than most bipolar units. Thus the amplifier is ideally suited for applications such

(Continued on page 28)





as high-speed integrators and sample/hold circuits, where high bias currents would be a real nuisance.

One possible disadvantage of the 3400B is its relatively low output - current capability. The maximum rated output is ±10 V at ±20 mA. Competing inverting-only amplifiers usually provide higher currents. For example, both the DDC VA23 and the Intronics A501 deliver outputs of ±50 mA at their maximum slew rates. Thus inverting-only amplifiers may still be required for line-driving applications, and other situations where large output currents are needed. But for the vast majority of applications, the 3400B's low price and compact package should give it a competitive edge.

Among the other key specs for the 3400B are an input impedance of 10^{11} ohms, a bias current of 100 pA, a voltage drift of ±50 μV/°C, and an open-loop gain of 80 dB. A lower-cost version, 3400A, has a voltage drift of ±100 μV/°C and costs $55 (1-9).

The amplifier is packaged in a low-profile epoxy case, only 1.125 × 1.125 × 0.4 inches. Small quantities are available from stock. ■

For more information, circle 644.

A wideband pulse-modulation multiplier

PROGRESS IN PACKAGED CIRCUITS

IN A NEW analog-multiplier circuit, Analog Devices has exploited the inherently-high accuracy of the pulse height/width modulation principle, while simultaneously pushing bandwidths way beyond those of competing units that employ the same basic circuit technique. Thus Analog's new Model 424K achieves 0.1-percent accuracy and has a bandwidth of 100 kHz. The new unit's bandwidth is a hundredfold improvement over the performance of other available height/width modulation multipliers—that have maximum bandwidths of around 1 kHz.

High-frequency carrier

Analog's engineers achieved the increased bandwidth by using a repetition rate (carrier frequency) of 3 MHz for the multiplier's internal pulse train. This contrasts with carrier frequencies of around 50 kHz to 100 kHz that are currently being used by other manufactures. Of course, because of the lowpass filtering that's needed to remove the carrier frequency and

(Continued on page 30)

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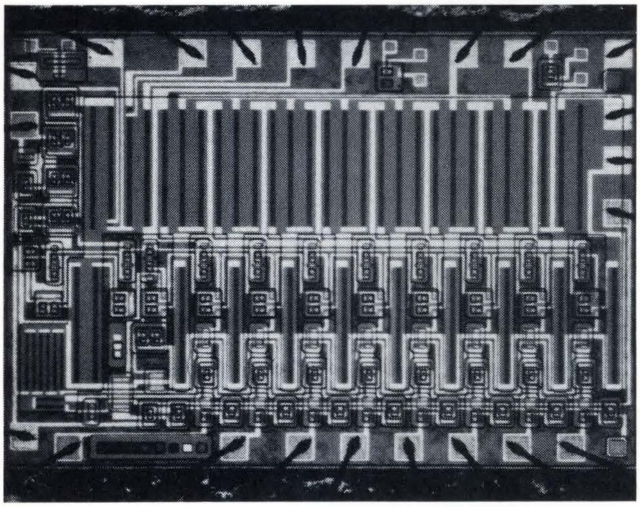

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Analog Devices' new analog multiplier has an accuracy of 0.1%, and a bandwidth of 100 kHz, yet it is less expensive and more compact than other computer-grade units.

its harmonics, the maximum bandwidth of a pulse-modultiplier is necessarily less than about ten-percent of the carrier frequency.

The need for a pulse-modulation multiplier with a high carrier frequency has been obvious for several years. But practical design problems have hitherto made it impossible to build such a circuit at reasonable cost. Now Analog's engineers have been able to solve the problems, thanks, partly, to the availability of wideband differential-amplifier IC's. These IC's are used extensively throughout the Model 424, and are crucial elements in the buffer amplifiers and in the pulse generation and modulation circuitry.

In another innovation, the 424's designers exploited current-mode operation for all switching, modulating and pulse-handling circuits. By using current-switching, rather than voltage switching, the engineers were able to minimize the effects of stray capacitance and, thus, achieve maximum operating speed with minimum distortion.

For the 424K, the total distortion at 25°C is less than 0.1 percent for frequencies up to 1 kHz. A lower cost version, 424J, offers 0.2-percent distortion over the same frequency range. Both types have a small signal bandwidth of 100 kHz and a full-power response of 30 kHz.

Competing circuits

Availability of the new wideband 0.1-percent unit will force engineers to reconsider the cost/performance tradeoffs between different types of multipliers. Not only does the Model 424 compete with other pulse-modulation multipliers; it can also offer the same performance as some quarter-square multipliers—but at much lower cost.

Traditionally the quarter-square multiplier has provided the best solution for applications that need precision and wide bandwidth. Quarter-square circuits can provide accuracies of 0.1 percent or less with bandwidths as high as 1 MHz. But, hitherto, multipliers with this sort of performance have cost from $400 to $1200, or more.

Though the Model 424 can't match the bandwidth of the best

(Continued on page 32)

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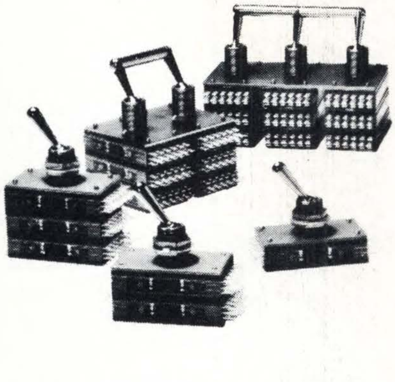

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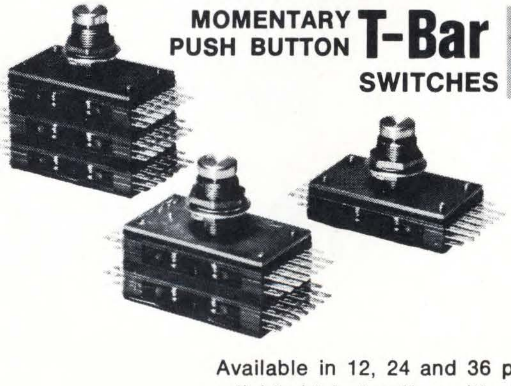

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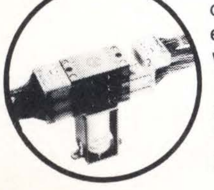

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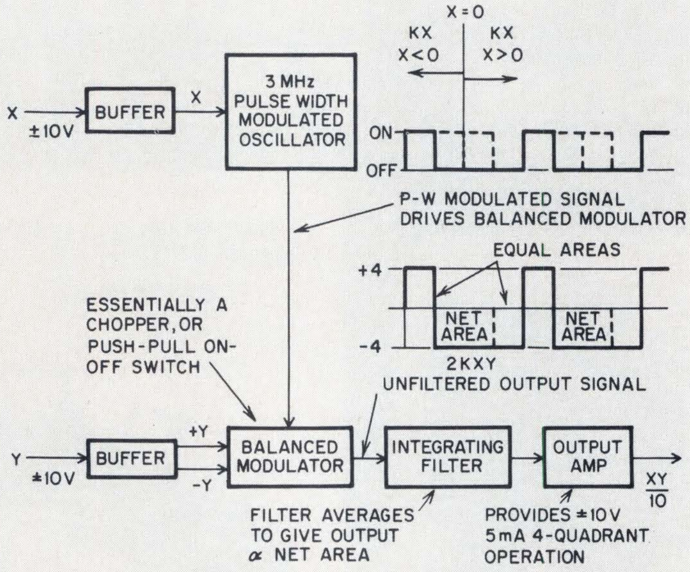
quarter-square multipliers, it is much less expensive and is clearly the best choice for applications that don't need the ultimate in bandwidth. In quantities of 1 to 9, the 424J costs $175, while the superior-accuracy 424K costs $195.

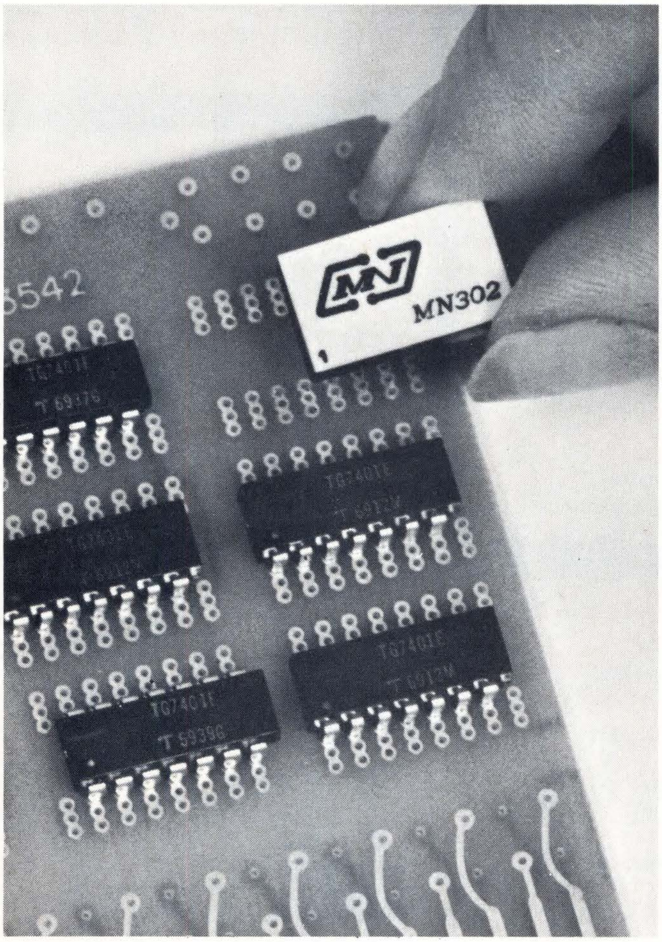


In a pulse-modulation multiplier, one input determines the width of the carrier pulses while the other input determines the height. The net area of the pulse is thus proportional to the product of the inputs. Analog Devices' Model 424 uses a pulse repetition rate of 3 MHz.

In addition to their low cost, pulse-modulation multipliers have other important advantages over quarter-square types. The pulse-modulation circuit provides exellent linearity over a wide dynamic range, whereas quarter-square circuits tend to cause severe nonlinearity at low signal levels. And because of its extensive use of ICs, Analog's new multiplier is much more compact than older quarter-square units. The Model 420 comes in an encapsulated PC-mounting package with dimensions of 3.06 × 1.65 × 0.625 inches.

Of course transconductance multipliers can offer bandwidths up to around 10 MHz and are usually more compact and cheaper than either the pulse-modulation or quarter-square types. But transconductance types have poor accuracy (rarely better than 1 percent) and hence can't complete with other types for precision applications. ■

For more information on Analog Devices' Model 424, circle 645.



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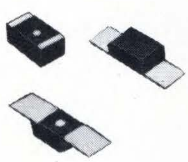

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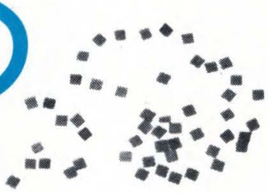

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MIXERS – This catalog provides basic specifications and packaging information on RELCOM's line of single- and double-balanced mixers, dc to 4 GHz. Application notes describe the mixers' use as modulators, phase detectors, current-controlled attenuators and up-down frequency converters. Typical circuits are shown, along with performance data. Tables of intermodulation harmonics for both standard and high-level mixers are included.

WIDEBAND TRANSFORMERS — An important part of this catalog of balanced and single-ended transformers is a section of "how to" application notes. These notes describe various techniques for constructing a frequency doubler, 180° power divider, power combiner, phase splitter and detector, pulse shaper, sampler and wideband amplifier. Schematic diagrams are included along with performance specifications and package descriptions. Frequency range for the BT- and T-series transformers is 0.2 to 700 MHz.

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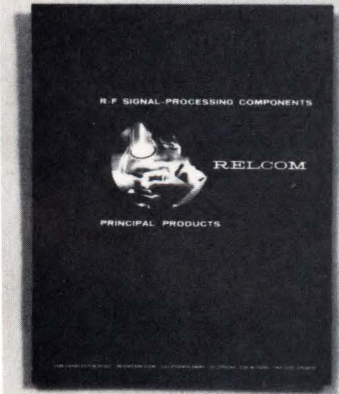

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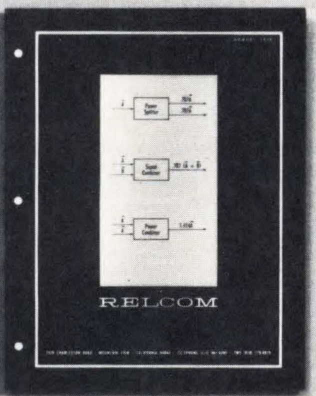
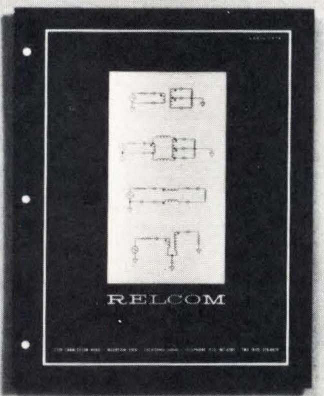
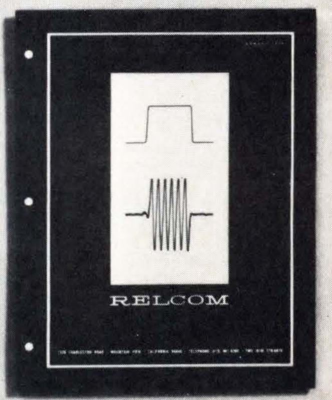


TRANSFORMERS



REACTIVE HYBRIDS



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Walt Hirschberg of ACDC Speaks Out On What's Wrong With Miniature-Power-Supply Specs

All the problems you get in a conventional power supply you get in a miniature, and then some. If specsmanship is bad with standard-sized supplies, its treacherous with small ones. The problems faced by the power-supply designer are bigger, precisely because they come in small packages. And your problems are compounded because your system has forced you to a miniature supply in the first place.

Some people go to miniaturization because it's a fad—it's the *in* thing to do. But most engineers—the good ones—miniaturize because they must. Let's face it. Miniaturization costs money. A 100-watt regulated supply that costs $250 in a conventional package might go for $400 in a package one-fifth the original size.

So we all know about the price penalty. What about the other tradeoffs?

While almost every component accepts miniaturization more or less gracefully, the power supply doesn't. The conventional supply has bulky transformers, filter chokes, capacitors and heat sinks. And you can't shrink them without some clever and very careful design.

Further, if you try to dissipate the same amount of heat from a smaller package, you have to demand a lot from your components. And you really have to worry about getting the heat out of a small volume that your already crowded system has forced on you.

Now let's take a look at some of the specs. The first thing you look for, of course, is the voltage output. And you're already on quicksand. Is the voltage in the printed spec the one you need across your load, or is it just what you get across the supply terminals?

The drop in load cables can increase your voltage requirement by as much as a volt. If you use remote sensing, you'd better find out how much cable drop the supply can compensate for.

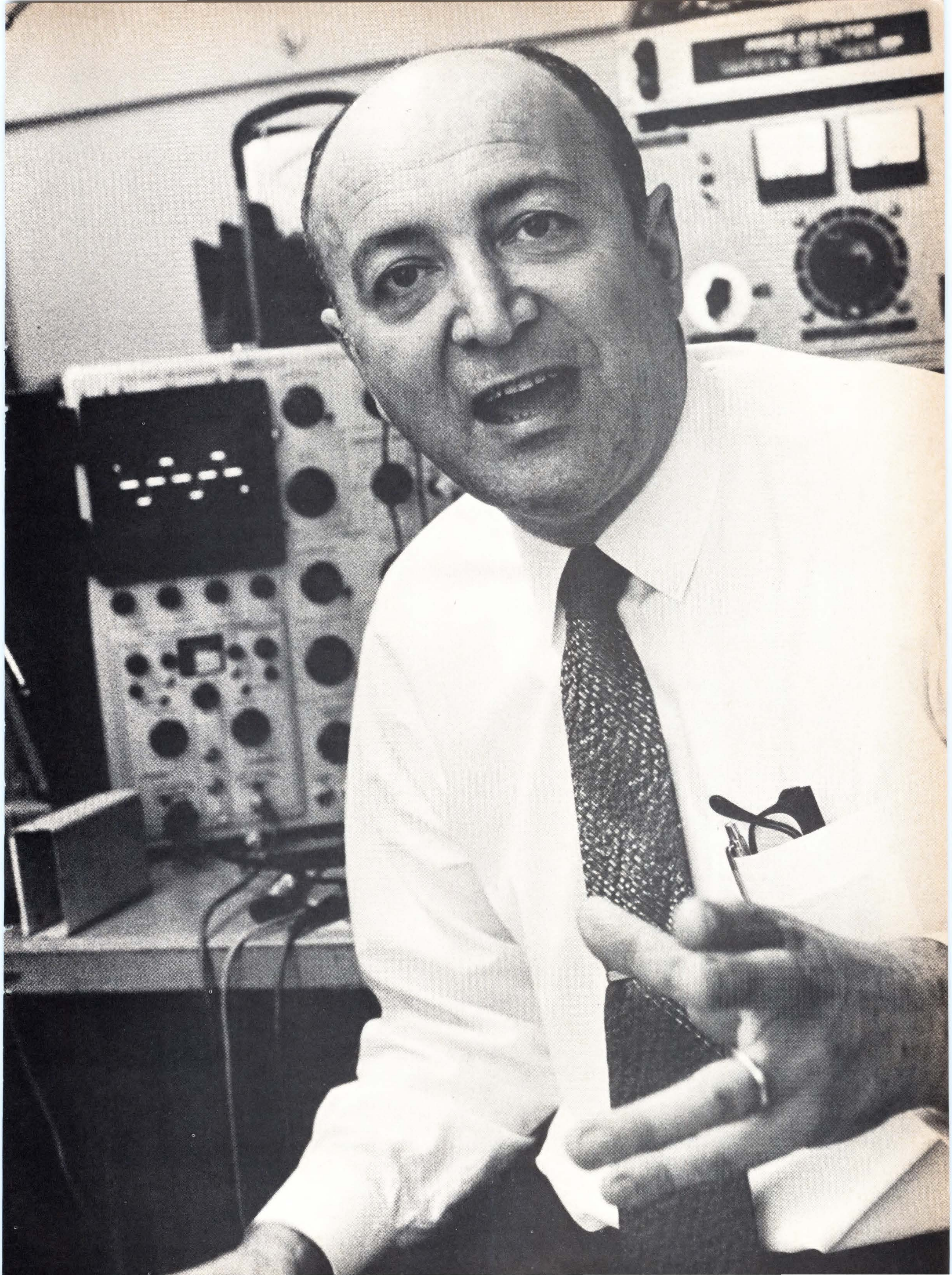
I find it rather interesting that 90 percent of the supplies on the market don't have that figure mentioned. And few engineers stop to remember that using remote sensing isn't the same as bringing the supply terminals up to the load.

The ac output impedance (or transient-response behavior) is completely different. This output impedance is the parallel combination of the output impedance of the regulating loop and the impedance of the output capacitor (which, remember, includes inductance). At frequencies beyond the amplifier's cutoff, the output capacitor becomes the dominant factor. But remote sensing remains effective only within the usable bandwidth of the feedback amp, so the benefit of the supply's output capacitor is lost at the remote load.

What about load current? You wouldn't expect a single parameter like that to be misunderstood.

Current means output power. That spells internal dissipation. And that produces heat. Most circuitry is designed to be raised to some temperature, say 85°C, before performance and reliability suffer. You get that temperature with different power-output levels if the ambient temperature and/or the heat-removing mechanism changes. But there is another aspect to the current rating.

While continuous dc drawn from the supply is primarily tied to temperature, performance with regard to specs like regulation and ripple can suffer long before we reach the temperature-limited current level. The clue here is duty cycle. This is somewhat implicit in the so-called "multi-rated" supplies. Several manufacturers have



taken the continuous current rating as a function of temperature, with possibly twice as much current available at 40° as at 71°C. This suggests that a peak current equal to the 40° value can be drawn at 71°C as long as the duty cycle is only 50 percent and as long as the peak current duration is short compared to the thermal time constant of the critical power-supply components involved. In the end, current rating, particularly of a miniature supply is intimately tied to temperature.

But which temperature? You look at ten power-supply catalogs and get ten different meanings of temperature. Some talk about base-plate temperature, some about heat-sink temperature. Others discuss ambient temperature, but that can be misleading because the supply creates its own ambient if you let it.

In a miniature power supply, particulary, regardless of the definitions, be prepared to have to remove heat. If the base-plate temperature is "allowed" to go to 80°C, it means *you* have to cool it down to 80°C. If the ambient temperature corresponding to the rated current is 65°C, it's up to you to see that the air immediately surrounding the supply does not rise higher.

The manufacturer, faced with stiff competition, tends to play down this factor. The fact that more users don't get into trouble is due to extenuating circumstances like lower than 100 percent duty cycle, or just seat-of-the-pants conservatism in planning for the actual current required.

Many specs combine ripple and noise so you can't really tell what you're getting. The difference is important.

Ripple and noise are very important parts of the miniature-power-supply spec. Ripple is usually line-frequency related, so the ratio of peak to peak to rms is about 3 to 1. But to express noise in rms or include noise in the rms-ripple figure is outright misleading. Switching spikes can have destructive amplitudes without contributing to an rms reading. And speaking of noise measurement, be sure the scope has the necessary bandwidth to display what's there. A 500-kHz scope, plenty good for watching 120-Hz ripple, will completely ignore 100-nanosecond spikes.

A few companies take advantage of this confusion. They measure ripple with an rms-reading voltmeter, multiply by three, then write a "peak-to-peak" spec for ripple and noise.

Other companies, and national and international organizations have tried to eliminate the confusion—without much success. I think they've had most success in developing acronyms—PARD, for Periodic And Random Deviations; CRUD, for Continuous and Random Unwanted Deviations; and a term derived from Continuous and Random Amplitude Perturbations.

But the real problem continues. Noise spikes can change logic states in digital systems and, if they're severe enough, they can destroy costly components.

Temperature coefficient is another important and deceptive spec. It's easy to measure the output voltage at two temperatures. Then you can plot the two voltages and their corresponding temperatures and the slope of the line gives you the tempco. The beauty of the method is that if you pick the temperature judiciously, you can get practically any tempco you like. The tempco spec gives no indication of what happens *during* temperature change or in between the points you picked.

Since parameters of all components don't necessarily change by the same amount (nor in the same direction) with temperature, the output voltage can take wild excursions before the supply stabilizes at the second temperature. We've all heard of the man who drowned crossing the stream whose average depth was two feet.

In other words, a 15-volt supply with a tempco of 0.01%/°C can change output voltage by 45 millivolts as the temperature changes from 20° to 50°C but *while* the temperature is changing, the output variation can be several times that value. If you compare this with a 0.1% or 15-mV regulation figure you see how fast you can get drowned by the "fringe" factors.

Along the same lines, you have to check the adjustment resolution of an output-voltage control. Since this is usually a wirewound potentiometer, the voltage is actually adjusted in steps as the wiper jumps from turn to turn. One of those steps can actually occur due to temperature changes or possibly vibration—without your finger on the pot. If the adjustment resolution is 30 mV (a common figure) while the regulation is 5 mV, you're in for a much bigger output variation than you bargained for.

There's something else about temperature. We all know that internal heat generation is a function of load current. But nobody ever mentions gradual output-voltage drift due to load change. In some supplies, this can overshadow the regulation and you really get something quite different from what you thought you bought.

If the package is truly small in relation to the power it handles, its internally dissipated power in the form of heat probably exceeds that which can be convected away by its surface area alone. This means you have to plan for conduction or forced-air cooling. This planning is too often neglected.

Here is where the manufacturer has to do a better job of educating the user. He should furnish better data than we find in most spec sheets. It's fine to tell a user to keep the mounting surface below 80°C, but without knowing the wattage which must be sinked to keep the temperature below 80°C, the user cannot make proper heat-flow plans.

Some manufacturers supply extensive thermal curves that lead directly to the required convecting-surface area. That's fine. But check these data before you buy. You may find that the power supply measuring 4 × 5 × 6 inches needs a heat-sink measuring 30 × 30 × 1/8 inches to keep it at the required base temperature. This can wipe out any space savings. You may find that a finned heat sink and forced air are necessary. The ultimate responsibility of proper application is still yours but you have a right to insist on complete data from the manufacturer.

Let's see what it takes to make a miniature supply. And let's see what you have to pay for it.

Look at what miniature packages look like. They're small cubes, the least practical form factor from many points of view. It's hard to get the heat out of a cube; it's difficult to manufacture; it's less accessible for servicing and awkward to integrate into equipment. This shape is a carryover from the Mil-T-27 cans designed to house transformers.

Transformers use the least amount of iron and copper when approaching the cubic configuration. But regulated power supplies contain semiconductors and capacitors, which are more sensitive to heat. Their packaging configuration should allow maximum surface area for minimum volume.

This leads us to a relatively flat shape. It offers many advantages in design as well as application of small supplies. It provides the largest surface area for best heat removal; it lends itself to printed-circuit wiring; and it exposes every component for testing and replacement. And last, not least, the flat shape is quite compatible with cardrack-packaging methods.

There are several approaches to miniaturization. None is perfect. From the all-important thermal point of view, the most popular approach uses a switching regulator instead of a linear regulator.

The linear regulator is always on to some extent, so it always dissipates heat. In the switching regulator, the pass element (transistor or SCR) is either completely on (so dissipation occurs only in the small saturation resistance) or completely off (so there's no current flow and thus no I^2R). Regulation is achieved by controlling the on and off periods, then averaging the output in an LC filter to reduce ripple.

The big boast of switching supplies is efficiency. But they're noisy and they create other problems, too. Further, without other measures, they don't provide dramatic size reduction. To really save space we must attack bulky items like the 60-Hz transformer and filter.

The first thing to do is get rid of that massive input transformer. We can do this by rectifying and filtering the 60-Hz line voltage right at the input. This gives immediate advantages. The rectifier is more efficient because its own voltage drop is a much smaller percentage of the voltage it's handling. The filter capacitor operates more efficiently, too, since, for a given volume, the energy it stores is proportional to the square of the voltage.

Next, we can invert this dc to a frequency much higher than that of the line. This allows us to use a much smaller transformer and filter. This three-pronged attack—direct rectification at the line, high-frequency operation and switching regulation—allows dramatic size reduction with minimum overall heat generation.

We can't get something for nothing. The switching regulator has another limitation.

Transient response of a switching regulator is usually an order of magnitude slower than that of the linear regulator. This results from its limited operating frequency (sampling rate). Because feedback control can be exercised only in discrete pulses, a time lag exists in the feedback loop. This means the feedback-system gain must be made to roll off below the sampling frequency to maintain stability. The higher the switching frequency, the higher the feedback-amplifier bandwidth can be made and the better will be the transient response.

Knowing the operating frequency can tell you something about the transient response. Depending on the operating frequency and loop response, the recovery time after a load step can be many milliseconds. What's even more important and most manufacturers don't breathe a word of it, is what happens while you're out of regulation. What transient amplitude can be expected as a function of a load step or as a function of possible additional external capacitance? Questions like these are vital, yet answers are almost never in published specifications. Consider yourself lucky if the data are at least available for the asking.

While we're talking about operating frequency of a switching supply, find out if you can hear it. Audible noise may be perfectly tolerable in an unattended instrument but it can murder you, for example, in a desktop computer. I've yet to see this mentioned in anybody's catalog. Even the customer installing a supply in his instrument may not become aware of the problem until it's too late, particularly if the production floor is relatively noisy.

Of course, the best known problem with switching supplies is noise. Switching produces square wavefronts. Even if all circuit ringing could be suppressed, which is rarely the case, we get high-frequency components that are hard to filter out. As an example, pulses that are 20-microseconds wide and 1-volt high and have rise and fall times of 1 microsecond, produce conducted interference which is 45 dB above Mil-Std-461 allowable limits at 2 MHz. When that switching is done at 300 volts peak to peak, the figure jumps to 95 dB above limits. These are relative figures, referring to a 50-ohm system, but they suggest the magnitude of the problem.

With extensive low-pass filtering at the output, we can usually control conducted interference. However, rfi fed back into the power line may not have been taken care of. Filtering here is usually required when susceptible equipment such as receivers are operated near the power supply. The degree of sensitivity to this interference depends a lot on the application. Because of size restriction, maximum filtering is usually not built into every switching supply.

This puts added responsibility on you to recognize susceptibility problems when you choose your supply and to plan for necessary filtering at that time. Ideally, the manufacturer of interference-producing equipment should furnish an emi "signature." Remember that noise-suppression filters can add 50 percent to the volume of a miniature power supply.

Now look at the most comforting of all specs — the guarantee.

Everyone "warrants" his equipment to be free of defects in materials and workmanship. The time periods vary all the way from one year to "forever." But in the final analysis, the fact that the factory will repair or replace the supply is incidental to the amount of red tape and the time that can be consumed in putting yourself back in business. The quality of this type of customer service is, unfortunately, never apparent from the written word and personal experience with a manufacturer is the best source of information. So take the written "warranty" with a grain of salt until you know better.

What about reliability? It's still a numbers game. Tell me how many parts you're using and I'll tell you how long it will last. This is, of course, an oversimplification. But it's justified as the first-order-of-magnitude approach. The environment, temperature, shock and vibration and the individual component stresses are important contributing factors.

In the case of a high-frequency conversion or switching regulator, you have two to three times as many components as in the conventional class-A regulator supply. Because of miniaturization, component temperatures tend to be on the high side. All this points to a lower MTBF figure. So quality of design and construction are doubly important in a miniature supply. Buying price alone can be a real booby trap.

Here's where a word is in order about the controversy of a custom unit versus a catalog supply. In most military applications, for instance, the requirement calls for a power supply tailored to the application. Couple that with the relatively small number of units (compared to commercial quantities) that is usually involved and the short delivery cycle required (say what you will, power supplies are still the last thing electronic designers freeze), and you have all the built-in factors for incomplete design and hasty application.

True, random component failure is supposed to be reduced by using military-quality components but a complete prediction of the stresses and temperatures involved is often impossible. Hindsight is always better than foresight but most of the time there is no second chance.

Contrast this with the reliability of a commercial catalog item that has been in production for a while. Stresses and failure-prone components have become known and field-performance data have been fed back, resulting in any necessary corrective action. If, in addition, such a seasoned product is put through an intelligently devised "run-in" procedure, you may well exceed the ultimate reliability of a one-shot custom military unit.

These considerations apply particularly to miniature supplies. With the state of the art being relatively new, the chances of an incomplete one-shot design are even greater and, if the supply has a greater complexity, the reliability requirement is even more stringent. There is no excuse for sloppy design but after the best possible design job, there is no substitute for field experience. **EEE**

Who is Walt Hirschberg

If it weren't for Walter Hirschberg, ACDC Electronics might not be in the power-supply business today. He's the man who urged the company to enter this important marketplace at a time when it was much less crowded. More recently, as vice president of product development, he was the man who spearheaded the development of ACDC's new miniature power supplies.

Born in Berlin, Germany, Walt started his electronics career there during high school, when he discovered an introductory text book, "Die Rundfunk Technik" (Radio Engineering), which he still keeps as a souvenir.

Since then, he amassed a great deal of practical experience, starting as a teen-age test-equipment technician and as a radar technician in the U.S. Navy. While in the Navy, Walt co-authored a patent on a topographic radar-mapping system.

He took his BSEE from CalTech with honors, then took his MSEE from the same school while serving as a part-time instructor. He's a long-time member of Tau Beta Pi and of IEEE (since the IRE days). After school, he worked for Consolidated Electro-Dynamics and Essex Electronics before he joined ACDC.

Walt and his wife Sylvia live with their children, Jim and Marianne, in Carlsbad, California. They enjoy sailing on the Pacific, though Walt is between boats now. He's an avid photographer and, in spare moments, he loves to play the piano.

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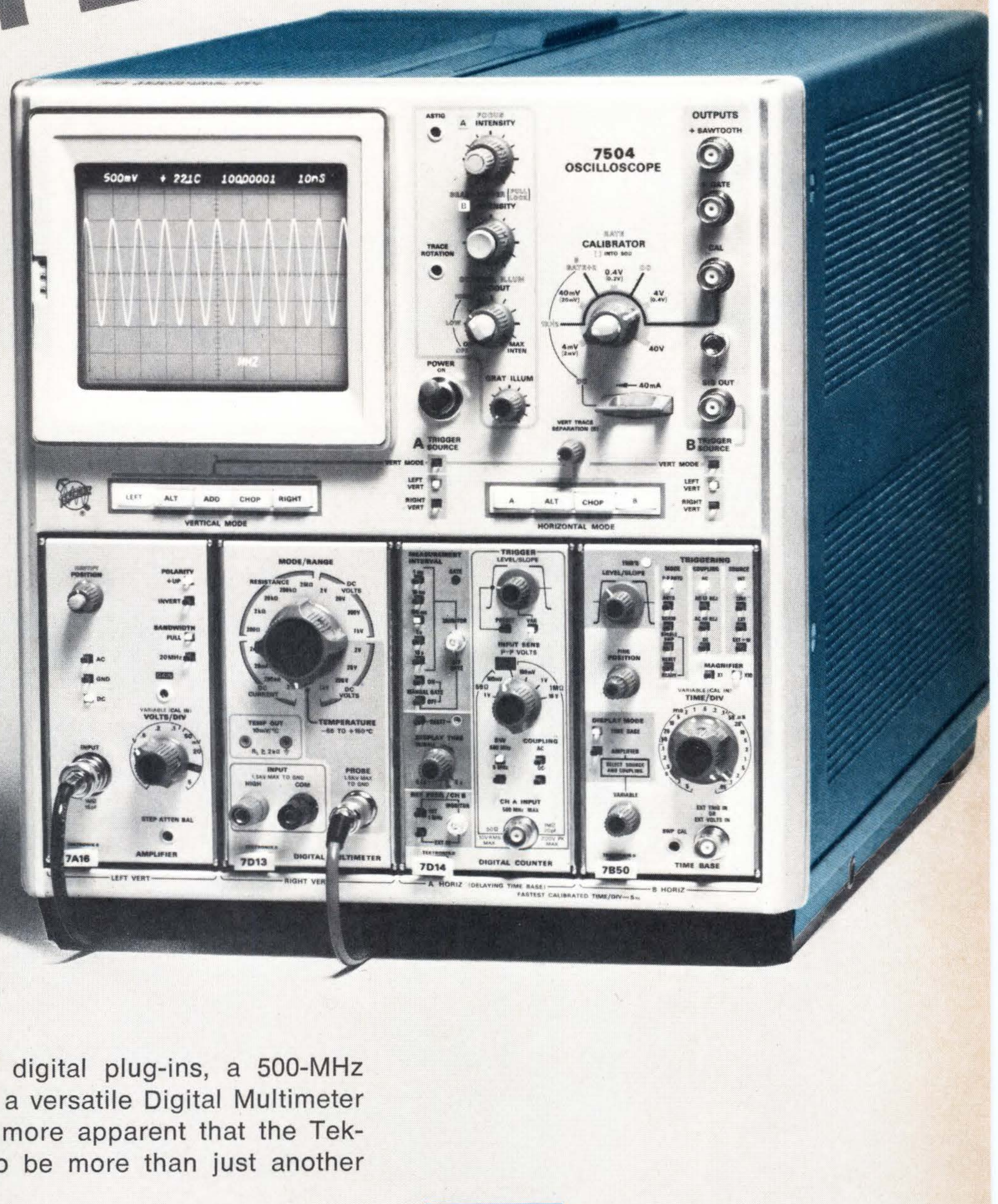

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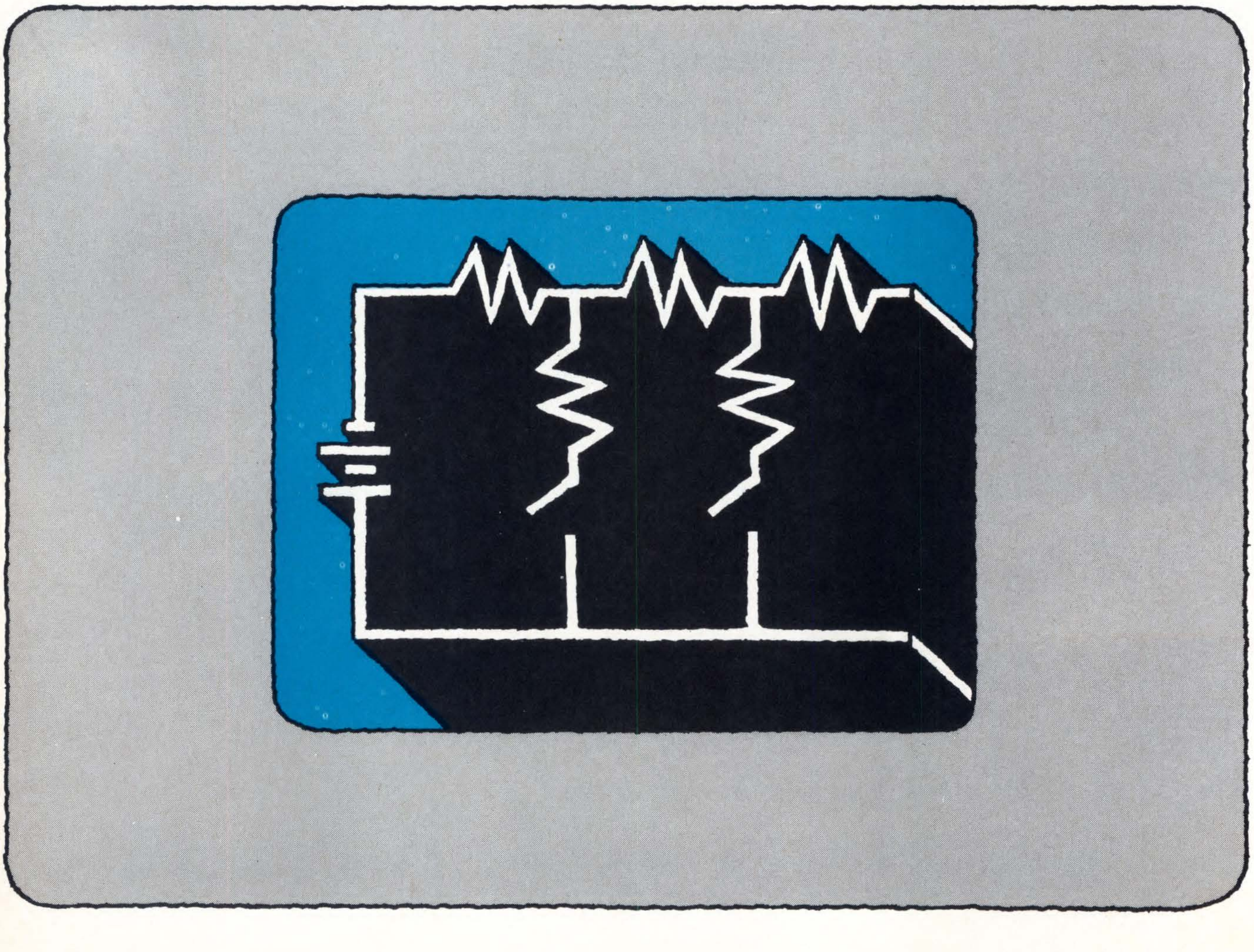
Designer's Guide: D/A Converters

EEE
September, 1970
Number 12 Part 1



Current Status of D/A Converters

The explosive growth in electronic data processing has created a large market for data-conversion circuits and equipment that can interface digital computers with the real world (which is predominantly analog). Wherever a computer must control an analog system or provide an analog display, then some sort of digital-to-analog converter is required.

Fortunately for the system designer, the growing market has attracted many new DAC vendors. As can be seen in our directory, the man who needs a ready-made DAC has plenty of possible sources to choose from.

But the diversity of DAC manufacturers can cause confusion. Though each of the companies makes DACs, the products cover a broad spectrum of price, performance and size. Some of the companies are primarily instrument manufacturers, others are module manufacturers, and a few are integrated-circuit manufacturers. One of the purposes of this Designer's Guide is to help the engineer design or specify the right DAC for the job.

Partly because of growing competition, and partly because of the availability of low-cost ICs, DACs are becoming better, cheaper and smaller, every day. With a wide choice of excellent circuits available at modest cost, many engineers are now choosing to buy, rather than build. Off-the-shelf units can fill the vast majority of applications. And, even in special situations, it may be possible to modify an existing unit or to assemble a custom array of microelectronic D/A "building blocks."

Microelectronic DACs

Three years ago there weren't any microelectronic DACs, and most packaged DACs were quite bulky. Then Fairchild introduced the μA722, a monolithic 10-bit current switch that could be interconnected with a resistor network to form a complete DAC. Though the μA722 couldn't compete with high-performance DACs (it wouldn't operate over the full military temperature range and could provide only 7-bit accuracy over the range −20 to +85°C) it had a dramatic impact on the low-performance end of the DAC market. Manufacturers who had been producing bulky modules, costing several hundred dollars, realized that they would now have to compete with tiny low-cost ICs. The fight was on.

By the beginning of this year, several companies had started to offer low-cost modules costing under $75 in unit quantity. Among the companies offering DACs in this price range were Analog Devices, Beckman, Computer Products and Hybrid Systems (see EEE, February 1970, pp. 20-22). And, in the last few months, other companies have either started to manufacture low cost DACs or have slashed the prices of existing units. Recently, Analogic, Burr-Brown, Varadyne Systems (formerly Datel), DDC, Hy Comp, Micro Networks, Precision Monolithics, Zeltex and Teledyne Philbrick Nexus have all entered the low-cost arena. The latter company's DAC line made an impressive debut at Wescon.

Availability of monolithic chips (for amplifiers, logic, and current or voltage switches) has led to substantial reductions in the size of complete DACs. And widespread use of hybrid packaging techniques has allowed further size reductions. Both thick- and thin-film packaging techniques are currently being employed for DACs. Among the companies making thick-film hybrids are Beckman, Columbia Components and Datel. Recently there seems to have been a trend towards thin-film fabrication—with companies like Micro Networks, Precision Monolithics and Sprague favoring this approach. Thin-film weighting networks usually offer better accuracy than thick films, but thick films are said to be less expensive (see EEE, August 1970, pp. 40-44). Some companies now claim, however, that they can manufacture thin-film ladder networks that are less expensive than thick-film networks.

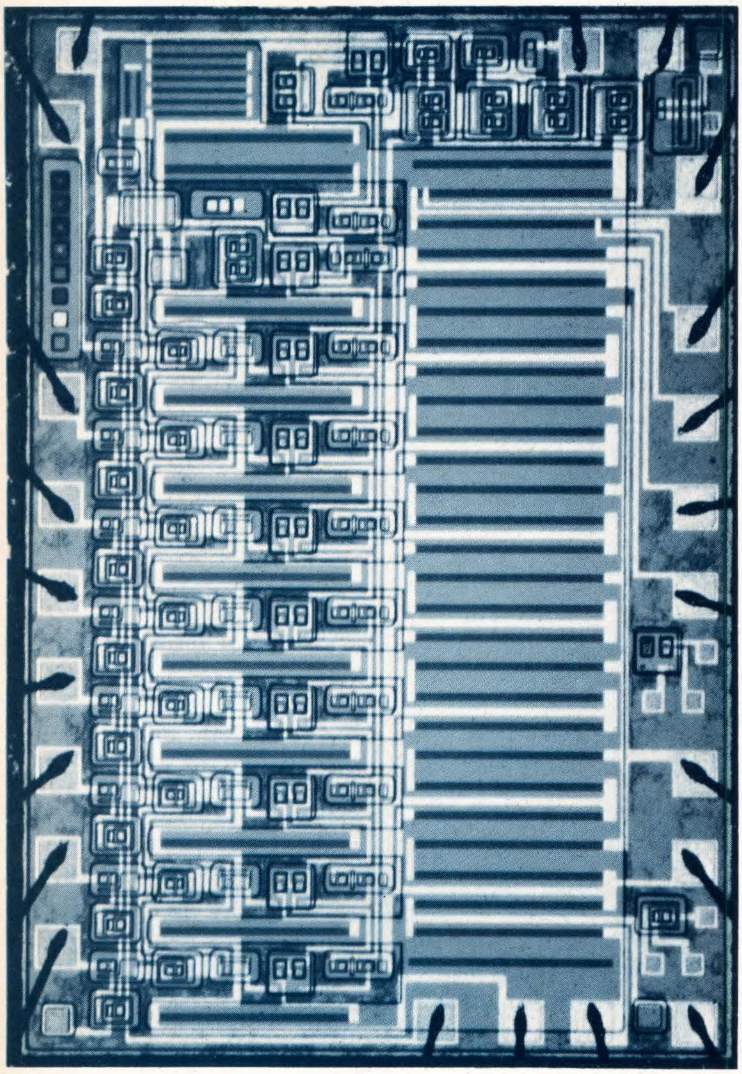
Monolithic fabrication

While manufacturers of packaged circuits have been making giant strides, the IC manufacturers haven't been standing still. Various companies have introduced ICs that can offer better performance than the μA722 in DAC applications. For example, earlier this year Precision Monolithics introduced what it called a "premium monolithic D/A converter." This device is a 10-bit current switch, similar to the μA722 but with superior temperature performance and speed (see EEE, March 1970, pp. 64-65). Analog Devices chose a slightly different approach and introduced a series of monolithic quad switches that could be cascaded to form DACs with resolutions up to 16 bits (see EEE, August 1970, pp. 18-19).

One possible disadvantage of monolithic switching networks (like the Precision Monolithics monoDAI-01 and Analog Devices' AD550 and AD555) is that they need external resistor networks to form a complete DAC. It can be argued, of course, that having the switching network in a separate package is an advantage because it allows greater flexibility.

Switching networks can be cascaded and used as building blocks for larger systems. Temperature coefficients and other errors can be graded to meet the overall requirements at minimum cost. Nevertheless, in simple applications it is usually more convenient to have a complete DAC in a single package.

Perhaps the most dramatic recent DAC development has been the advent of complete, monolithic, DACs. A few months ago, Radiation introduced the



Radiation's RI-1080 is an 8-bit monolithic D/A converter with a thin-film ladder network deposited on the dielectrically isolated chip. The circuit operates over the full military temperature range and is supplied in a 24-lead flat pack.

Manufacturers of D/A converters

Adage, Boston, Mass.
A.D. Data Systems, Rochester, N.Y.
American Astrionics, Palo Alto, Cal.
Amtron, Subs. Republic Corp., Midlothian, Ill.
Anadex Instruments, Van Nuys, Cal.
Analog Devices, Pastoriza Div., Cambridge, Mass.
Analogic, Wakefield, Mass.
Analog Technology, Pasadena, Cal.
Ann Arbor Computer, Ann Arbor, Mich.
Applied Dynamics, Ann Arbor, Mich.
Astrodata, Anaheim, Cal.
Astrosystems, New Hyde Park, N.Y.
Atec, Houston, Tex.
Automatic Data Processing of Mass, Boston, Mass.
Automation Development, Culver City, Cal.
Automation Management, Westboro, Mass.
Autonetics, Anaheim, Cal.
Avco Electronics Div., Cincinnati, Ohio.

Ball Brothers Research, Boulder, Colo.
Beckman Instruments, Helipot Div., Fullerton, Cal.
Bendix Corp., Teterboro, N.J.
Bowmar Instrument, Fort Wayne, Ind.
Bulova, Woodside, N.Y.
Bunker-Ramo, Canoga Park, Cal.
Burr-Brown Reasearch, Tucson, Ariz.
B & W Electronic Research Labs., Dallas, Tex.

California Systems Components, Chatsworth, Cal.
Cambridge Thermionic Corp., Cambridge, Mass.
Canberra Industries, Meriden, Conn.
Canoga Industries, Los Angeles, Cal.
Cardion Electronics Div., Woodbury, N.Y.
Clifton Div., Litton Industries, Drexel Hill, Pa.
Coldspring Instrument, Huntington, N.Y.
Collectron Corp., New York, N.Y.
Columbia Components Corp., Hempstead, N.Y.
Compudyne Corp., Hatboro, Pa.
Computer Central, Detroit, Mich.
Computer Conversions, East Northport, N.Y.
Computer Labs, Greensboro, N.C.
Computer Logic, Santa Monica, Cal.
Computer Products, Fort Lauderdale, Fla.
Conductron-Missouri, St. Charles, Mo.
Connor-Winfield, Winfield, Ill.
Conrac Corp., New York, N.Y.
Control Logic, Natick, Mass.
Control Technology, Long Island City, N.Y.
Cosmos Industries, Brooklyn, N.Y.

Data-Control Systems, Danbury, Conn.
DDC, Hicksville, N.Y.
Data Technology Corp. Palo Alto, Cal.
Data Technology Inc., Watertown, Mass.
Datatron, Santa Ana, Cal.
DatCon Electronics, Mt. Vernon, N.Y.
Datum, Anaheim, Cal.
Daytron, Mountain View, Cal.
Defense Electronics, Rockville, Md.
Digiac Corp., Plainview, N.Y.
Digital Equipment Corp., Maynard, Mass.
Digital Instruments, Shawnee-Mission, Kans.
Digital Products, Fort Lauderdale, Fla.
Discon Corp., Fort Lauderdale, Fla.
Ditran Div. Clifton/Litton, Burlington, Mass.
Dorsett Electronics, Tulsa, Okla.
Dynamic Measurements, Arlington, Mass.
Dynamics Instrumentation, Monterey Park, Cal.
Dynamic System Electronics, Tempe, Ariz.
Dynapar Corp., Gurnee, Ill.
Dynatronics Oper., General Dynamics, Orlando, Fla.

E-H Research Labs, Oakland, Cal.
Electronic Associates, West Long Branch, N.J.
Electronic Design Labs., Philadelphia, Pa.
Electronic Development Corp., Boston, Mass.
Electronic Engineering Co., Santa Ana, Cal.
Electronic Resources, Los Angeles, Cal.

RI-1080—a complete 8-bit DAC with a thin-film resistor network deposited on the dielectrically isolated active chip (see EEE, June 1970, pp. 32-38). More recently, Precision Monolithics introduced a 6-bit monolithic DAC that uses diffused resistors in the weighting network. This new circuit, designated monoDAC-01 is the first truly monolithic DAC, in the sense that it's constructed on a single chip without additional thin-film processing.

It is unlikely that monolithic DACs with diffused resistors will ever achieve really high accuracies, as diffused resistors can't match the temperature performance of thin films. But they offer a low-cost solution for routine applications. In large quantities, the monoDAC-01 costs around $25, and lower prices for this type of device are probable in the future. It should be pointed out, however, that though the monoDAC-01 and RI-1080 are complete DACs, they may need external output amplifiers in many applications.

(Continued on next page)

E & L Instruments, Derby, Conn.
Elpac, Irvine, Cal.
EMR Div., Weston Instruments, Princeton, N.J.
Epsco, Westwood, Mass.

Fairchild Hiller, Germantown, Md.
Fairchild Semiconductor, Mountain View, Cal.
Fairchild Space & Defense Systems Div., Syosset, N.Y.
Fifth Dimension, Princeton, N.J.
Fisher-Akin, Manhattan Beach, Cal.
Flow Technology, Tempe, Ariz.
Foxboro Co., Foxboro, Mass.
Frequency Engineering Labs, Farmingdale, N.J.

GAP Instrument, Westbury, N.Y.
General Devices, Princeton, N.J.
General Dynamics, Rochester, N.Y.
General Electric, Phoenix, Ariz.
General Instrument, Hicksville, N.Y.
General Radio, West Concord, Mass.
General Resistance, Mount Vernon, N.Y.
Genisco Technology, Compton, Cal.
Geo Space Systems, St. Petersburg, Fla.
Gulton Industries, Metuchen, N.J.

Harris-Intertype, Cleveland, Ohio
Hewlett-Packard, Palo Alto, Cal.
Honeywell, Computer Control Div., Framingham, Mass.
Honeywell, Test Instruments Div., Denver, Colo.
Hughes Aircraft Co., Newport Beach, Cal.
Hybrid Systems Corp., Burlington, Mass.
Hybridyne, Los Angeles, Cal.
Hy Comp, Maynard, Mass.

IBM, White Plains, N.Y.
Icon Corp., Cambridge, Mass.
Industrial Control Co., Farmingdale, N.Y.
Infomax, Palo Alto, Cal.
Information Control Corp., El Segundo, Cal.
Information Displays, Mt. Kisco, N.Y.
Instrumentation Technology, Northridge, Cal.
Intech, Santa Clara, Cal.
Inter-Computer Electronics, Lansdale, Pa.
International Components Corp., Asbury Park, N.J.
Intersil, Cupertino, Cal.
Intronics, Newton, Mass.
ITT Aerospace, San Fernando, Cal.

Julie Research Labs., New York, N.Y.

Kearfott Div., Singer-GP, Little Falls, N.J.
Keltron Corp., Waltham, Mass.
Kepco, Flushing, N.Y.

Labtron Div., KDI, Dayton, Ohio
Lear Siegler, Anaheim, Cal.
Lear Siegler, Grand Rapids, Mich.
LFE Electronics, Waltham, Mass.
Librascope Div., Singer-GP, Glendale, Cal.
Logic Corp., Haddonfield, N.J.
Logic Science, San Diego, Cal.
Lorch Electronics, Englewood, N.J.

Marstan Electronics, Orange, N.J.
Massey Dickinson, Saxonville, Mass.
McMaster Products, Chicago, Ill.
Measurement Technology, Canoga Park, Cal.
Mepco, Morristown, N.J.
Metric Systems, Fort Walton Beach, Fla.
Micro Metrics, Paterson, N.J.
Micro Networks, Worcester, Mass.
Milgo Electronic, Miami, Fla.
Monitor Systems, Fort Washington, Pa.
Monsanto, West Caldwell, N.J.
Moore Products, Spring House, Pa.

NanoFast, Chicago, Ill.
Navcor Div., KDI, Norristown, Pa.
Norden Div., United Aircraft, Norwalk, Conn.
North Atlantic Industries, Plainview, N.Y.
North Hills Electronics, Glen Cove, N.Y.
Northern Precision Labs., Fairchild, N.J.
Nytronics, Kutztown, Pa.

Pacific Data & Controls, San Carlos, Cal.
Pacific Electro Dynamics, Bellevue, Wash.
Performance Measurements, Detroit, Mich.
Perkin-Elmer, Wilton, Conn.
Philco-Ford, Washington, D.C.
Phoenix Data, Phoenix, Ariz.
Plessey Airborne Corp., Hillside, N.J.
Powertec, Chatsworth, Cal.
PPM, Cleveland, Ohio
Precision Monolithics, Santa Clara, Cal.
Preston Scientific, Anaheim, Cal.

Radiation Inc., Subs. Harris Intertype, Melbourne, Fla.
Radix Electronics, Anaheim, Cal.
Raytheon Computer, Santa Ana, Cal.
RC-95, New York, N.Y.
Reaction Instruments, Vienna, Va.
Redcor Corp., Canoga Park, Cal.
Reeves Instrument, Garden City, N.Y.
Reflectone, Englewood Cliffs, N.J.
Reliance Electric, Cleveland, Ohio
RFL Industries, Boonton, N.J.
Rohde & Schwarz, Passaic, N.J.

Saturn Electronics, Garland, Tex.
Science Accessories, Southport, Conn.
Sensor Corp., Greenwich, Conn.
Servo Development Corp., Hicksville, N.Y.
Servonetics, Northridge, Cal.
Sierra Research, Buffalo, N.Y.
Sigma Instruments, Braintree, Mass.
Signet Controls, Tulsa, Okla.
Siltronics, Oakmont, Pa.
Simpson Electric, Chicago, Ill.
Singer Instrumentation Div., Los Angeles, Cal.
Solid State Electronics, Sepulveda, Cal.
Solid State Radiations, Los Angeles, Cal.
Space Craft, Huntsville, Ala.
Space & Systems Div., General Time, Stamford, Conn.
Space & Tactical Systems, Burlington, Mass.
Sprague Electric, North Adams, Mass.
Stellarmetrics, Santa Barbara, Cal.
Stelma, Stamford, Conn.
Superior Electric Co., Bristol, Conn.
Superior Mfg. & Instrument, Long Island City, N.Y.
Systems Engineering Labs., Ft. Lauderdale, Fla.

Taft Electrosystems, Metuchen, N.J.
Technical Material, Mamaroneck, N.Y.
Teledata, Queens Village, N.Y.
Tele-Dynamics Div., Philadelphia, Pa.
Teledyne Crystalonics, Cambridge, Mass.
Teledyne Philbrick Nexus, Dedham, Mass.
Teledyne Systems Control, El Segundo, Cal.
Teledyne Telemetry, Los Angeles, Cal.
Tele-Signal Corp., Woodbury, N.Y.
Texas Instruments, Industrial Products Div., Houston, Tex.
Theta Instrument, Fairfield, N.J.
Towson Labs., Baltimore, Md.
Transmagnetics, Farmingdale, N.Y.
TRW Systems, Redondo Beach, Cal.
Tyco Instrument Div., Waltham, Mass.

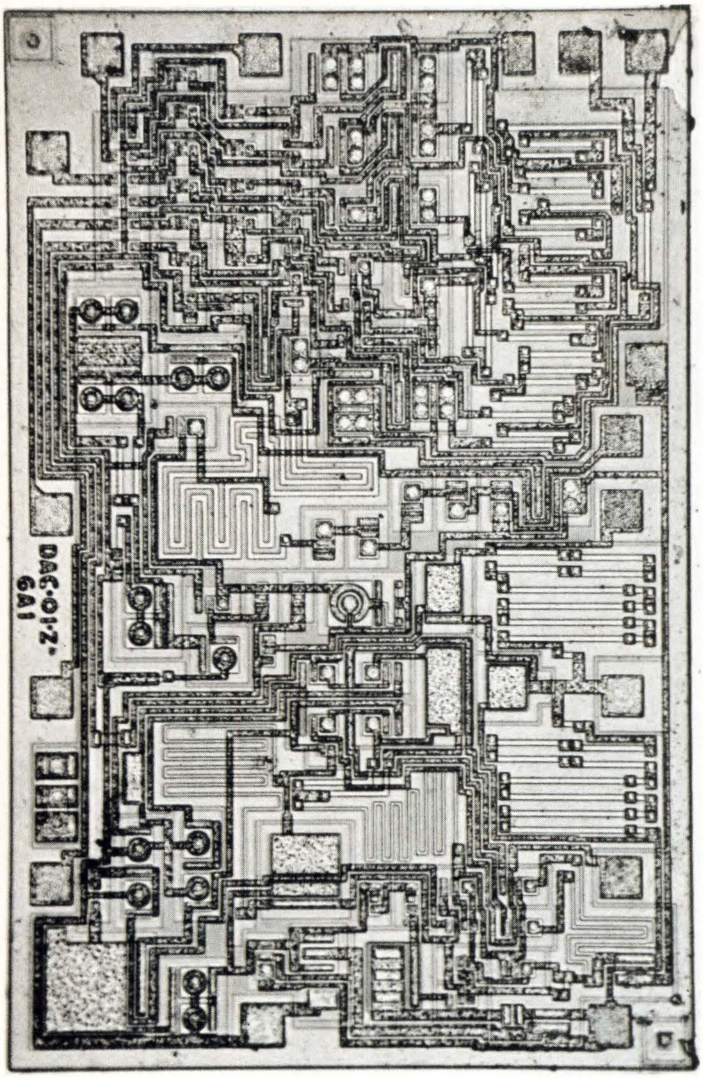
Ultronix, Grand Junction, Colo.

Varadyne Systems, Canton, Mass.
Varian Data Machines, Irvine, Calif.
Veeder-Root, Hartford, Conn.
Vega Precision Labs., Vienna, Va.
Vernitron, Farmingdale, N.Y.
Vidar Corp., Mountain View, Cal.
Vitro Labs., Silver Spring, Md.

Weston-Transicoil, Worcester, Pa.
Wyle Labs., El Segundo, Cal.

Xerox Data Systems, El Segundo, Cal.

Zeltex, Concord, Cal.



Precision Monolithics' new mono-DAC-01 is a complete 6-bit D/A converter on a single chip. Diffused resistors are used for the ladder network. The circuit comes in a 14-lead DIP and operates with ±1/2 LSB accuracy over the full military temperature range.

Many applications

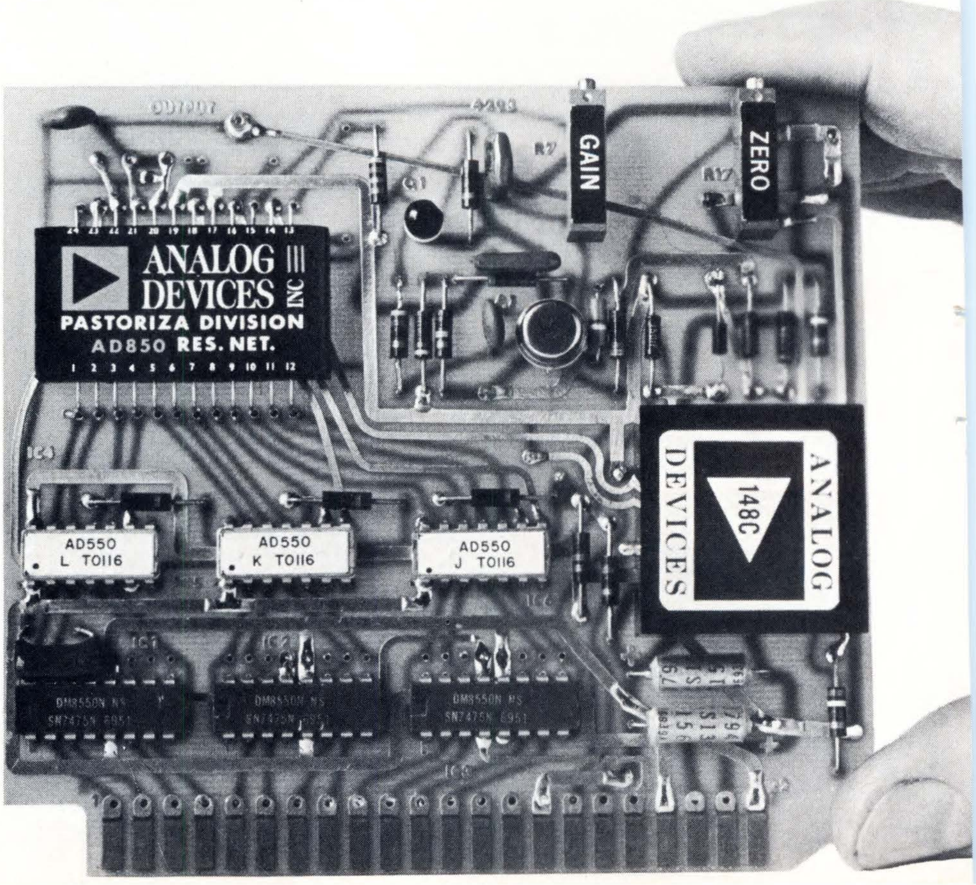
Though the most significant improvements in DACs have been in the areas of size and cost, important progress has been made in other areas, too. There have been gradual improvements in accuracy and speed, and many companies have started to pay attention to some of the more subtle aspects of DAC performance (such as "glitches," monotonicity and common-mode errors). Most companies offer a set of options with their catalog items—the user can choose what he needs from a variety of different coding systems and full-scale output voltages.

The proliferation of commercially available DACs and the downward price trend are, together, opening up many new DAC applications that were, hitherto, impractical or uneconomical. DACs have many applications beyond their obvious function as an interface between digital and analog equipment.

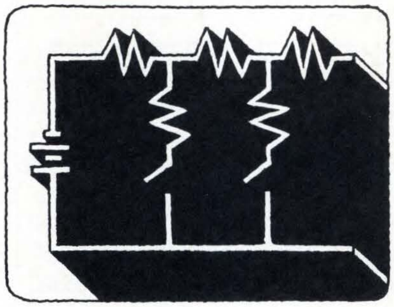
This Designer's Guide is in two parts. The second part will be published later. The two articles in this section of the Designer's Guide concentrate on applications for complete DACs. A future article will describe the various circuit techniques used in the design of DACs.

This month's article by Mike Lindheimer reviews some popular DAC applications and shows how DAC characteristics can influence and be influenced by other system elements. The article by Michael Neidich concentrates on an interesting subclass of DACs—the "multiplying" or "external-reference" DAC. He shows how the ability to manipulate the reference voltage opens up a whole new field of DAC applications. Also included within Neidich's article is a discussion of "ac-reference" DACs.

It is hoped that this Designer's Guide will not only help engineers solve existing problems but will also stimulate the discovery of further applications for DACs. **EEE**



Analog Devices is one of its own best customers. The company uses its μDAC monolithic quad switches to build a complete 12-bit D/A converter on a PC board. The circuit shown includes a high speed output amplifier and a digital input register. Other configurations are available.



Guidelines For Digital-To-Analog Converter Applications

By Michael Lindheimer

Digital computation is usually employed wherever one needs to perform complicated analyses of data. And digital computation is often used for relatively simple analyses and operations in situations involving nonlinear functions or large numbers of data channels.

In the real world, however, we usually need to control analog quantities — such as voltage, force, or shaft rotation. Very often, therefore, the output from a computer must drive a non-digital device. In this type of situation, a digital-to-analog converter provides the required interface.

The name digital-to-analog converter (DAC) is self-explanatory. It is worth noting, however, that a DAC need not be electrical. The basic functional elements of a DAC are a set of digital controllers, such as switches or valves, and a weighted network whose outputs are summed.[1] The digital controllers are actuated in accordance with the digits of the numerical input, and the weighted network assigns the proper significance to each digit in determining the analog output.

An additional functional element of a DAC allows outputs to be expressed in terms of a known standard (usually a calibrated reference voltage). Sometimes the reference element is a functional part of the DAC, and sometimes the reference signal is supplied externally as a separate input to the DAC. If both the analog reference input and the digital input to the DAC are permitted to vary, the circuit is called a multiplying DAC. The output is then the product of the reference and the input.

A typical DAC consists of a set of solid state analog switches, logic drivers to control the switches, and a binary weighting network. The latter may be a resistive ladder network or a set of current sources. In some types of DACs, a fixed reference voltage may be internally derived from a power-supply line. Often an op amp will be included to scale the output and provide low output impedance.[2]

The resolution and accuracy of DACs are often expressed in terms of word length, *i.e.*, the number of bits converted. The most popular word lengths are 8, 10 and 12 bits. It is important to distinguish between accuracy and resolution, however. For example, a four-bit DAC would have an output resolution of about six percent of full scale. But it is possible that the accuracy of each of its 16 available output levels could be, say, 0.01 percent of full scale. This order of accuracy, however, would be more typical of a fourteen-bit DAC.

Because accuracy and resolution are usually compatible (*i.e.*, about the same number of bits), it is common practice to express accuracy as the resolution plus-or-minus some toler-

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ance. Most companies specify the output accuracy of their DACs, in terms of a calibrated reference, as ±½ LSB or ±1 LSB. With this terminology, "LSB" refers to the weight, in percent of full scale, of the least significant bit of the input data.

Application problems

Several application problems may limit the ability of a DAC to deliver its specified performance. If the reference voltage is externally supplied, its errors add to those of the DAC. The varying load, presented by many types of DAC, can induce transients in the reference, thereby prolonging the DAC's output settling time. This problem is especially severe when several DACs share a common reference.

During the transition immediately after receipt of a fresh input code, a DAC's output may pass through values that are unrelated to either the old data or the new data. Differences in in times of arrival of the bit transitions (data skew) and unequal on and off switching times in the DAC can cause "spikes", or "glitches", in the output.[3] Depending on the design of the DAC and the response characteristics of its load, this may or may not be a problem.

When the analog device to be controlled is distant (say more than 20 feet) from the source of digital control information, additional application problems may arise. If the DAC is installed at the location of the controlled device, many conductors must run from the computer to the remote location. For this reason, one is tempted to locate the DAC near the computer, since the analog output requires only a twisted pair or a single shielded cable. But under these conditions, with a grounded load, an error voltage generally occurs due to potential difference between the load ground and that of the DAC. While the exact magnitude of this problem is difficult to predict, it is usually worse for long cable runs through electrically noisy areas.

Noise voltages in the ground return can cause several counts of error with high-accuracy converters (say 12 to 15 bits). One solution to the problem, albeit at higher cost, is to use a differential amplifier to receive the signal at the remote end of the cable.

Dynamic performance, too, may be degraded by a remote load. Cable capacitance can cause oscillation or severe ringing on the output of the DAC unless the cable is correctly terminated. Unfortunately, most commercially available DACs cannot deliver their full output voltage into the 50- to 100-ohm load presented by terminated cables.

For a trouble-free installation, therefore, it is best to locate the DAC near its load, and to run the digital signals through long cables if necessary. When speed requirements permit, the DAC can be driven serially on one or a few lines.

To see more clearly the role of DACs in system design, let's look at some typical current applications.

Analog chart recorders

In the past, most industrial processes have been monitored with analog recorders, such as strip charts or circle charts, and operators have become accustomed to these types of information display. But modern digital data acquisition systems usually provide numerical printout, via teleprinter or line printer, as the prime display.

To ease the transition, when installing a digital system, it may be desirable to retain the more traditional analog presentation — at least for an interim period. The output of the data acquisition system can then be processed through a DAC to drive analog charts.

Unfortunately, analog recorders have a nasty habit of running off scale when left unattended for many hours (possibly a consequence of one of Murphy's Laws). Important information may be lost. There is a simple solution to this problem, however. If the input to the recorder is derived from a DAC, the trace can be made to fold over or wrap around. This is achieved by using a DAC whose full-scale output is equal to (or slightly less than) the span of the recorder.

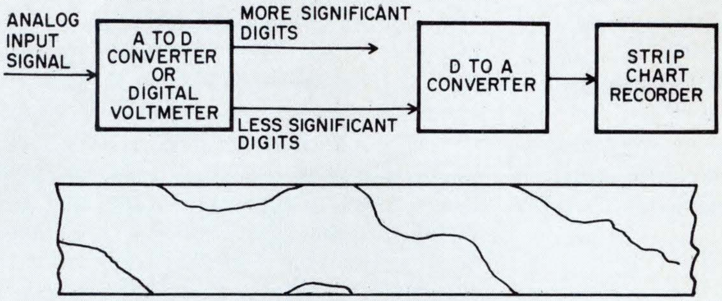
Suppose that the information to be displayed has a 12-bit word length, but that the analog recorder has a resolution of only one percent. The recorder can be driven through an 8-bit DAC, looking at only the eight less significant bits of the input data. Then if the input changes slowly through a large part of its range, the total change can be calculated by counting the number of times the chart goes off one side and returns on the other side of its span. A block diagram of the setup is shown in Fig. 1. If required, the discontinuous chart can be cut and pasted onto a larger sheet of paper to reconstruct a continuous plot.

Electromagnets and solenoids

Suppose that one needs to control digitally the magnetic field (or current drive) of a precision research electromagnet. In terms of dc accuracy and stability, this is one of the most demanding applications for a DAC. Though an absolute accuracy and resolution of 0.01 percent of full scale (13 bits) is adequate, the short-term stability must be 10 ppm or better. In many cases, even a 15-bit DAC may drift excessively unless its temperature is controlled.

In this type of application, however, dynamic performance is relatively unimportant, since the magnet current cannot be varied rapidly. A few percent modulation at 50 to 100 hertz is a typical requirement.

One way to relax the accuracy and stability requirements is to use the DAC as a vernier, superimposing it on a fixed reference voltage, or quiescent signal, by analog summation as shown in Fig. 2. If three-percent modulation is needed with 30-ppm resolution and accuracy,



TYPICAL CHART SECTION

Fig. 1. The resolution of an analog chart recorder can be effectively increased by "fold-over." This is achieved by recording only the less significant digits of the input signal. If required, the chart can be cut and pasted to reconstruct a continuous plot.

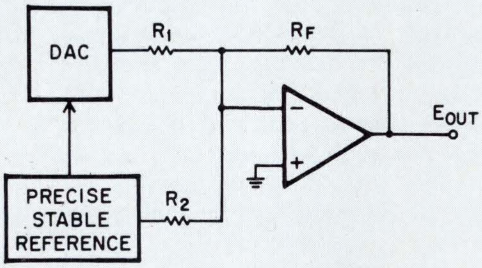


Fig. 2. A digital-to-analog converter can be "piggy-backed" on a stable reference voltage to allow high-resolution "vernier" adjustment of the output voltage.

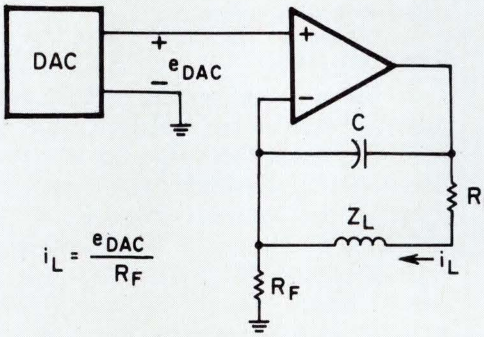
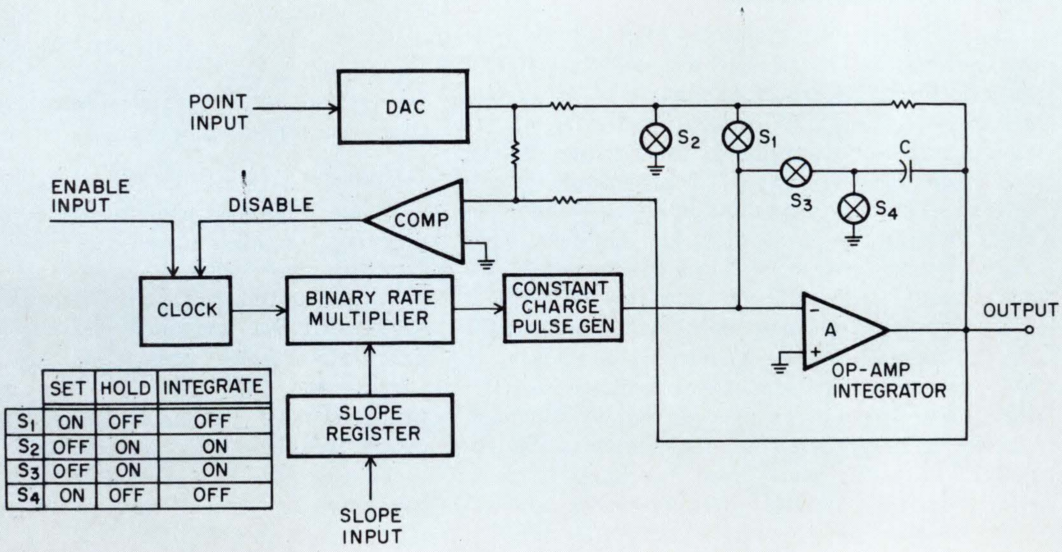


Fig. 3. Circuit for driving a high-current floating load from the output of a DAC. Capacitor C and resistor R_D are added to prevent parasitic resonances of the load and cabling.



	SET	HOLD	INTEGRATE
S1	ON	OFF	OFF
S2	OFF	ON	ON
S3	OFF	ON	ON
S4	ON	OFF	OFF

Fig. 4. In this integrating arbitrary-function generator, a binary rate multiplier produces a train of pulses which are conditioned to provide constant charge into an operational integrator. The start point, end point and slope of each straight-line segment of the output waveform can all be externally programmed.

a 10-bit DAC may suffice. A 12-bit DAC will allow four-percent peak-to-peak variation with 10-ppm incremental resolution.

Of course, the concept of using a DAC to modulate an analog signal is quite general, and it may prove useful in other applications too.

In process control, solenoid-operated valves are often used to interface with hydraulic and pneumatic equipment. For direct digital control, a DAC can drive a solenoid. Usually, a low-resolution DAC (say 8 bits) is adequate for this type of application.

If necessary, voltage from the DAC can be converted to high current for the solenoid as shown in Fig. 3.

The RC network (C and R_D) prevents oscillations caused by high-frequency parasitic resonances of the load and cabling. In Fig. 3, Z_L is the solenoid coil or any suitable load that is isolated from ground.

Component testing

In testing and sorting components such as diodes, transistors, resistors, relays, and meters, two basic categories of test requirements occur. For measuring impendance parameters, current transfer parameters, or zener and breakdown voltages, a programmable test current is needed. If, on the other hand, the parameter under test is an admittance, voltage gain, or leakage current, then the applied voltage must be programmed.

A circuit similar to the coil driver of Fig. 3 can be used to apply a programmed current or voltage to the device under test. But, since neither side of the DUT can be grounded, the voltage across it must be measured differentially. However, most digital voltmeters and digital data-acquisition systems satisfy this requirement.

Computer-controlled simulation

Some more-sophisticated applications for DACs occur in the field of simulation. Often it may be too awkward or expensive to use a real device or system for training purposes or for evaluation. For example, in the military world, one might need to simulate thermonuclear warheads, submarine systems, newly designed aircraft or missiles, etc. And, in industry, many complex processes must be modeled mathematically before full-scale versions can be built.

In medicine, one can simulate the responses of the human body, especially the heart, to help determine the effects of drugs and other therapeutic agents or procedures. In the past, analog tape recorders together with anthropometric dummies were used for this purpose. But a digital computer driving DACs can usually provide the simulation more effectively.

One interesting example of an arbitrary waveform for simulation is the output of a gas chromatograph. This type of instrument produces an output with frequency components of interest spanning the range 0.001 hertz to 1 hertz. The baseline of a chromatograph's output has thermal drift and flicker noise superimposed on it, along with the "peaks" that convey significant information. To analyze the output, one calculates the area under the peaks by integration. The end points of a peak are located by detecting changes in slope.

Unfortunately, it is not easy to test the ability of a chromatographic analysis system to quantitate peaks properly (especially when two peaks overlap. Simulation provides an answer to the problem. Fig. 4 shows the schematic for a programmable function generator than can simulate the output of a chromatograph.

Other problems requiring the simulation of arbitrary waveforms can be attacked in the same way as for the chromatograph. For example, systems have been designed for computer generation of music and art.

In music generation, frequencies up to 10 or 20 kilohertz are desired. Though this frequency range might not tax the response capabilities of a DAC, it could load the feeding computer quite heavily, leaving little time for processing. In the past, this problem could be solved only by pre-processing and tape recording at low speed. But, with this approach, a minute of output might take 10 to 100 minutes to synthesize. Using DACs augmented by analog line and curve generators, however, one can generate many wide-range audio signals in real time.

One major problem in waveform synthesis is the possible presence of glitches in DAC outputs. Spikes can occur because the switching devices used in the DAC do not all turn on and off in equal times. Therefore, when the DAC input is incremented around half scale or at other major switching points, spurious output excursions approaching half of full scale can occur. These spikes can be of either polarity and they generally last somewhere between a few nanoseconds to a few hundred nanoseconds. The most straightforward way of removing these unwanted transients is by filtering. Of course, if the load device has slow response, filtering may not be necessary.

CRT displays

When a DAC is used to drive the deflection circuitry of high speed CRT displays, glitch filtering may cause unacceptable delays. One popular solution to this problem is to blank the CRT until the transient has passed. This approach is effective only when the circuitry following the DAC can recover rapidly from glitch-induced overload. Sample-and-hold circuitry, too, may help to remove glitches, provided the new transient caused when switching between "track" and "hold" can be kept within tolerable limits.

A clean, continuous output for vector plotting or function generation can be generated by using an incremental, or integrating, DAC. With this arrangement, a binary rate multiplier produces a variable-rate pulse train. The output pulses are conditioned to provide constant charge into the operational integrator, and a very linear sweep can be produced.[4] The starting point of such a sweep can be determined by a conventional DAC. The end point can be determined by a programmable voltage comparator looking at the output of the integrator. A complete system of this type is shown in Fig. 4. Alternatively, if the pulse increment is made equal to one count (or a known number of counts) of the DAC that specifies the starting point, the end point can be determined digitally (by pulse count).

Due to integrator drift, incremental variation of the output of an integrator cannot be extended indefinitely. Generally, one would program the DAC to reset the integrator periodically (30 to 100 times per second in a refreshed CRT display). Then the integrator would be designed to handle the lowest output-frequency of interest.

In the circuit of Fig. 4, amplifier *A* functions as a trimode integrator. Any arbitrary starting point can be established in the "set" mode (with switches S_1 and S_4 on) under control of the DAC. The end point is then fed to the DAC through a buffer register, the slope is set in another buffer register, and the clock is enabled. This starts the integrator, which then generates a ramp. When the output reaches the preset end point, the comparator disables the clock to terminate the integration. The schematic does not show any circuitry to control the direction of integration, but this is easily implemented.

It should be noted that, with this type of circuit, each straight-line segment of the output requires only three words of digital input (start point, end point, and slope). Thus the computer is freed to do other jobs, rather than being tied up in point-by-point plotting. If required, the comparator output could be allowed to interrupt the computing sequence to request new data.

In some applications, true sine-wave outputs may be required. In this type of situation, straight-line approximation probably won't be the best approach, because the circuitry to achieve adequately low distortion may become unwieldy. The alternative is some sort of direct synthesis. [5]

Analog synthesis (for example, using a Wien bridge oscillator) is a popular method that is inexpensive and effective. Or, using a digital-differential analyzer (DDA), it is now possible to synthesize a waveform, digitally, at the input to a DAC. When multiple DDAs are used, it is possible to implement a wide variety of transcendental functions.

Before making a final choice among various methods of waveform syntheses, one should analyze the cost-performance tradeoffs. In this rapidly moving field, the relative merits of analog and digital devices change frequently, so it is impossible to lay down rigid rules.

Nonlinear devices

Another set of application problems arises when one must produce non-electrical and, possibly, non-linear analog outputs from a DAC. If one needed a digitally programmable light source, for example, he would face the problem of nonlinearity of the transfer function relating light intensity to current or voltage.

Feedback from a linear photodetector (such as a PIN photo-diode) is one way of linearizing a programmable light source. Similarly, a digital oven or furnace control can be linearized by feedback. If a thermocouple is used, its small, predictable, nonlinearity can be compensated by a computer program, assuming that the feedback path includes a digital data acquisition system.

Mechanical output variables — such as shaft rotation — introduce problems of backlash, friction, etc. This situation frequently arises when a device originally designed for a human operator is brought under computer control. Front-panel controls are not normally intended to be "tweaked by a machine." If the backlash exceeds the allowable setting error, then new settings must always be approached from the same direction. The most common devices employed for "knob-twiddling" adjustments are digital-to-synchro converters (plus a synchro) and stepping motors. The latter type of device is obviously a DAC in the broad sense.

The first step in evaluating how to use a DAC in solving a control problem is to "get a handle" on the device to be controlled. If the device can be digitally controlled, then, of course, a DAC is not needed. If voltage or current programming can be used, many standard DACs are available to do the job. If resistance programming is the only possibility, a ready-made solution is harder to come by — especially if neither end of the programming resistor can be grounded.

This last problem is most readily handled by a relay-switched resistance decade (a DAC of sorts), provided the speed is adequate.

The applications that we've looked at should serve to place the DAC in proper perspective as a system building block. We've seen how DAC characteristics can influence, and be influenced by, those system elements that interface with the DAC. Armed with a greater knowledge of its strengths and limitations, a system designer can more effectively employ the DAC to solve his "real-world" problems, allowing both the digital and the analog parts of his system to make a maximum contribution.

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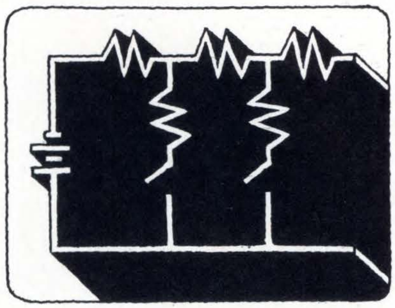
4. Robert H. Stotz, "A New Display Terminal," *Computer Design,* April, 1968.
5. Michael J. Dertouzos, "Phase plot: On-Line Graphical Display Technique," *IEEE Trans. on Electronic Computers,* April, 1967.



Multiplying Digital-To-Analog Converters

By Michael I. Neidich

There is a broad category of digital to analog converters (DACs) that have one common characteristic. In this type of DAC, the output voltage is controlled by *both* the applied digital word weight *and* an externally applied analog reference voltage. Depending on the manufacturer, this class of circuit may be called a multiplying, external reference, or universal-reference DAC — or some other combination of these names. In a true multiplying DAC the output voltage is, in fact, precisely the product of the analog reference and the digital word weight.

With multiplying DACs, output accuracy is *relative* to the applied reference; therefore good overall accuracies are more easily achieved with this type of circuit than with internal-reference DACs. In an ideal multiplying DAC, the reference signal (V_{ref}) could be arbitrary — that is, it could be of any voltage magnitude and spectral content. This arbitrary waveform applied as the reference would appear at the output, scaled or otherwise modified in amplitude according to the digital-word weight.

The way in which digital-word weight controls the scaling of the applied reference can be represented as follows:

Manufacturers of Multiplying DAC Modules

Analog Devices Inc.
221 Fifth Street
Cambridge, Mass.

Analogic Corp.
Audubon Rd.
Wakefield, Mass.

Astrosystems, Inc.
6 Nevada Drive
New Hyde Park, N.Y.

Burr-Brown Research Corp.
International Airport Industrial Park
Tucson, Ariz.

DDC
100 Tec Street
Hicksville, N.Y.

Hybrid Systems Corp.
95 Terrace Hall Ave.
Burlington, Mass.

Intronics, Inc.
57 Chapel Street
Newton, Mass.

North Atlantic Industries
200 Terminal Drive
Plainview, N.Y.

Perkin-Elmer Corp.
Main Street
Norwalk, Conn.

Redcor Corp.
Box 1031
Canoga Park, Calif.

Transmagnetics Inc.
210 Adams Blvd.
Farmingdale, N.Y.

Vernitron Corp.
59 Central Avenue
Farmingdale, N.Y.

Author: Michael I. Neidich is Product Manager, Data Conversion Modules, for DDC (Div. of Solid State Scientific Devices) in Hicksville, N. Y.

$$V_o = V_{REF}\left[\frac{a_1}{Z^1} + \frac{a_2}{Z^2} + \frac{a_3}{Z^3} \cdots \frac{a_n}{Z^n}\right]$$

$$= V_{REF}\sum_{i=1}^{n}\frac{a_i}{Z^i} \qquad (1)$$

(where a_n is 1 if the corresponding bit is logic "1," and zero if "0").

It follows from this equation that, unless the gain is made slightly greater than unity, the maximum full-scale output is not V_{ref}, but one least-significant bit less. This is because, when $a_i = 1$,

$$V_{ref}\sum_{i=1}^{n}\frac{a^i}{\mathbf{Z}_i}$$

$$= V_{ref}\left(1 - \frac{1}{2^n}\right)$$

For example, in a 13-bit converter the maximum output would be 99.987 percent of V_{ref}, whereas half scale is precisely $V_{ref}/2$.

If the reference could be as universal as we've assumed, then one would be able to consider the multiplying DAC as a digitally programmable precision attenuator. Unfortunately practical DAC circuits don't readily yield high accuracy at high analog frequencies. As users of wideband pads and attenuators are aware, 0.5 db is considered quite a reasonable accuracy; but it represents only 1-percent, or the equivalent of 7-bit accuracy. Therefore, with multiplying DACs, the accuracy bandwidth trade-off is as real a problem as the more obvious cost size trade-off.

Let's now review the basic circuit approaches for building a multiplying DAC.

Basic multiplying DAC

As shown in Fig. 1, a practical multiplying DAC has three basic parts. These are as follows:

(A) a reference buffer or conditioner, usually an op amp, driving

(B) a network capable of binarily weighting the reference, and precision switches which feed the selected weighted currents to

(C) an output buffer capable of summing the binarily-weighted reference currents and driving the designated load.

One could argue that only section (B) is necessary. But that would be skirting the issue, placing rather stringent performance requirements on the reference source; and only a very specialized load could be driven.

Though the *ideal* multiplying DAC would have infinite input impedance and zero output impedance (along with infinite bandwidth and zero settling time), practical DAC designs achieve a high enough degree of perfection to be widely useful.

Binary-weighting networks

Let's turn our attention first to the binary weighting network. There are only a few basic types of weighting networks, and these are summarized in Fig. 2. The advantages and disadvantages of each type are described in great detail in the literature.[1] Suffice it to say that there is no "best" way, and that the specific application will determine which configuration should be selected—especially when cost comparisons are made. All of the methods have one thing in common—they use precision resistors and precision switches configured to produce a binary-weighted output voltage and/or current.

For a multiplying DAC, we face some circuit-design problems that don't occur with simple dc-output DACs. We are no longer dealing with a fixed, well-defined, internal reference voltage, but, rather, one whose amplitude may vary widely. If we require wideband performance, accurate switching becomes even more difficult to achieve.

With careful design, it is possible to use either bipolar transistors or FETs for switching. Low device "on" resistance (r_{on}) makes a 13-bit converter quite practical. Several practical FET and bi-polar-transistor switch configurations are being used in commercially-available converters. Regardless of which type of switching device is used, performance will be about the same. In most situations, there will, of course, be some trade-offs of accuracy versus speed or bandwith, depending on the specific requirements.

With an *ideal* multiplying DAC, the output will follow changes in the digital-input word instantly (i.e., the circuit will have zero settling time). When one asks for switches and resistor networks that are both speedy and accurate, one should be ready to compromise. At the time of writing, the practical limit of accuracy is around 13 bits with best switching times of around 1 microsecond. Higher speeds usually result in less accuracy.

The bandwidth of most multiplying DAC's does not exceed 1 kHz at rated (dc) accuracy. However 10-kHz operation is feasible at slightly reduced accuracy, and 100 kHz is possible. (Measuring accuracy at even 10 kHz is no easy task.) Special-purpose multiplying DAC's can be built for a specific reference waveform, such as a ramp, and can achieve higher performance. But, usually, universality is sacrificed in the process.

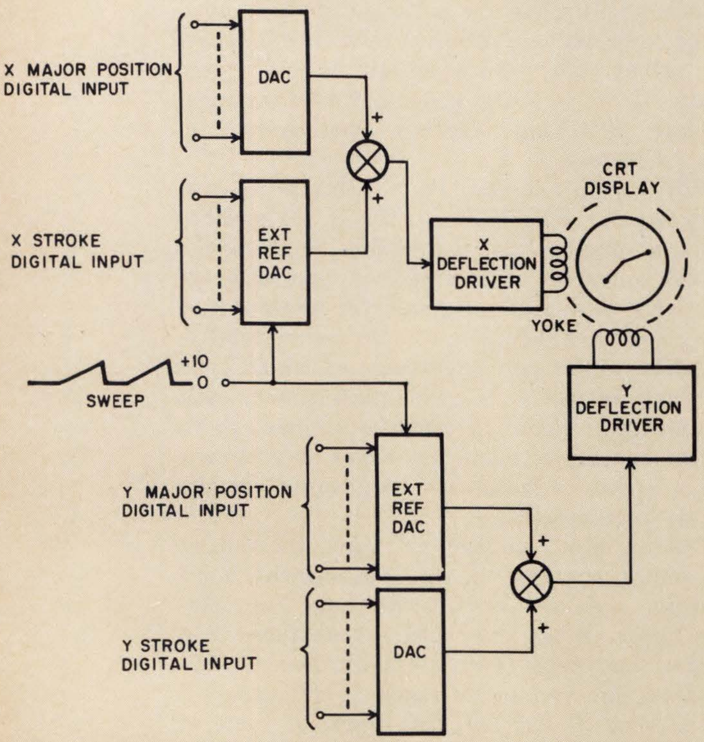
Reference buffer

Let's now return to Fig. 1, and take another look at sections (A) and (C) of the multiplying DAC circuit. This will help us understand more clearly the reasons for settling-time, accuracy, and bandwidth limitations.

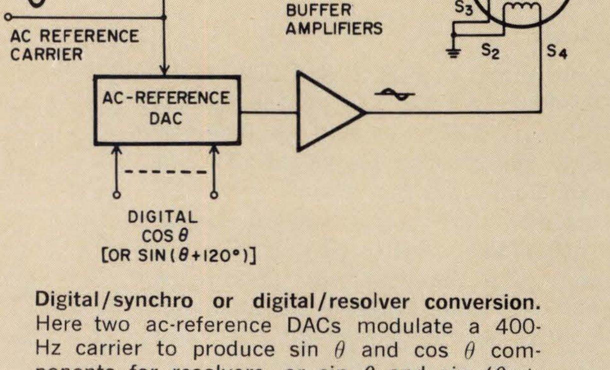
The reference buffer has several different and very demanding roles to play. If high overall accuracy is to be achieved, the amplifier should have a true differential-input configuration with a wide common-mode voltage range (CMV) and good common-mode rejection ratio (CMRR). Otherwise, potential differences between the external-reference analog-ground and converter analog-ground will appear directly as error. In practical installations, hundreds of millivolts of potential difference between grounds can exist, thus reducing the accuracy of a 13-bit DAC to about 6 bits.

The usual disadvantage of a true-differential input configuration, however, is relatively low input impedance (typically 20-40 kΩ). If very high input impedance, *and* a true differential configuration are both required, then an instrumentation amplifier should be used, and it must be used correctly. If however, there is no ground-loop problem, then very high input

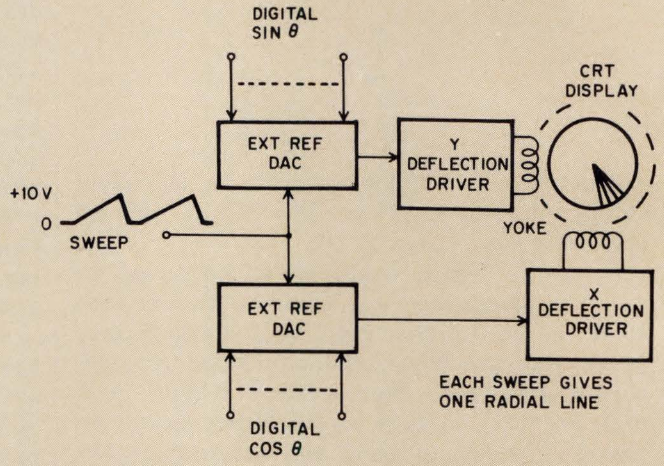
Applications For Multiplying D/A Converters



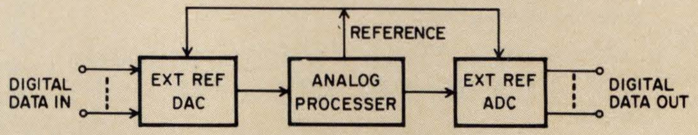
Character generation for CRT displays. A vector of any direction can be generated using a ramp reference and digital sin/cos scale-factor control. Usually two DACs are employed — one for the starting point and one for the line itself.



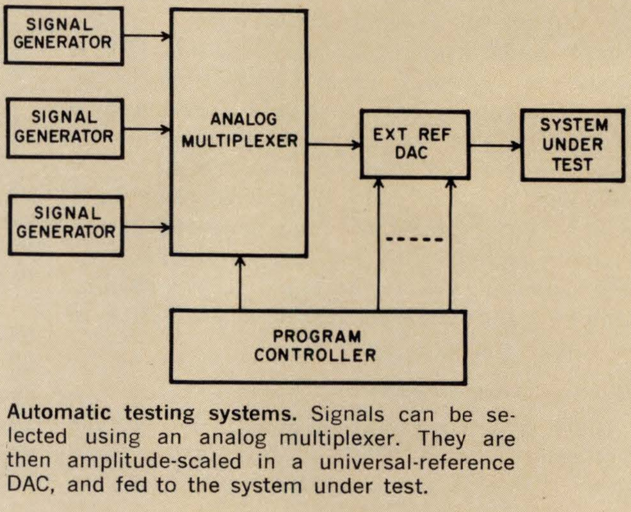
Digital/synchro or digital/resolver conversion. Here two ac-reference DACs modulate a 400-Hz carrier to produce sin θ and cos θ components for resolvers, or sin θ and sin (θ + 120°) for synchros.



Radar raster generation. This circuit is similar to that for CRT character generation, except that single DACs only are required to generate the X and Y deflection signals.



Single-reference systems. Using a single reference for all DACs and ADCs, reference drift can be neglected. Because the reference voltage is unimportant, the reference need not have good thermal stabiltiy or absolute accuracy.

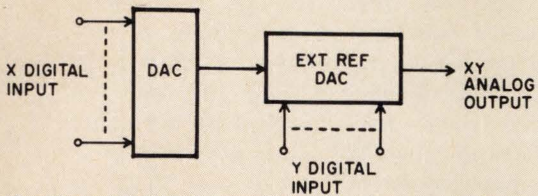


Automatic testing systems. Signals can be selected using an analog multiplexer. They are then amplitude-scaled in a universal-reference DAC, and fed to the system under test.

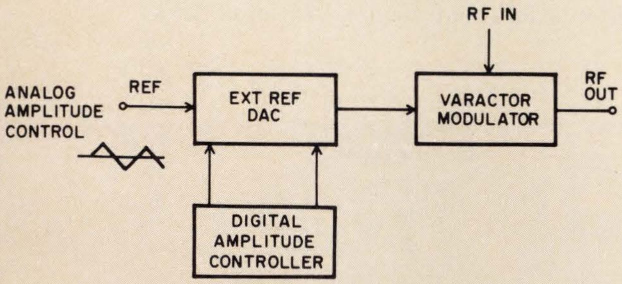
impedance can be achieved simply by using a non-inverting op-amp.

Usually, the reference buffer must drive a load of widely varying impedance—especially when it drives an R-2R ladder. Therefore it must have excellent output-voltage regulation.

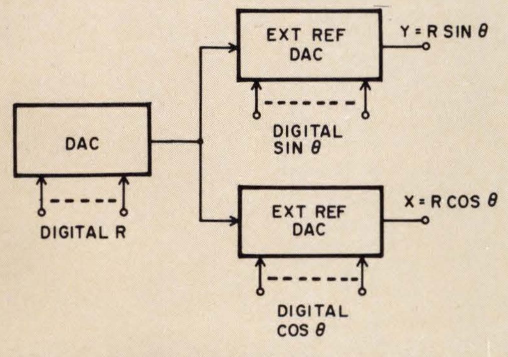
For the overall converter to settle at reasonable speed, the reference buffer must be a fast-settling design (i.e., it should have high phase margin). If the reference buffer rings due to loading changes, the weighting network and output amplifier will follow it — regardless of how good their individual response characteristics may be.



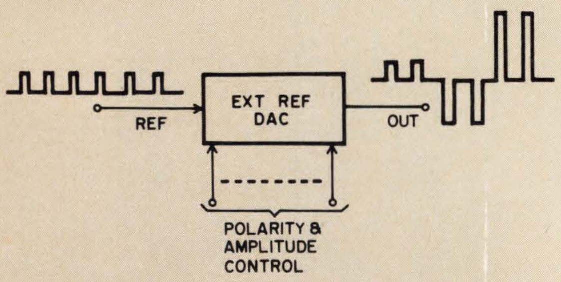
Non-linear D/A conversion. Non-linear analog functions can be produced by DACs instead of by analog circuits. In this example, the analog output is proportional to the product of the two digital inputs.



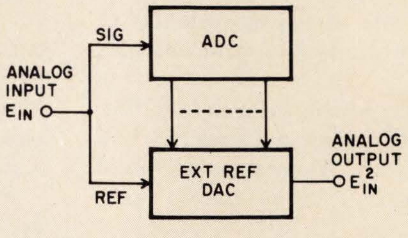
Digital modulation systems. Many types of modulators can be driven directly from DACs. Multiplying DACs allow generation of a wide variety of waveforms.



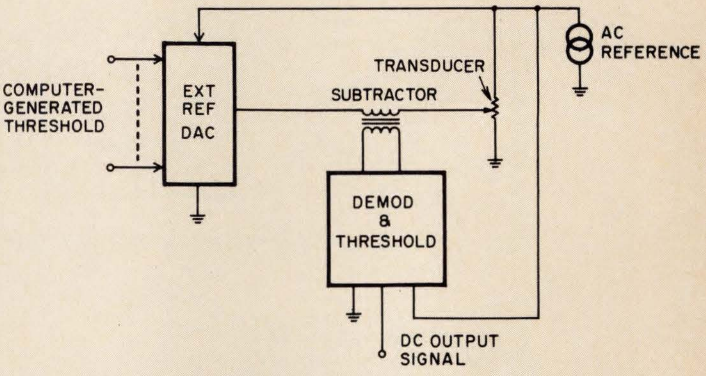
Polar-to-rectangular coordinate conversion. A conventional DAC and two multiplying DACs can be configured to convert R, sin θ and cos θ to the **X** and **Y** components.



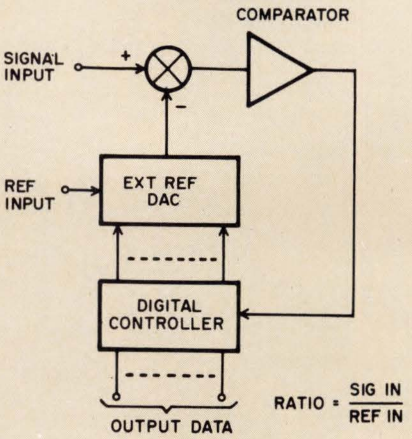
Programmable-amplitude pulse generation. A train of pulses is applied as reference, and the digital word weight determines pulse amplitude and polarity.



Accurate analog-signal squaring. Conventional analog multipliers rarely provide squaring-mode accuracies better than about 1 percent. Using an ADC and a multiplying DAC, as shown here, it's possible to achieve accuracies of around 0.1 percent.



High-accuracy ac comparators. The ac comparison scheme, shown here, offers significantly better performance than dc comparators, because dc drifts do not cause errors. Other errors are minimized by the synchronous, carrier-type, detection.



Ratiometric analog/digital conversion. Error output from the comparator advances a counter which controls the DAC. A full count is obtained when the input signal equals the external reference.

As those familiar with op amps know, good transient performance depends upon loop gain (negative feedback) and rolloff rate. The combination of good accuracy with fast settling requires extremely wideband amplifier designs, and, of course, there is a limit to the gain-bandwidth products currently available. Very wide bandwidth and large phase margin are difficult to achieve simultaneously. This is due to the presence of parasitic poles at high frequencies. The bandwidth of the reference buffer, therefore, affects the performance of the converter for both sinusoidal and complex reference waveforms.

To estimate the effect of the reference buffer, one can treat it as a single-network with a known cutoff frequency f_T. Then calculations of small-signal bandwidth and delay can be made accordingly.

Output buffer

Many of the constraints placed upon the reference buffer also hold true for the output amplifier. Naturally, current-output multiplying DACs usually don't include output buffer amplifiers. With this type of circuit, the user will be responsible for the over-all performance of the converter, as he will have to design the output amplifier if the application requires a voltage (rather than current) output.

The output buffer has the job of handling a variety of load impedances without undue degradation of performance. The load should preferably be reasonably resistive. This is because the amplifier can ring when driving a capacitive load (resulting in worsened settling time) unless it is designed expressly for the specific capacitive load. In general, fast settling and wideband operation are not consistent with capacitive loads.

For the same reasons that it's desirable to have a separate analog ground on the reference input, it's also necessary to have an output analog ground. One exception to this rule, of course, is when the output signal is being fed to a differential-input device. To provide an

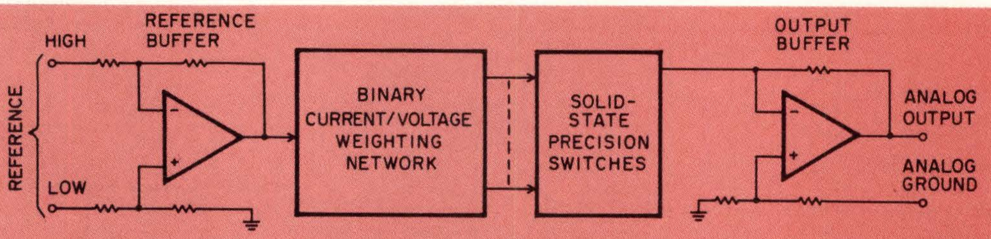


Fig. 1. Basic external-reference multiplying DAC.

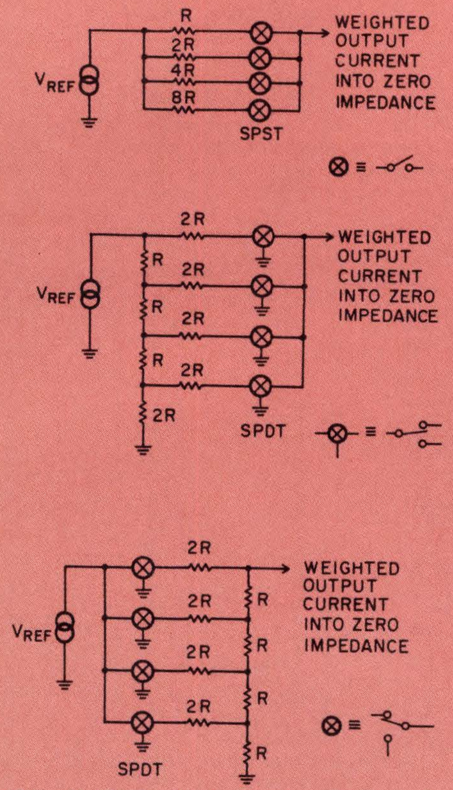
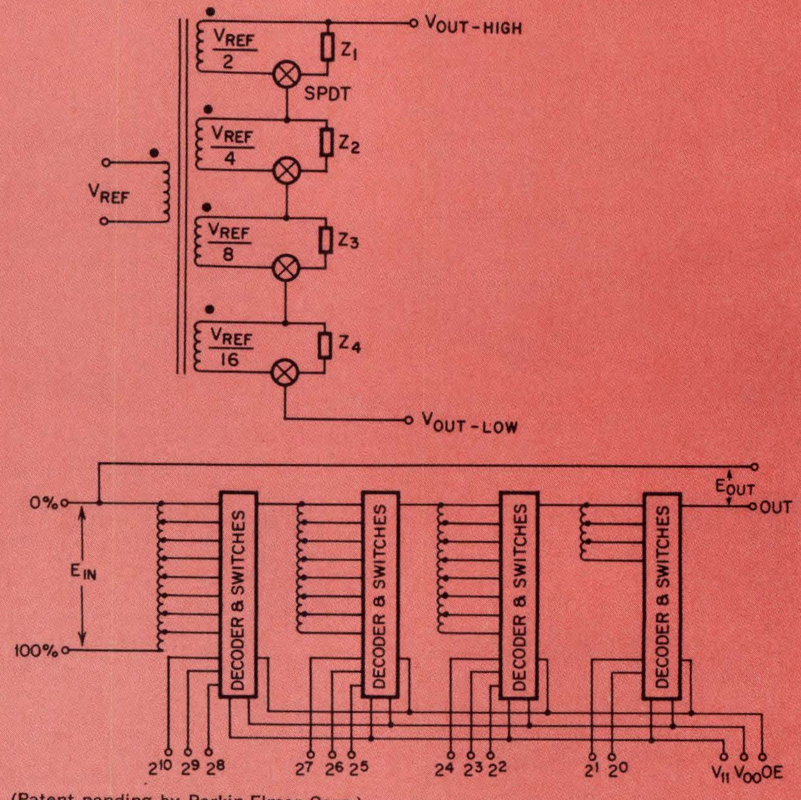


Fig. 2. Methods for generating a binary-weighted current.



(Patent pending by Perkin-Elmer Corp.)

Fig. 3. Circuit approaches for ac-reference DACs using transformers.

analog ground, where necessary, the output op amp should be connected as shown in Fig. 1.

Along with the three basic parts of the multiplying DAC that we've looked at, the digital interface also bears some consideration. So far as the digital input data is concerned, the most important characteristic of the analog switches is their compatibility with the digital logic circuits feeding the DAC. Not only should they accept the correct logic levels (DTL, TTL, RTL, etc.) but they *must* be non-injurious to the digital driving circuits (i.e., loading rules must not be violated). Also, some form of storage may be required at the DAC, since the DAC itself has no inherent memory. These matters are common to all DACs, and all that need be said is that interface specification is very important and can cause much embarrassment if neglected.

Ac-reference DACs

Before going on to look at specific applications for multiplying DACs, let's briefly look at one special type of multiplying DAC — the ac reference type. The basic circuit for this type of DAC is distinctly different from the conventional multiplying DAC.

There is no reason, of course, why conventional multiplying DACs cannot be used at, say, 400 Hz. But, for ac performance only, a simpler and less costly DAC can be designed.

In an ac system, the dc characteristics of a DAC (within reason) are of little or no consequence. Therefore, in the DAC's precision switches, dc leakage of FETs or dc offset *and* leakage of bipolar transistors are relatively unimportant. Only r_{on} is critical. In the reference and output buffer op amps, the effects of dc offsets, drifts, etc., can be eliminated with a series capacitor.

Because savings may be effected in numerous ways, an ac-reference DAC can be about one-half to two-thirds the cost of a comparable universal-reference DAC. Also, the ac approach allows precision transformers to be used in place of resistors in the weighting network.

There are various ways of using transformers in ac reference DACs. A couple of methods are shown in Fig. 3.

Use of transformers also offers improved temperature performance and the possibility of greater overall accuracy. Most designers will agree that there is no electrical parameter quite so stable as the ratios of a tapped transformer. But, though a superior performance transformer-type ac-DAC can be made, the cost tends to be higher. For this reason, most commercial units use precision wire-wound resistors. As we will see, the ac reference DAC has many applications, and economy dictates its use when a dc reference is not encountered.

Applications for multiplying DACs

This article includes schematic diagrams of some of the most common applications for ac reference and universal reference DACs. As most of these circuits are self explanatory or have been described elsewhere, only brief descriptive captions are included here. While there are, no doubt, many other possible applications, the circuits shown are representative of most *classes* of applications.

As can be seen, some of the applications make clever use of known characteristics of specific DACs. Thus it is wise to study commercial literature and consult vendors to determine the most suitable device for a specific application. Also, some vendors may be prepared to tailor a circuit for a customer's requirements.

In reviewing the list of applications, it will be noticed that some require a non-sinusoidal reference (i.e., a ramp). In such applications one needs to know the slew rates, delay, and settling times of the reference and output buffers. Settling time of DACs is usually measured for a fixed maximum-value reference and with the digital data changing from negative to positive full-scale. But limited amplifier bandwidth will cause a time lag between the reference ramp and the output ramp. For a fixed ramp rate, one can compensate for time delays (which convert to equivalent amplitude errors) so that they will not worsen dynamic accuracy.

Several applications demand true four-quadrant operation. That is, the sign or MSB may be positive or negative and the reference may be positive or negative. The algebraic product rules are maintained. In general, the digital codes are handled the same way as in conventional DACs. Binary, one's-complement or two's-complement (for negative outputs) are popular. Binary magnitude-plus-sign is also available.

A conventional DAC can often be modified to produce a multiplying DAC — if the external reference need only vary a small amount (say ±5 percent). Since this is feasible with even the simplest DACs, one should investigate this avenue before specifying a full-range multiplying DAC. But, remember, no simple DACs employ circuits that will handle a full-amplitude, high-frequency, sinusoid or ramp. For such an application, the system designer will need a good universal-reference, or ac-reference DAC, designed to meet his needs.

To assist the reader in locating manufacturers of multiplying DACs from among the many companies that make DACs, this article includes a list of vendors. It should be noted, however, that not all of the vendors make all types of multiplying DACs. For example, some make only ac-reference DACs while others make only universal-reference DACs. It is suggested, therefore, that readers contact the individual sources for further information. **EEE**

Reference

1. Hermann Schmid, "An Electronic Design Practical Guide to A/D Conversion," *Electronic Design,* No. 26, Dec. 19, 1968, pp. 57-76.

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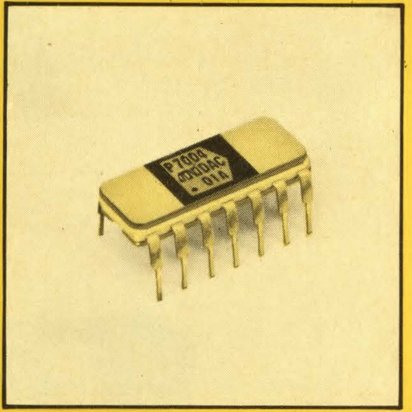

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MOS FET Biasing Techniques

by Seymour Reich

A wide variety of applications exist for field-effect transistors today including rf amplifiers and mixers, i-f and audio amplifiers, electrometer and memory circuits, attenuators, and switching circuits.

Several different FET structures have also evolved. The dual-gate metal-oxide-semiconductor FET, for example, appears particularly advantageous in rf stages because of low feedback capacitance, high transconductance and superior cross modulation with automatic-gain-control capability.

The rules for biasing FETs vary slightly depending upon the type of FET being applied. But we'll attempt to cover most of the possibilities by looking at several typical examples.

As you know, all FETs including junction devices, can be classified as depletion or enhancement types, depending upon the conductivity state of the channel at zero gate-to-source voltage or bias. In a depletion type, charge carriers are present and the channel is conductive when no bias is applied to the gate. Reverse bias depletes this charge and reduces channel conductivity; forward bias draws more charge carriers into the channel and increases conductivity. In an enhancement type, no useful channel conductivity exists at either zero or reverse gate bias; the gate must be forward-biased to produce active carriers and permit conduction through the channel.

Test circuits which can be used to measure the zero-bias drain current I_{DSS} of junction-gate and insulated-gate field-effect transistors are shown in Fig. 1. The junction-gate device, shown in Fig. 1(a), is always a depletion type and thus exhibits a reading for I_{DSS}. Insulated-gate or MOS devices may be either depletion or enhancement types; depletion types exhibit reasonable I_{DSS} readings in the circuit of Fig. 1(b), while enhancement types are cut off. The transistor

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Author: Seymour Reich is a semiconductor-device applications engineer for RCA, Somerville, N.J.

symbol shown in Fig. 1(b) uses a solid channel line to indicate the "normally ON" channel of a depletion type. An enhancement type is represented by an interrupted channel line, that indicates the "normally OFF" channel.

Although enhancement types are always operated (activated) in the enhancement mode (because application of reverse bias would simply cut the device off), depletion types can operate in either mode. Junction-gate devices can operate in the enhancement mode only within a very limited range because gate voltages exceeding 0.3 V also forward-bias the gate-to-source input diode and load the signal source. However, MOS depletion devices can operate in either the enhancement or the depletion mode without the constraints associated with input-diode loading.

The field-effect transistors shown in Fig. 1 are single-channel, single-gate, or triode-type devices. Although it is possible that the substrate of either the junction-gate or insulated-gate transistor may be used as a separate control element, in most circuits it is adequate as a control element and is extrinsically connected to the source or operated at a fixed potential.

When two separate control elements are required in a circuit, a dual-gate MOS transistor such as that shown in Fig. 2 is usually used. In this type of device, two independent gate electrodes that control individual channels are serially interconnected. In newer dual-gate MOS transistors, gate protection is provided by intrinsic back-to-back diodes, as shown in Fig. 2(b). The substrate in this type of device is internally connected to the source.

Biasing a single-gate MOS transistor

The bias circuit for a single-gate MOS transistor may take three forms, as shown in Fig. 3: (a) self-bias, (b) an external supply, or (c) a combination of the two. The design of a self-bias circuit is fairly straightforward. For example, if it is desired to operate a 3N128 MOS transistor (an n-channel, depletion device) with a drain-to-source V_{DS} voltage of 15 V and a small-signal transconductance g_{fs} of 7.4 mmhos, the drain current I_D required for the desired transconductance is first obtained from published transfer-characteristics curves such as those shown in Fig. 4(a). A published curve such as the one shown in Fig. 4(b) is then used to determine the gate-to-source voltage V_{GS} required for the desired value of I_D. The circuit parameters can then be calculated using $V_{DS} = 15$ V, $I_D = 5$ mA, $V_{GS} = -1.1$ V and $V_G = 0$.

$$V_S = V_G - V_{GS} = 1.1 \text{ V} \quad (1)$$

$$R_S = V_S/I_D = 1.1/5 = 220\ \Omega \quad (2)$$

$$V_{DD} = V_{DS} + V_S = 15 + 1.1 = 16.1 \text{ V} \quad (3)$$

In a circuit designed for applied bias only, the problem becomes more complicated. For example, the voltage divider consisting of R_1 and R_2 in Fig. 3(b) may be required to apply a V_{GS} of -1.1 V. In addition to the fact that a negative supply is required, a more serious problem exists. The bias-voltage computations shown above were based on the solid-line curve shown in Fig. 4(b) for a typical device.

However, the drain currents for individual devices may cover a wide range of values, as indicated by the dashed curves H and L representing high- and low-limit devices, respectively. With a fixed-bias supply of -1.1 V, therefore, drain current could range from cutoff to 18.5 mA. Some form of dc feedback is obviously desirable to maintain the drain current constant over the normal range of product variation.

The combination bias method shown in Fig. 3(c) makes use of a larger value of R_S to narrow the range of drain current to plus or minus a few milliamperes. Figure 5 shows curves of I_{DSS} as a function of I_D for various values of R_S. The normal range of I_{DSS} for the 3N128 is from 5 to 25 mA, or a spread of 20 mA. The use of the 220-Ω source resistor R_S calculated in the previous example reduces this spread to about 5 mA, for a 4-to-1 improvement. Higher values of R_S achieve tighter control of the spread of drain-current values.

As an example, the circuit of Fig. 3(c) may be required to maintain drain current constant within ±1 mA for the same conditions given in the previous example. Figure 5 shows that a value of R_S equal to or greater than 1000 Ω will satisfy the required drain-current tolerance. However, a quiescent current of 5 mA through a source resistor of 1000 Ω produces a V_{GS} value of -5 V, which is incompatible with a drain current of 5 mA. Therefore, an applied bias must be used in conjunction with the self-bias. The circuit parameters for Fig. 3(c) are then calculated using $V_{DS} = 15$ V, $I_D = 5$ mA, $V_{GS} = -1.1$ V, and $R_S = 1000$ Ω.

$$V_S = I_D\, R_S = (0.005)\ (1000) = 5 \text{ V} \quad (4)$$

$$V_G = V_{GS} + V_S = -1.1 + 5 = 3.9 \text{ V} \quad (5)$$

$$V_{DD} = V_{DS} + V_S = 15 + 5 = 20 \text{ V} \quad (6)$$

$$\frac{V_{DD}}{V_G} = \frac{R_1 + R_2}{R_2} = \frac{20}{3.9} = 5.12 \quad (7)$$

The lower limits of R_1 and R_2 are established by determining the maximum permissible loading of the input circuit and setting this value equal to the parallel combination of the two resistors. For example, if the total shunting of the input circuit is to be no less than 50,000 Ω, R_1 and R_2 are calculated as follows:

$$\frac{R_1\, R_2}{R_1 + R_2} = 50{,}000 \quad (8)$$

$$\frac{R_1 + R_2}{R_2} = 5.12 \quad (9)$$

$R_1 = 256{,}000$ Ω, and $R_2 = 62{,}000$ Ω.

In practice, the effects of input-circuit loading can frequently be eliminated by the use of the circuit arrangement shown in Fig. 5.

The upper limits of R_1 and R_2 are usually determined by practical consideration of the resistor component values because the absolute values of gate-leakage current I_{GSS} are extremely small. In unique applications where I_{GSS} is a significant factor, a maximum value for the parallel combination of R_1 and R_2 can be determined by dividing the total permissible change in voltage V_G across the combination by the maximum allowable value of I_{GSS} at the expected operating temperature, as determined from the published data for the transistor used.

Because I_{GSS} consists of leakage currents from both drain and source, and these currents are usually measured with a maximum-rated voltage stress on the gate with respect to all other elements, the published value of I_{GSS} is generally much higher than that which could be expected under typical circuit conditions. As a result, the values of R_1 and R_2 determined in this manner are conservative.

Substrate biasing

As mentioned previously, many single-gate FETs incorporate provisions for separate connection to the substrate because it is sometimes desirable to apply a separate bias to the substrate and use it as an additional control element. A simple arrangement for achieving this bias is shown in Fig. 7(a). In this circuit, the substrate bias V_{US} is equal to $I_D\ (R_1 + R_2)$ and the gate bias V_{GS} is equal to $I_D R_1$.

One application in which substrate bias is mandatory is the attenuator circuit shown in Fig. 7(b). An MOS transistor is extremely useful as an attenuation device because it acts as a fairly linear resistance whose intrinsic conductivity can be drastically changed by means of a dc voltage applied to the gate. In the circuit of Fig. 7(b), for example, a signal applied to the drain can be attenuated by application of a positive voltage to the MOS transistor gate. The attenuation A_V obtained is given by

$$A_V = \frac{R_D}{R_D + R_s} \quad (10)$$

where R_D, the device channel resistance, is a function of bias voltage and can be varied from approximately 100 Ω to 10^5 MΩ. Because of the construction of the MOS transistor, however, the drain must always be positive with respect to the substrate so that the drain-to-source diode (diffusion) will not be biased into conduction. Therefore, the substrate must be back-biased to at least the peak value of the negative-going signal that might be applied to the drain. Figure 7(b) shows how this back-bias is obtained.

Biasing a junction-gate transistor

The biasing techniques that have been described for single-gate MOS transistors are directly applicable to junction-gate devices with one exception. Because the input gate of a junction-gate field-effect transistor consists of a back-biased diode, the device must always be biased so that the input-gate diode is not in conduction. Effectively, therefore, a junction-gate device will almost always be operated in the depletion mode.

Although the biasing considerations covered thus far are applicable to all types of single-gate transistors, it should be remembered that enhancement-type devices must be turned on before they can be used as amplifiers. Therefore, applied bias such as shown in Fig. 3(b) and 3(c) must always be used with these devices. In addition, it is desirable to narrow the range of drain current by means of a source resistor, such as that shown in Fig. 3(c), that produces self-bias after the transistor is turned on.

As an example of this type of biasing, it may be assumed that a 2N4065 p-channel enchance-

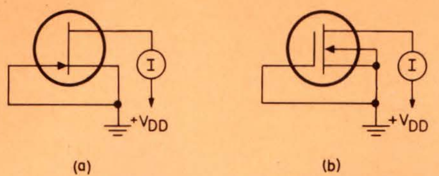

Fig. 1. I_{DSS} test circuits for (a) junction-gate and (b) insulated-gate field-effect transistors.

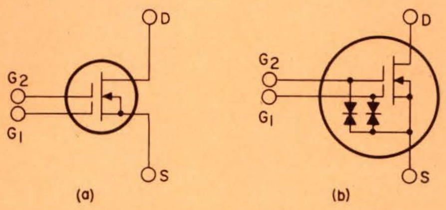

Fig. 2. Dual-gate MOS transistors. (a) conventional symbol, (b) modified symbol to show gate-protected device.

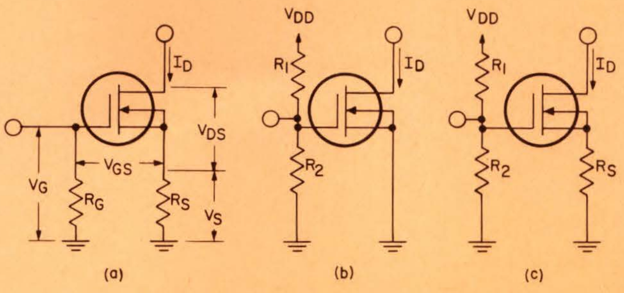

Fig. 3. Biasing circuits for single-gate transistors: (a) self-biasing; (b) external biasing; (c) a combination of self-biasing and external biasing.

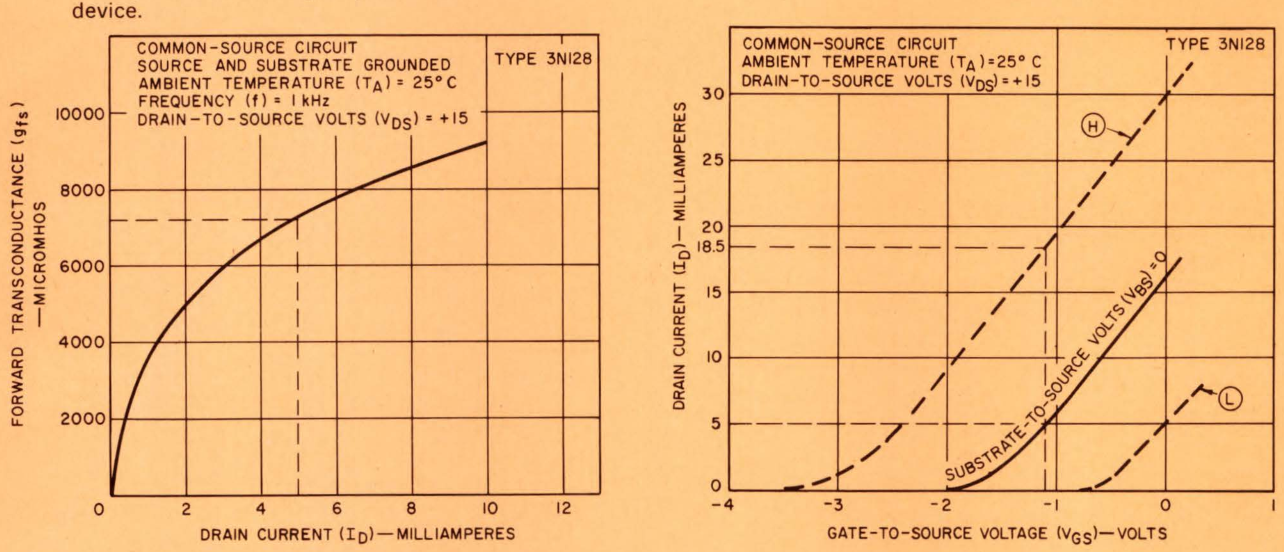

Fig. 4. (a) Transfer and (b) operating characteristics of the 3N128 single-gate MOS transistor.

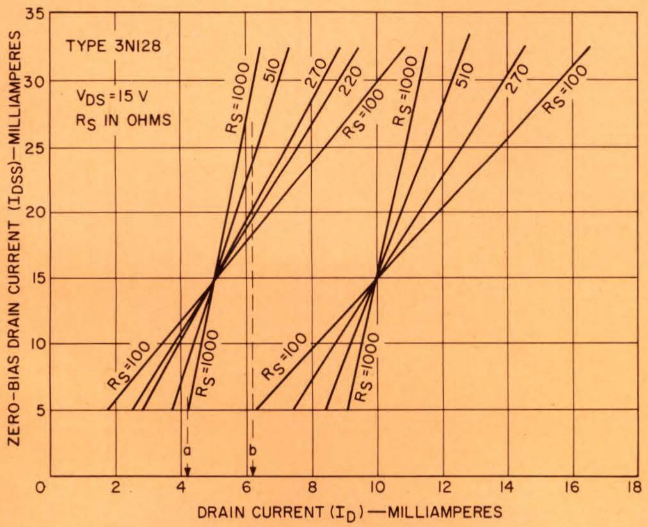

Fig. 5. Zero-bias drain current I_{DSS} as a function of drain current I_D for various values of source resistance R_S in a 3N128 single-gate MOS transistor.

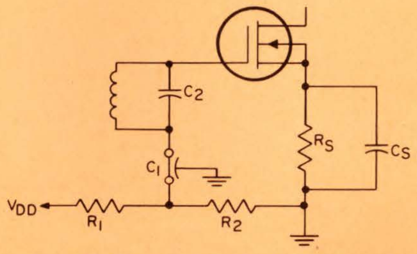

Fig. 6. Circuit used to eliminate input-circuit loading.

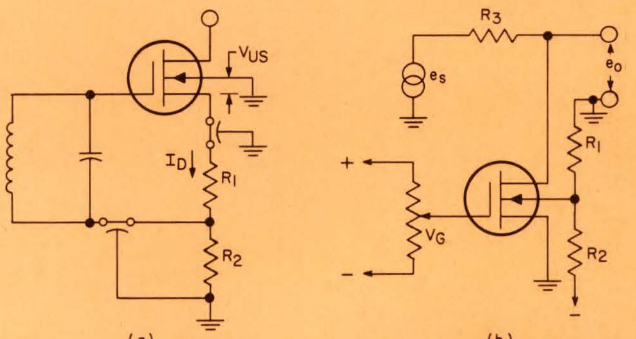

Fig. 7. Substrate biasing circuits.

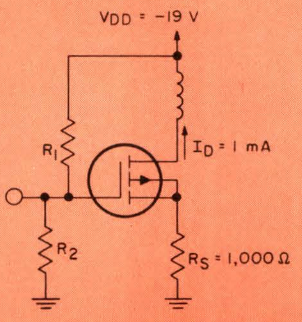

Fig. 8. Biasing circuit for an enhancement-type MOS transistor.

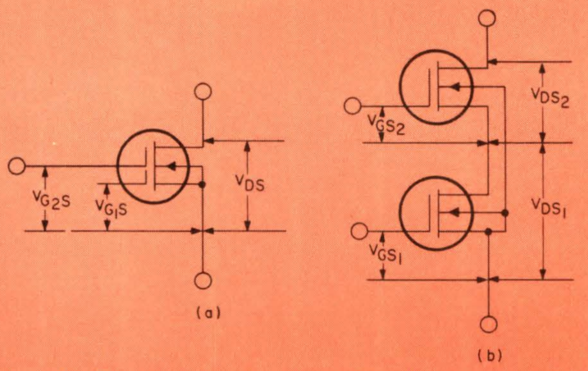

Fig. 9. Circuits showing element voltage associated with MOS dual-gate transistors.

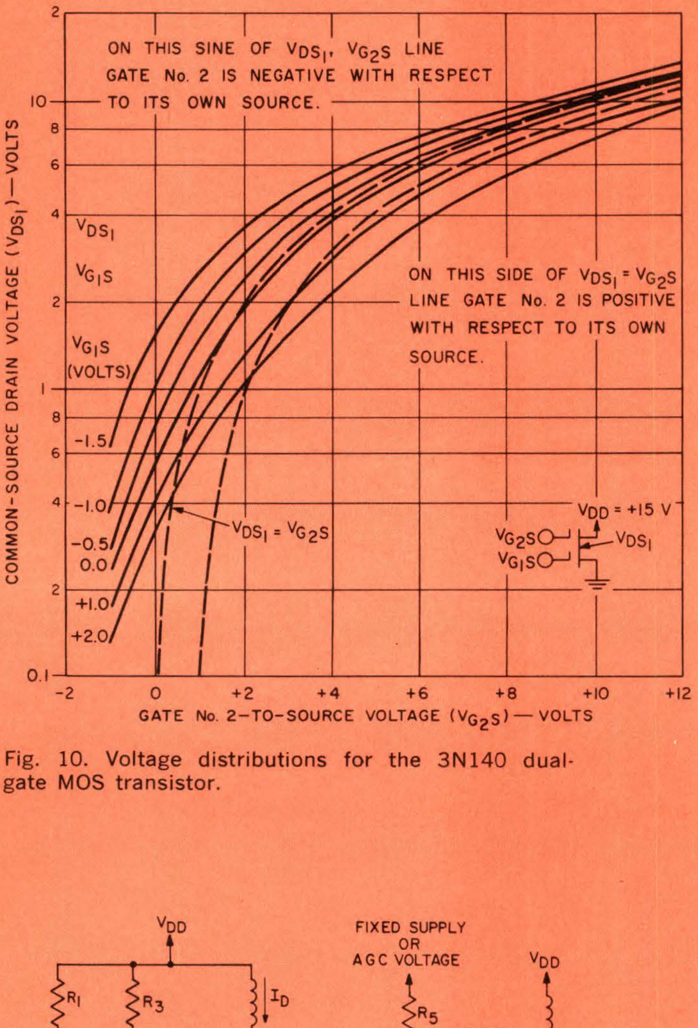

Fig. 10. Voltage distributions for the 3N140 dual-gate MOS transistor.

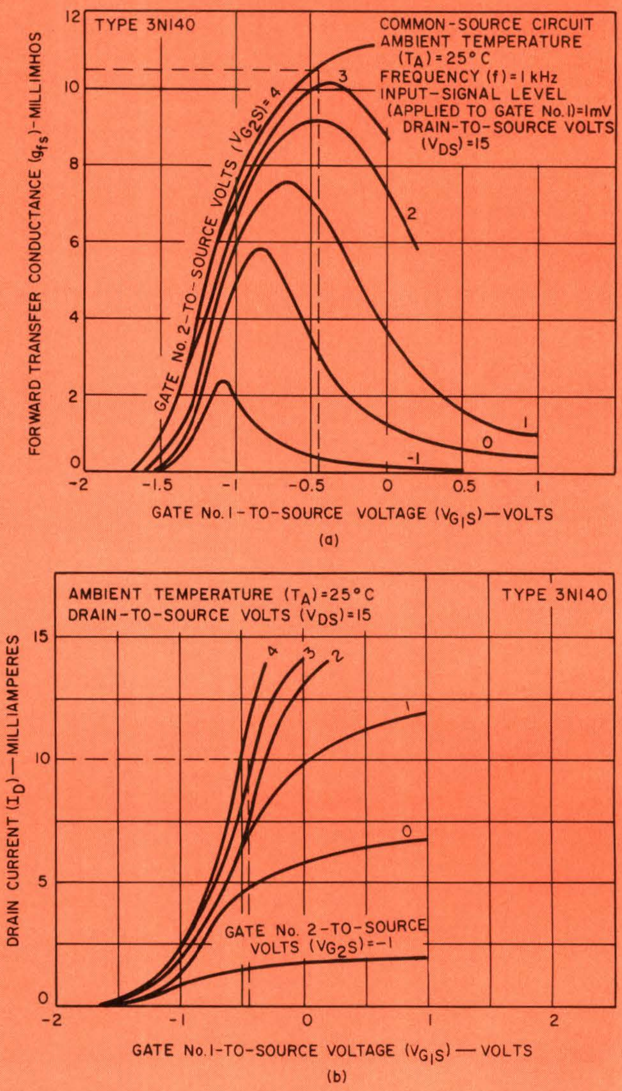

Fig. 11. Characteristics curves for the 3N140.

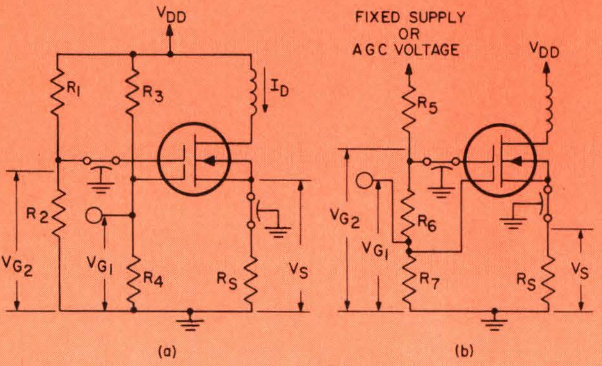

Fig. 12. Typical biasing circuits for the 3N140.

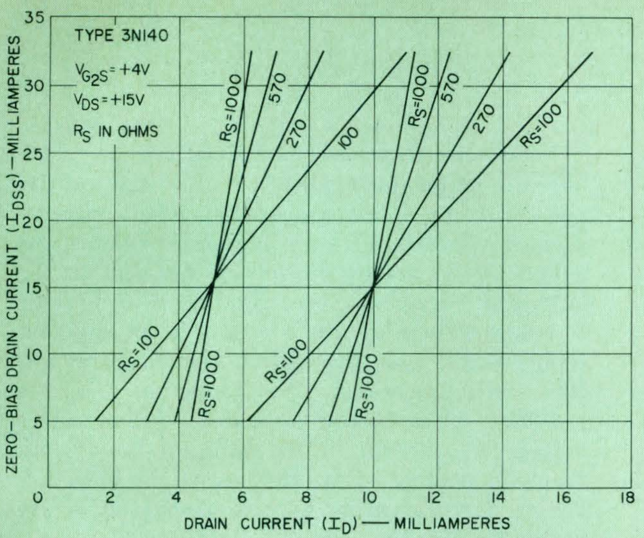

Fig. 13. Drain-current curves for various values of R_s for the 3N140.

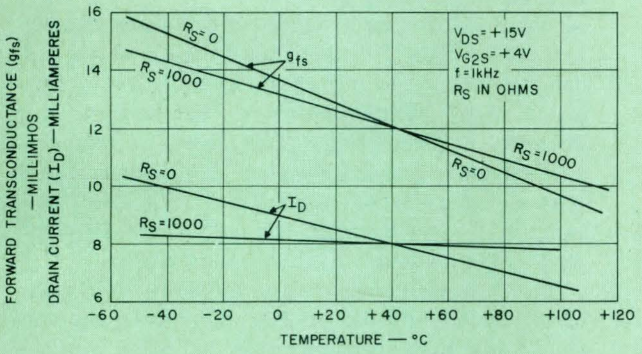

Fig. 14. Drain current and transconductance as a function of temperature for the 3N140.

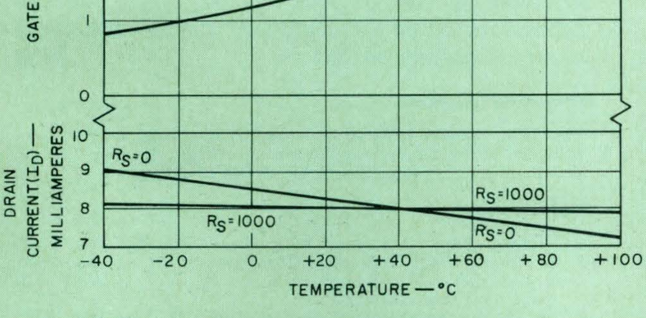

Fig. 15. Drain current and gate-No. 2-to-source voltage for constant I_D as a function of temperature for the circuit of Fig. 14 (b).

ment-type MOS transistor is to be operated at room temperature with a supply voltage of 19 V, a source resistance of 1000 Ω, and a drain current of 1 mA, as shown in Fig. 8. To complete the bias circuit, it is necessary to determine the values of R_1 and R_2 to satisfy a total input-loading requirement of 10,000 Ω.

The 2N4065 transistor has a typical threshold voltage of −5.3 V and requires a gate voltage of approximately −9.2 V for a drain current of 1 mA. (The threshold voltage V_{TH} for an enhancement-type device is comparable to the cut-off voltage V_{GS} (OFF) for a depletion-type device, and is the value of gate voltage required to initiate drain current. It is usually specified for a drain-current value between 10 and 100 mA). Circuit parameters for the network of Fig. 8 are then calculated as follows:

$$V_S = I_S R_S = (-0.001)(1000) = -1 \text{ V} \quad (11)$$

$$V_{DS} = V_{DD} - V_S = -19 + 1 = -18 \text{ V} \quad (12)$$

$$V_G = V_{GS} + V_S = -9.2 - 1 = -10.2 \text{ V} \quad (13)$$

$$\frac{R_1 + R_2}{R_2} = \frac{V_{DD}}{V_G} = \frac{19}{10.2} = 1.86 \quad (14)$$

$$\frac{R_1 R_2}{R_1 + R_2} = 10{,}000 \ \Omega \quad (15)$$

$$R_1 = 18{,}600 \ \Omega \quad (16)$$

$$R_2 = 21{,}500 \ \Omega \quad (17)$$

Biasing the dual-gate MOS transistor

A dual-gate MOS transistor such as that shown in Fig. 9(a) is actually a combination of two single-gate MOS transistors arranged in a cascode configuration, as depicted in Fig. 9 (b). The element voltages associated with each of the individual transistors can be analyzed as follows:

$$V_{DS} = V_{DS1} + V_{DS2} \quad (18)$$

$$V_{G2S} = V_{DS1} + V_{GS2} \quad (19)$$

$$V_{G1S} = V_{GS1} \quad (20)$$

Curves of the voltage distributions for the 3N140 dual-gate MOS transistor are shown in Fig. 10. It can be seen for an applied gate-No. 1-to-source voltage V_{G1S} of zero, a supply voltage V_{DD} of +15 V and a gate-No. 2-to-source voltage V_{G2S} of + 3 V ,the actual drain voltage across the grounded-source unit is approximately +2.75 V and gate No. 2 is 0.25 V positive with respect to its own source. These curves explain the logic behind the apparently high positive gate-No. 2 voltages (in the order of +4 V) recommended for typical operation of dual-gate MOS transistors.

Operating curves for the 3N140 are shown in Fig. 11. These curves can be used to establish a quiescent operating condition for the transistor. For example, a typical application may require the 3N140 to be operated at a drain-to-source voltage V_{DS} of 15 V and a transconductance g_{fs} of 10.5 mmhos. As shown in Fig. 11(a), the desired value of g_{fs} can be obtained with a gate-No. 2-to-source voltage V_{G2S} of +4 V and a gate-No. 1-to-source voltage V_{G1S} of −0.45 V. From Fig. 11(b), the drain current compatible with these gate voltages is 10 mA.

Two biasing arrangements which can be used to provide these operating conditions for the 3N140 are shown in Fig. 12. For the application mentioned above, it may be assumed that shunt resistance for gate No. 1 should be 25,000 Ω and the dc potential on gate No. 2 should be fixed and at rf ground. The remaining parameters for the biasing circuits can then be obtained from the curves showing I_D as a function of R_S in Fig. 13, with $R_S = 270\ \Omega$:

$$V_S = I_D R_S = +2.7 \text{ V} \qquad (21)$$

$$V_{G1} = V_{G1S} + V_S = +2.25 \text{ V} \qquad (22)$$

$$V_{G2} = V_{G2S} + V_S = +6.7 \text{ V} \qquad (23)$$

$$V_{DD} = V_{DS} + V_S = +17.7 \text{ V} \qquad (24)$$

The values of the resistance voltage dividers required to provide the appropriate gate voltages are determined in the same manner as shown previously for single-gate transistors. For the circuit of Fig. 12(a), R_3 is 197,000 Ω, R_4 is 28,600 Ω, and $R_1 R_2 = 11/6.7$.

The circuit of Fig. 12(a) is normally used in rf-mixer applications and in rf-amplifier circuits which do not use agc. The circuit of Fig. 12(b) is recommended for the application of agc voltage to rf-amplifier stages. In this circuit, the rf signal is applied to gate No. 1, and the agc voltage to gate No. 2.

The dual-gate MOS transistor is useful in agc-supplied rf amplifiers because almost no agc power is required by the device as a result of the high dc input resistance indigenous to the MOS transistor. Another advantage provided by the MOS transistor is revealed by the ease with which it obtains delayed agc action and good cross-modulation characteristics as a function of agc. The application of agc bias to gate No. 2 while the bias on gate No, 1 is changed improves the cross-modulation characteristics of the transistor as a function of agc applied.

Biasing to compensate for temperature variations

Unlike bipolar transistors, MOS transistors exhibit a negative temperature coefficient for typical values of drain current. That is, drain current and dissipation decrease as temperature increases, and there is no possibility of I_D runaway with elevated temperature. Unfortunately, transconductance and rf power gain also decrease as temperature increases. Figure 14 shows curves of drain current and transconductance as a function of temperature. These curves also show the compensating effects produced by the use of source resistance R_S; variations in drain current are reduced significantly by use of an R_S value of 1000 Ω.

Variations in transconductance can be virtually eliminated by application of a gain-control voltage from a temperature-dependent voltage-divider network to gate No. 2. For example, the values of the resistance voltage dividers in the circuit of Fig. 12(a) were determined to provide a transconductance of 9.5 mmhos at ambient temperature, and the device temperature was then varied through the range of −45 to +100°C. The values of gate-No. 2-to-source voltage V_{G2S} required to maintain a constant transconductance over the entire temperature range, for R_S values of zero and 1000 Ω are shown in Fig. 15.

In a practical circuit, the required voltages can be applied to gate No. 2 if R_1, or the combination of R_1 and R_2, is a temperature-sensitive resistor that is thermally linked to the MOS transistor package. This thermistor network can be designed to provide a desired voltage characteristic at gate No. 2 either to keep the transconductance constant or to permit some variation with temperature to compensate for changes in other stages. The effects of temperature given in percentages on these other stages may be summarized as follows: R_{in}—one percent; C_{in}—one percent; $C_{feedback}$—one percent; R_{out}—plus 45 percent; C_{out}—one percent.

The data was measured on a 3N140 MOS transistor in the circuit of Fig. 12(a). Drain current was 8 mA, frequency was 200 MHz, and the temperature varied from 0 to 100°C.

Summary

All field-effect transistors may be biased similarly. Uniform quiescent operating points can be easily achieved in MOS field-effect transistors by employing circuit designs that incorporate a source resistance. For a given I_{DSS} range, the value of the source resistance inversely affects the in-circuit I_D spread. An increase in the value of the source resistance minimizes variations in I_D as a function of temperature. The dual-gate MOS field-effect transistor is ideally suited for use in gain-controlled stages; dual-gate transistor biasing can provide various types of agc action including temperature compensation to assure constant output. **EEE**

Acknowledgements

The author thanks L.A. Jacobus and W.A. Harris for the computations and computer run-off for the curves shown in Fig. 10, and R. Miller for collecting much of the data shown.

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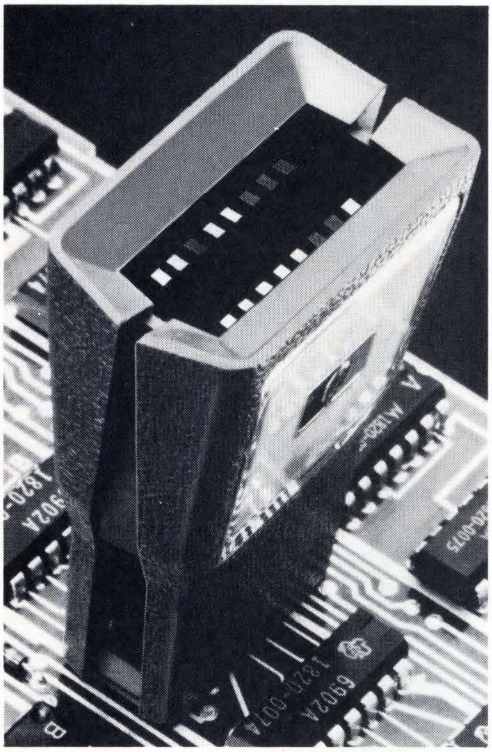
The IC troubleshooters.



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(Continued on page 72)

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Dual 128-bit static shift register, $10.30. TEXAS INSTRUMENTS. **575**
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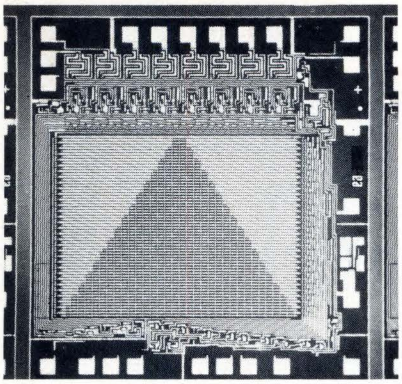
Semiconductor and Microcircuits Division, Slatersville,
Rhode Island, 02876.

Amperex®
TOMORROW'S THINKING IN TODAY'S PRODUCTS
A NORTH AMERICAN PHILIPS COMPANY

Circle 129 on Inquiry Card



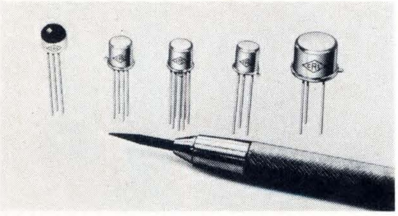
bits per word array. Output inhibit control allows use of multiple EA 3300s in wire-or'd configuration. 4692 transistors. Diss, 100 mW, access time, 1.2 μs. 24-lead DIP. $60. ELECTRONIC ARRAYS. **577**

Read/write 4096-bit memory, CM2400, bipolar/MOS hybrid. Access time, 300 ns typ; cycle time, 450 ns typ; diss., 0.4 mW/bit typ. 26-lead square flat pack. $1200 each. COMPUTER MICROTECHNOLOGY. **578**

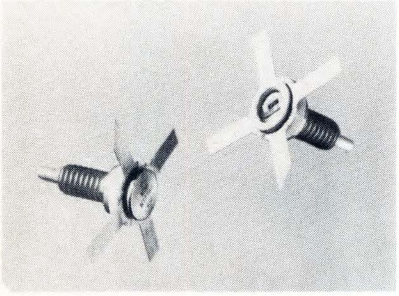
MOS 1024-bit ROM, UC62525, compatible with bipolar logic circuits. Logic "1" input is 2.4 V min, logic "0" input is 0.4 V max. Access time, 500 ns. 24-lead DIP and flat pack. SOLITRON. **579**

IC digital, linear chips, 101, 107, 715, 723, 741, 748, also other devices. Tested and glass protected. Shipped in 100-unit protective carriers. $3.00 to $3.95. ADVANCED MICRO DEVICES. **580**

Ninety new FETs, new line, amplifiers and switches. Said to accommodate 90% of all FET applications. Choice of five packages. 50¢ to $10.00. CENTRALAB. **581**



Silicon-nitride transistors, new family, for use in 1.5-2 GHz range. Outputs of 1 to 20 W available in broadband use. Stripline package. $40.50 (100-249). FAIRCHILD. **582**



Soft-gate-control SCR, T507, handles 10 kHz inputs. Turn-on time 3.5 μs; forward voltage drop 4.5 V max. Forward current, 110 A; turn-on time, 30 μs; gate triggering current, 150 mA max; voltages to 1200 V. 600 V price: $43.50 (10-99). WESTINGHOUSE. **583**

General purpose SCRs, 2N5719, 2N-5724 series, ratings to 400 V. Gate trigger current, 20 μA max; dV/dt, 100 V/μs. TO-18 and TO-5. $2.35 (100-999). UNITRODE. **584**

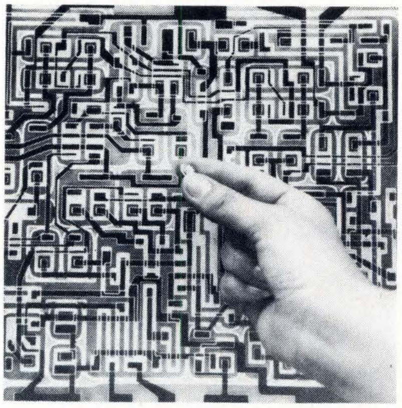
Custom-tailored-gate SCRs, 3TCR to 35TCR series, turn-on characteristics can be modified to specific requirements Current ratings, 500 mA to 35 A. turn-off time, 30 μs; gate power, 5 W peak. SARKES TARZIAN. **585**

Light-emitting diodes, FLV100-1, priced at 99¢. Brightness, 1500 ft/lamberts, viewing angle, 160°. TO-18 type package with transparent (FLV100) or frosted (FLV101) lens. FAIRCHILD. **586**

Dual op amp, 747, equivalent to pair of 741s on one chip. Offset current, 30 ns typ; Bias current, 200 ns typ; CMRR, 70 dB min. Two voltage-gain versions available. 747B, with 50,000 min; 747C, with 20,000 min. 14-lead DIP. $18 (100-999). AMELCO. **589**

Variable-parameter op amps. TOA1748 series, require one capacitor for external frequency compensation. Bandwidth and slew rate can be changed by a factor of ten according to capacitor used. Devices interchangeable with units in National Semiconductor LM-101 series. $2.90 (100 up). TRANSITRON. **590**

Improved phase-locked-loop ICs, 562, 565, more versatile than original line. Loop can now be opened to permit insertion of external devices. Loop opening capability provided between voltage-controlled oscillator and phase comparator. 562 operates over 0.1 Hz to 50 MHz range; 565 operates to 500 kHz. 562, $18.00; 565, $6.35 (100 up). SIGNETICS. **591**



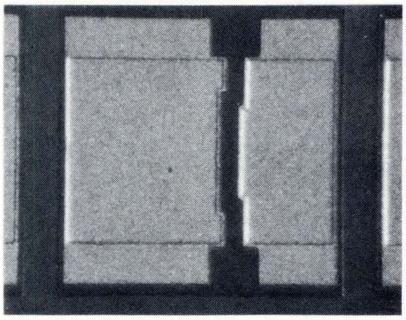
Transistor, diode chips, new series, includes zener diodes. Wafers also available, shipped in plastic cases with shock absorbers. SEMICONDUCTOR SERVICES. **587**

Semiconductor infrared dectors, new line, silicon, sapphire, germanium, indium, antimonide, other materials used to cover 0.2 to 35 micron spectial range. Resistance lowered with rise in temperature. Can be supplied with shielded compensator. TO-5 and TO-9 style packages. VICTORY ENGINEERING. **588**

Interface ICs, CM1150, CM1160, dual transmitter and dual receiver. Meet B and C revisions to EIA spec RS232; meet MIL-STD-188B. $8.45 (100 up). CERMETEK. **592**

Capacitors

MOS-capacitor chips for hybrid circuit applications. Six different geometries of single and dual units. Capacitance 0.5 to 220 pF. 25-75. V Chip sizes 20 to 45 mils square, 6 mils thick. Chips are gold backed with aluminum bonding pads. DIONICS. **534**



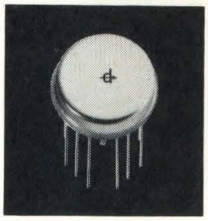
Phenolic-dipped ceramic capacitors, VK, with maximum capacitance of 100,000 pF. Rated at 200 V over −55 to 125°C. Can be operated at 150°C with no loss of reliability. Cap change of +5%, −8% from 0°C to 85°C and ±15% from −55°C to 150°C. Dissipation factor 1.5% for values through 680 pF and 2.5% for 820-100,000 pF. VK23,0.180 × 0.180 × 0.070 in. and VK33,0.280 × 0.280 × 0.080 in. Lead spacing 0.200. VITRAMON. **535**

Microcircuit trimmer capacitor, 7200, for uhf oscillators, striplines, balancing of semiconductors and microwave components. 10:1 tuning ratio. Cap from 0.1 - 2.0 pF. Constructed of gold plated brass. Uses high K glass and alumina ceramics. Available in pc or chip mountings. JOHANSON. **536**

Chip capacitor, ATC-300, for ultra-high packaging. Capacity 0.012 to 0.1 μF. Tolerances M(20%), N(30%), Z (GMV). Dissipation factor 4% at 1 kHz. Rated at 25 V. Case size 0.050 × 0.050 × 0.050 in. Weight 1/10 of

(Continued on page 74)

Need a hybrid op amp with 2 watts power output? DICKSON has it!



That's right!
A hybrid op amp with up to 2 watts power output in a 12-lead TO-8 package.

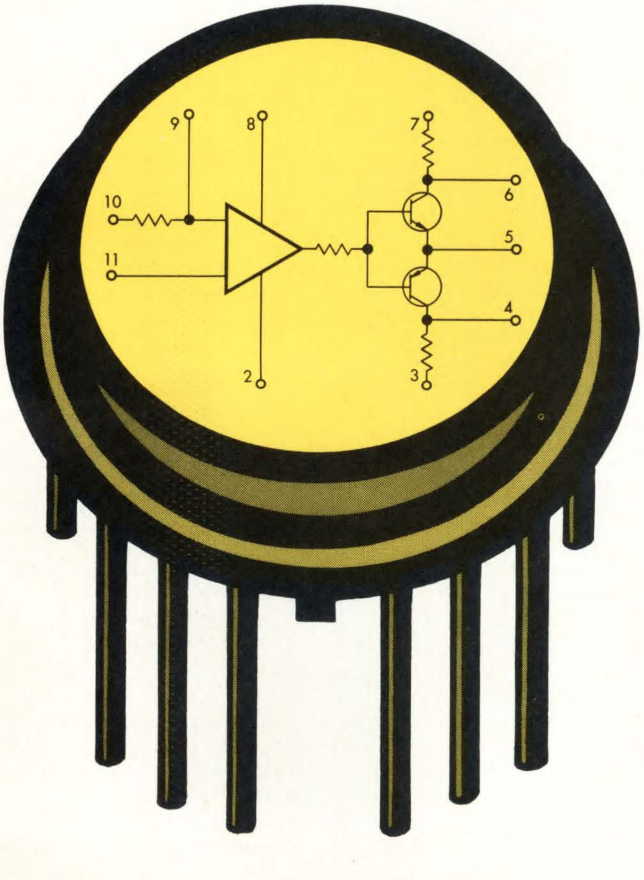
This new Dickson unit, the DPA 500, *combines* a standard monolithic operational amplifier with a complementary current amplifier. It has internal frequency compensation, a large input voltage range, and there's no danger of latch-up.

The price is just $14.50 (in 100 unit quantity) and it's in stock for immediate delivery.

EASILY CUSTOMIZED IN OEM QUANTITIES
The DPA 500's unique design also enables Dickson to supply customized units in OEM quantities at reasonable prices.

To meet your special requirements, a wide selection of resistors, voltage regulator diodes and voltage reference devices can be easily mounted inside the can without extensive engineering changes.

FOR COMPLETE DETAILS
on the DPA 500 including application information, use this publication's reader service card or phone Dickson Electronics Corporation.



DPA 500 POWER OPERATIONAL AMPLIFIER

- INTERNAL FREQUENCY COMPENSATION
- NO LATCH-UP
- LARGE INPUT VOLTAGE RANGE
- CAPABLE OF DRIVING EXTERNAL HIGH-POWER TRANSISTORS

ELECTRICAL CHARACTERISTICS

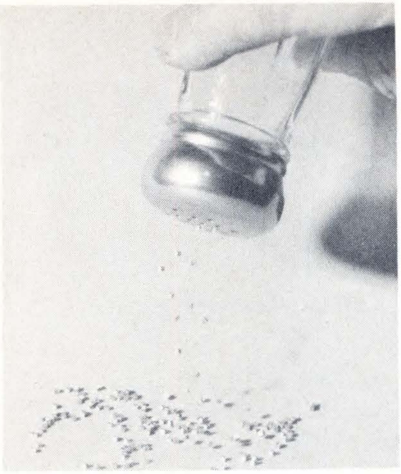
(Closed Loop, $1 \leq A_V \leq 10$) (Power Supplies = ± 15 Volts)

Input Voltage		± 15 Volts
Power Dissipation	@ $T_A = 25°C$	1.25 Watts
	@ $T_C = 25°C$	2.0 Watts
Harmonic Distortion		.2%
Output Voltage		26 Volts (P-P)
Output Current	DC	200 mA
	AC	500 mA pk
Offset Voltage		5 mV
Output Impedance		4.0 ohms

DICKSON
ELECTRONICS CORPORATION

PHONE (602) 947-2231 TWX 910-950-1292 TELEX 667-406
P. O. BOX 1390 • SCOTTSDALE, ARIZONA 85252

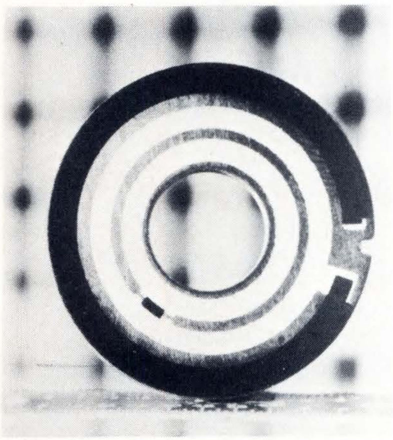
Circle 130 on Inquiry Card



a gram. 53¢ to $1.98. AMERICAN TECHNICAL CERAMICS. **537**

Resistors

Infinite-resolution variable-resistance elements for use as pick-offs, voltage dividers and like instrumentation. Resistance element is non-inductive film. Life 10 × 10^6 cycles. R, 500 Ω to 50 kΩ per inch of travel. Linearity 0.1% per inch of travel. Available in a wide variety of shapes and sizes. CIC. **559**



Temperature-sensing resistors, TEMPISTORS, with tempcos between −10 ppm/°C and +6000 ppm/°C. Construction to MIL R93D. Operation −55 to 125°C, 1/4 in. dia × 1/2 in. 75¢ in 100 qty. GENERAL RESISTANCE. **560**

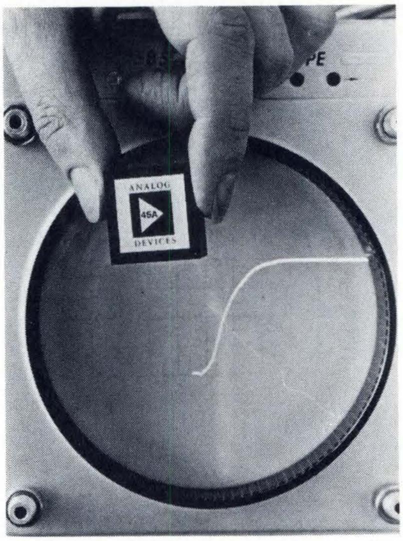
Precision resistor, HP202, with stability of 5 ppm/yr and absolute tolerance to ± 0.001%. Tempco 1 ppm/°C and tracking to 1/2 ppm/°C. 1 ns rise time. Res 30 Ω to 50 kΩ. 0.4 × 0.425 × 0.177 in. VISHAY. **561**

Ultra-miniature trimpot with 0.5 watt power dissipation at 85°C. 3/16 in.^{2} × 0.080 in. Single-turn construction with cermet element. Life 10^5 cycles. Clutch at both limits of travel. R 10 Ω to 1 MΩ. Tolerance 1%, 5% and 10%. 4 types of mounting configurations. MARK MICRO-ELECTRONICS. **562**

Packaged Circuits

High-CMRR op amp, A103A, with FET input stage. CMRR 106 dB. Dc gain 134 dB. Voltage drift 20 μV/°C. Input bias current 10 pA. Input impedance 10^{12} Ω. Encapsulated module, 1.5 × 1.5 × 0.43 in. $32 (unit qty). 2 wks. MONITOR SYSTEMS. **485**

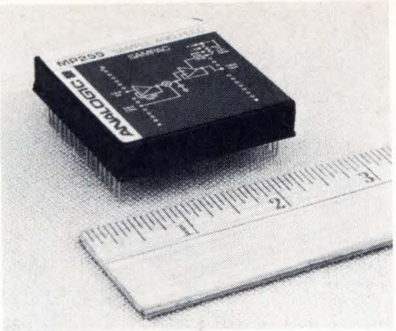
Fast differential op amp, Model 45, for inverting and noninverting applications. Settling time 0.8 μs to within 0.01% of final value. Slew rate 75 V/μs. Input resistance 10^{11} Ω (differential and common-mode). Small-signal bandwidth 10 MHz. Open-loop gain 10^5. Output ±10 V at 20 mA. Bias current 50 pA (J version) or 25 pA (K version). Voltage drift ±50 μV/°C (J) or ±15 μV/°C (K). $37 (45J) and $47 (45K). Stock. ANALOG DEVICES. **486**



Fast-settling op amp, 3401A, for buffer applications. Settles to within 0.01% of final value in 1 μs, when connected as voltage follower. Meets settling-time specs with capacitive loads of 100 pF or more. Common-mode voltage range ±10 V. Max gain error ±0.01% (including nonlinearity). Output ±10 V at 20 mA. Open-loop gain 100 dB. Bandwidth 10 MHz. Bias current 50 pA. Input Z 10^{11} Ω paralled with 3 pF. Voltage drift 50 μV/°C. 1.125 × 1.125 × 0.4 in. $45 (unit qty). Stock. BURR-BROWN. **487**

Low-level amplifier, MP297, with programmable gain. Offset 5 μV (referred to input). Offset adjustable to zero (rto). Single-ended or differential operation. DTL/TTL compatible. Input impedance 10 MΩ paralleled with 30 pF. Output ±10 V at 5 mA. Noise 1 μV rms (rti). Housed in pair of modules, each 2 × 2 × 0.39 in. Pins on 0.1-in. centers for PC board or DIP sockets. Electrically and mechanically shielded. Repairable. $600 (unit qty). 2-3 wks. ANALOGIC. **488**

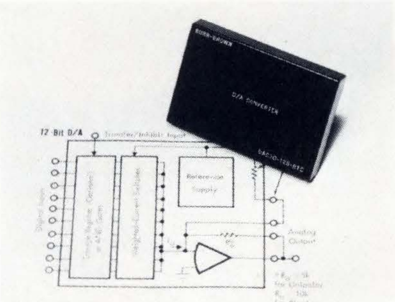
Buffered sample and hold, SAMPAC MP255, with accuracy of 0.01%. Input impedance 10^{11} Ω. Acquisition uncertainty 50 ns. Hold decay 15 μV/ms. DTL/TTL compatible. Minimal feedthru in "hold" mode. Compact module, 2 × 2 × 0.39 in. Electrically and mechanically shielded. Needs ±15 V at 12 mA. $150 (unit qty). 2-3 wks. ANALOGIC. **490**



A/D converter modules, ADC30 series, in 8-, 10-, or 12-bit versions. Available with or without input buffer amplifier. Successive-approximation circuitry provides rapid conversion. Conversion times 20 μs (8 bits) to 40 μs (12 bits). Accuracy ±1/2 LSB (relative accuracy) ±1/2 LSB (quantizing error) for all types. Tempco 20 ppm/°C for 12-bit converters. Operating temp 0 to +70°C. Choice of three output codes. $195 to $345. BURR-BROWN. **492**

Ultra-fast D/A converter, MDA-10F, with settling time of 60 ns to within 1 LSB. Accepts update rates to 10 MHz. Built-in reference. 10-bit resolution (8 bit optional). Tempco 20 ppm/°C. Output variation versus supply voltage 0.03% per %. Full-scale output 4 mA ±5%. Max glitch 50% f.s. with duration of 20 ns. Operates from ±15 V power supplies. PC-mounting module, 4 × 2 × 0.4 in. $370 (10 bits in unit qty) or $310 (8 bits in unity qty). 3 wks. ANALOG DEVICES. **493**

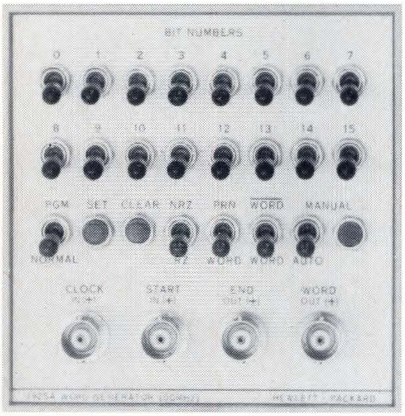
Modular D/A converters, DAC20 series, in compact PC-mtg packages, 3 × 2 × 0.4 in. Complete with input switches, resistor network, reference and output amplifier. TTL compatible. Available with resolutions from 8 to 12 bits. Relative accuracy ±½ LSB. Settling time 1.5 μs to within ½ LSB (8 and 10 bits) or 2.5 μs (12 bits). Tempco ±20 ppm/°C (10-bit binary version). Operating temp 0 to +70°C. Available with choice of 4 digital codes. Operate from ±15 V supply. Unit-qty prices: $95 (8 bits) to $155 (12 bits). BURR-BROWN. **494**



Hybrid-IC timer/pulser, LMD-70, for

(Continued on page 76)


89PR100K



use with electromechanical switching and positioning devices. Consists of UJT timing circuit and SCR switching circuit. "Adjust" terminal allows time intervals to be varied from 1 ms to 2 s, by varying value of external resistor. External capacitor allows extension of time interval to 20 s. Output 12 to 35 Vdc at 2 to 7 A. Compact encapsulated unit, 0.3 × 0.3 × 0.3 in., with wire leads. Operating temp −55 to +100°C. $17.90 (1-24). Stock (sample qty). LEDEX. **499**

Avalanche-diode oscillators, ADO series, in 18 different versions with rf outputs to 100 mW. Mechanical tuning over range of 200 to 1200 MHz about any frequency in X-band region. Typical power variation less than 1 dB across band. Typical frequency tempco 100 kHz/°C. Provide solid-state replacement for klystrons. RAYTHEON. **503**

Stereo-amplifier assembly, PCA-3C-18, for use in OEM phonographs, tape recorders and radios. Output 4 W per channel at 1 kHz with 10% distortion. Frequency response ±3 dB from 40 Hz to 30 kHz at 1 W per channel. Sensitivity 200 mV. 4 independent controls for volume, balance, bass and treble. Circuit has direct-coupled transistor power amplifier with IC preamp for each channel. PC board 3½ × 7½ in. Height 1½ in. From $10.60 (10,000 up) to $12.80 (500-999). AMPEREX. **504**

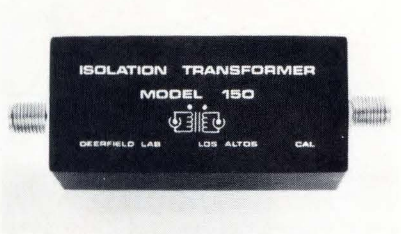
Transformers & Inductors

Miniature transformer, micro-Mini, for pulse or transistor circuitry. 0.038 cu. in. and 0.06 oz. Meet MIL-T-27B. −195° to +130°C. Leads 0.025 in. Type A Nickel. TRANSFORMER ENGINEERS. **555**

4-identical transformer module, 8000-9000, for computers and peripheral equipment. In a 16-lead, side egress, transfer-molded DIP package. Inductance 20 to 500 μH. Turns ratios 1:1 or 2:1. Peak pulse 50 V and insulation res exceeds 10,000 M Ω. $18.50 (1-9). PULSE ENGINEERING. **556**

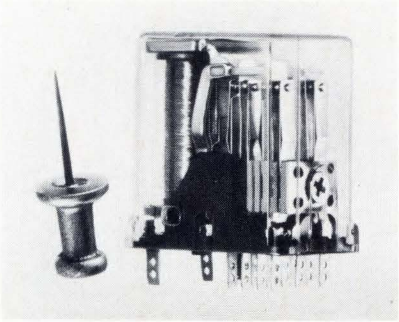
Modem-coupling transformer, MT35, for remote access data terminals. Input 600 Ω. Output 600 Ω center tapped and 600 Ω center tapped. Freq response 40-20,000 Hz ± 2 dB at 5 dBm. Hi-pot 500 V. Bifilar windings. 1 1/32 × 13/16 × 1 1/16 in. Weight 1 oz. Open frame or molded plug-in. $3.90 MICOTRAN. **557**

Isolation transformer, 150, with 3-dB bandwidth from 150 Hz to 150 MHz. 1-ns risetime and 0.1-ms pulse duration. CMRR 100 dB below 1 GHz and 40 dB at 150 MHz. For use in 50-Ω systems. SMA, BNC, or TNC female connectors. $65. DEERFIELD LAB. **558**



Switches & Relays

Very-high-sensitivity general - purpose relay, with 2, 4, 6 poles. 1 cu in. 35 mW pullin for spdt. Gold-plated terminals and contacts. Nickel-plated bearings. Filled-polycarbonate plug-in base. DEUTSCH. **513**

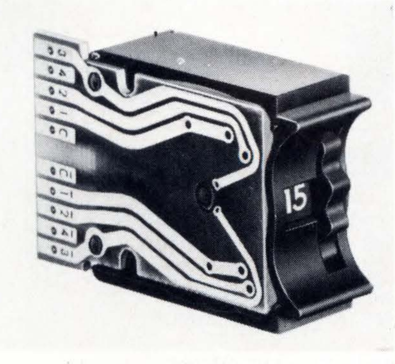


Solid-state time-delay relays in half crystal can or full crystal can. Half can with preset delays to 5 s, full can to 180 s. Output current to 100 mA. 5% acc. Meet Mil specs. Solid-state timing and switching. TEMPO. **514**

PC-mount reed relays, Tri-R, in line expanded to include smaller (0.4 × 1.25-in.) package with 6 leads max. Low profile allows board stacking as close as half inch. ALLIED CONTROL. **515**

10 × 10 matrix board with sealed panel, front-removable active-circuit snap-in lamps. SEALECTRO. **519**

16-position submin thumbwheels and lever-actuated thumbwheels, T20-09A,



(Continued on page 78)

Signetics throws design costs for a loop.

Again.

A short time back, we introduced the phase locked loop. Or, to be technical, the monolithic phase locked signal conditioner and demodulator.

Now we've gone ourselves two better.

First, with the PLL 562. This is our phase locked loop with the loop opened. It gives the designer access to the innards of the system. It also allows him to hook up the PLL to other standard parts like our 8200 series MSI. And this enables the PLL to do things like frequency multiplication and division. (If you ask us, the PLL 562's major uses will be in frequency synthesis and synchronizing data off tape and drum memories.)

Second, our low-cost PLL 565. This is a brand new design, again with the loop opened. It provides a reference on the output and operates from common power supply voltages. That's why the PLL 565 can drastically simplify modem designs.

Most important: you get the savings and benefits inherent in broader application of the PLL technique.

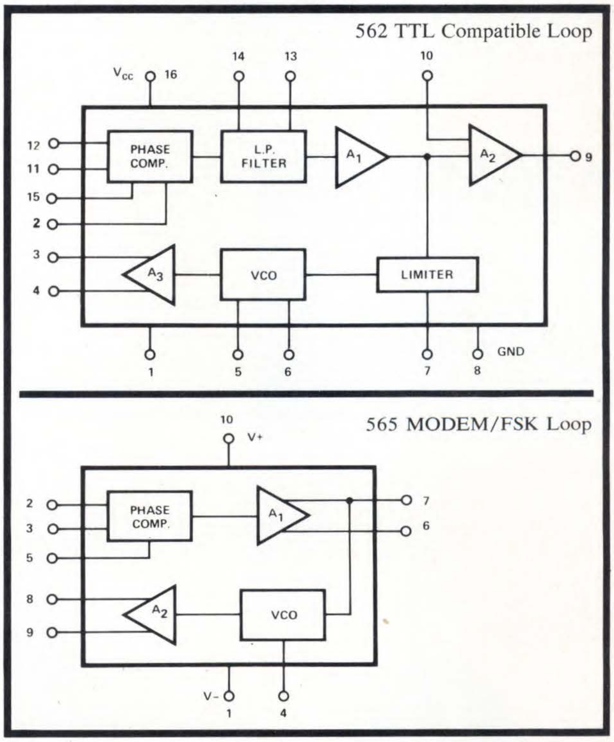
As we've said before, the PLL concept has many possibilities. It will be the universal building block that the op amp has become.

Our new phase locked loop devices are available now from Signetics and Signetics distributors. Nowhere else.

In 100-up quantities, the PLL 562 goes for $18; the PLL 565 for $6.35.

Build yourself a better whatever. Cheaper. Write for a complete description of performance, applications and spec sheets.

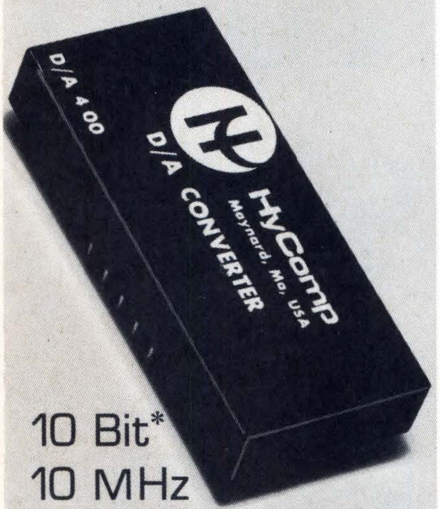
Be two up on everyone.

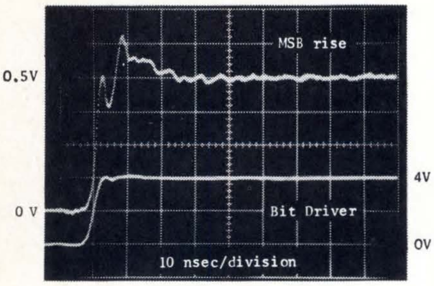


Signetics

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

Circle 133 on Inquiry Card

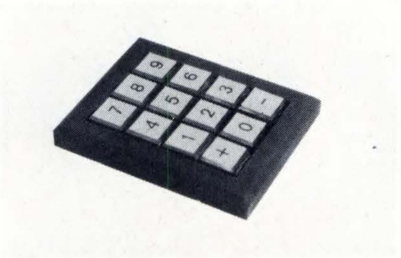




with hexadecimal-plus-complement coding, two commons. Readout numeric or numeric plus A through F. Front or back-of-panel mount. $12.40 (1-up), $9.95 (500-up). CHERRY. **520**

Latching reed switches, Memreed, with remanent magnetism of reeds maintaining closure without need for holding coils or bias magnets. 50-μs signal for energization. Form A or B, 15-VA contacts. 85¢ (100-up), 60¢ (1000-up). TEMPRESS ELECTRONIC. **517**

Low-cost, conductive-plastic keyboard with any number of keys on 3/4-in. centers. Contact made through silver-filled elastomer. Initial contact resistance 40 Ω. Any coding to 16 bits without external logic. Snap-action keys with 80-mil travel, 2-oz actuation. 10^6 operations at 40 mA, 30 Vdc. 12-key version $9.50 in prototype quantities. CHOMERICS. **523**

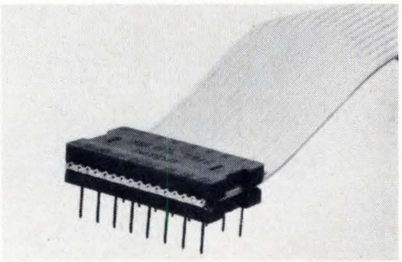


Packaging/Hardware

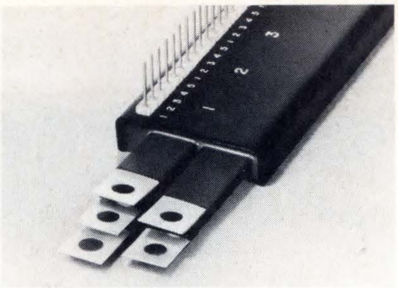
Tiny rf connector, NanoheX, with "telescoping" interface for consistent impedance match with repeated coupling and uncoupling. Metal body aligns first, then dielectric, then center contact. 50 or 75 ohms. Screw-on, snap-on or slide-on mating. SEALECTRO. **476**

PC connector, Hypertac 12, with helical-wires socket contact for low (2 oz) insertion/extraction force with low contact resistance, low wear, long life (100,000 insertions). INDUSTRIAL ELECTRONIC HARDWARE. **477**

Round-wire flat-cable connectors for mating to PCs, wrap posts or DIPs. Pressure-type "U" contacts pierce insulation and grab conductors on 50-mil centers, stripping away oxide films. Glass-filled nylon body with Au over Ni over BeCu contacts. 3M. **478**



Rigid laminar bus bars, Capitron, with layers of planar conductors and dielectric, epoxy potted in aluminum housing strong enough to serve as chassis structural member and mounting point for connectors. Capacitance to 1000 pF/sq in. AMP. **479**

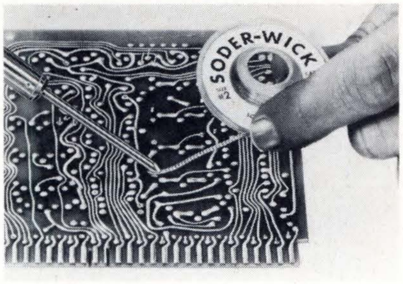


Adhesive-backed thin-film resistors on 5 × 12-in. Mylar sheets in thicknesses from 1 to 10 mils with resistivities from 50 to 377 ohms/square (standard), 1 to 750 ohms/square (special). FILMOHM. **480**

"Do-nothing" paste, 921, for setting up and aligning screen printers without wasting ceramic chips and costly conductor and resistor inks. Can be cleanly fired off substrates allowing their use with permanent inks. $2/troy oz. ELECTRO MATERIALS. **481**

Alumina, beryllia and Kovar-alloy microcircuit packages, Sealox, in high volume for almost any hybrid package. Die-mount areas can be metalized or supplied with screened pattern. NATIONAL BERYLLIA. **482**

Solder remover, Soder Wick, in form of rosin-treated copper wick which, heated by soldering iron, sucks solder off connection. TECHNI-TOOL. **483**



Computer-controlled component inserter, 6264, for mounting up to 5000 sequenced, reel-packaged components per hour on PCs. 999 computer-controlled center distances. System expandable to include component insertion, sequencing and wire termination. UNIVERSAL INSTRUMENTS. **484**

Power Supplies

Miniature-encapsulated module, P1.5.-1000, with 5 V at 1 A. 2.5 × 3.5 × 1.25 in. 5-watts power output from −25°C to 71°C. 105 to 125 Vac at 50 to 400 Hz. Reg (0 to full load) 0.1%. Ripple and noise 1 mV rms. Tempco 0.02%/°C. Short ckt proof. $69 (1-9). SEMICONDUCTOR CIRCUITS. **550**

5 V 50 AMP supply with 85% efficiency. Line and load reg each

(Continued on page 80)

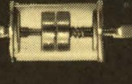
"ZERO" Reaction Time

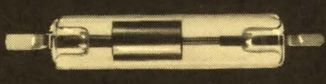
clip transients...

with the New Uni-Imp Voltage Surge Protector

- **Impulse Ratio** .... 1.1 to 1
- **Trip Voltages** .... 550V to 15kV (constant up to 50 kV/microsec.)
- **Life** .... greater than 5,000 shots @ max. rating
- **Follow-on Current** .... Compatible with normal relay closure times

Now it is possible to protect sensitive components, even semi-conductor equipment, against voltage transients without concern for the rate of voltage rise. The "zero" reaction time of Signalite's new Uni-Imp is only one of its many unique features. Others including its Bi-Polarity, immunity to di/dt restrictions, infinite leakage resistance, are described in a new data sheet.





Signalite new product release

Uni-Imp Voltage Surge Arrestors

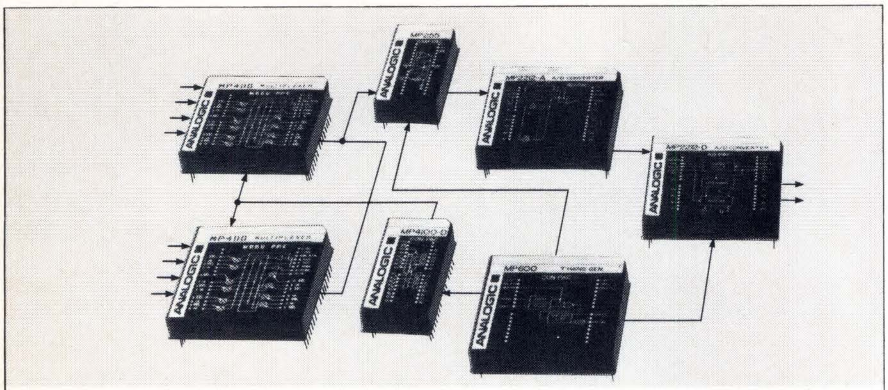
("zero" reaction time)

AVAILABLE UPON REQUEST Detailed Data Sheet . . . on Signalite's Uni-Imp Zero Reaction Time Voltage Surge Protectors.

Signalite

Division of General Instrument

1933 HECK AVENUE, NEPTUNE • NEW JERSEY 07753
(201) 775-2490



ANALOGIC INTRODUCES

the first family

Analogic's new **Modupac**™ line is the first **complete** family of analog-digital-analog signal conversion modules. They're available as independent single units, or in any combination, and easily interconnected to form all or part of a limitless range of systems. However you specify them, Analogic **Modupac**™ modules offer you the following advantages:

- ☐ Pre-system engineered for maximum performance and high M.T.B.F.
- ☐ Both electrostatically and electromagnetically shielded . . . yet easily repairable.
- ☐ Standardized terminal arrangement.
- ☐ 0.10" pin spacing . . . for P.C. or "DIP" socket mounting.
- ☐ 3 plan sizes: 1" x 2", 2" x 2", and 2" x 4"; most are 0.39" high.

Function for function, the best price-performance ratio available.

ANALOGIC
...The Digitizers
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Tel. (617) 246-0300, TWX (710) 348-0425

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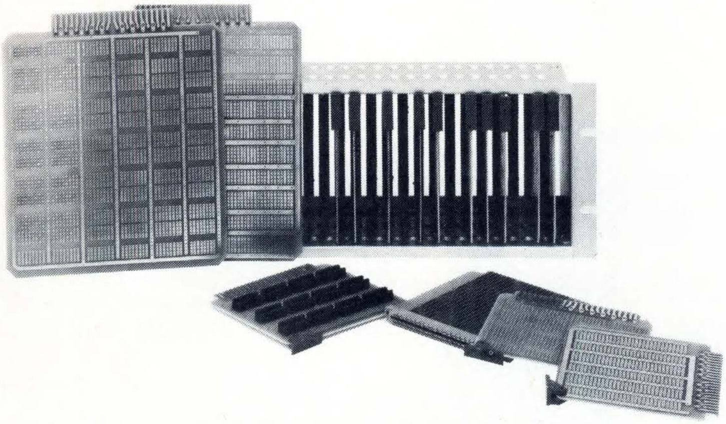

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Phone (415) 483-8770
718 Marina Blvd., San Leandro, Calif. 94577

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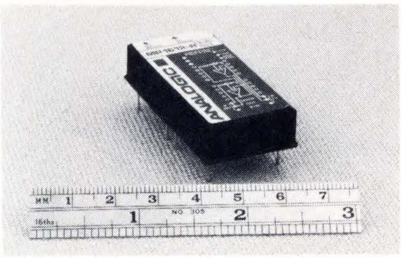
0.05%. Ripple and noise 50 mV pk-pk. Response time 200 μs. 0 to 50°C without heatsink or forced air. 4 × 4 × 6 in. 5 year warranty. $364. POWER DEVICES. **551**



Dual dc module, MP1612-R, with 5 V (20 mA) and 10 V (30 mA) references. Tempco ± 0.0009%/°C. Short ckt proof with dc and dynamic output Z of 0.01 and 5Ω respectively. 2 × 1 × 0.39 in. Operates from ± 15 V. $90 (unit qty). ANALOGIC. **549**

Precision-lab supply, QHS, with voltage ranges from 0 to 20, 40 and 100 volts respectively. 5 decade thumbwheel switch and fine control pot provide 11 μV resolution. Stability 10 ppm/8 hr. Line reg 1 ppm + 30 μV and load reg 50 ppm + 50 μV. Absolute acc 0.1%. Pk-pk noise 100 μV from 0-500 kHz. SORENSON. **552**

Ultra-quiet switching power converter, 301, with 500 μV of noise at the output. Input 105-130 Vac 50-1000 Hz. Output ± 12 to ± 15 Vdc at 6 A total or 24-30 Vdc at 3 A. Response 20 μs. Line reg ± 0.01% and load reg 0.1%. Size 5.26 × 10.6 × 1.69 in. Efficiency 65%. $350. RO **553**

Precision-ac power source, 751, with an output power of up to 750-VA single phase. 40-standard plug-in oscillators give fixed or variable outputs 45 Hz-10 kHz. Acc 0.1% to 0.0001%. Output V 0-30 Vac and 0-260 Vac. 7 × 19 × 18 in. $1725 plus oscillator. ELGAR. **554**

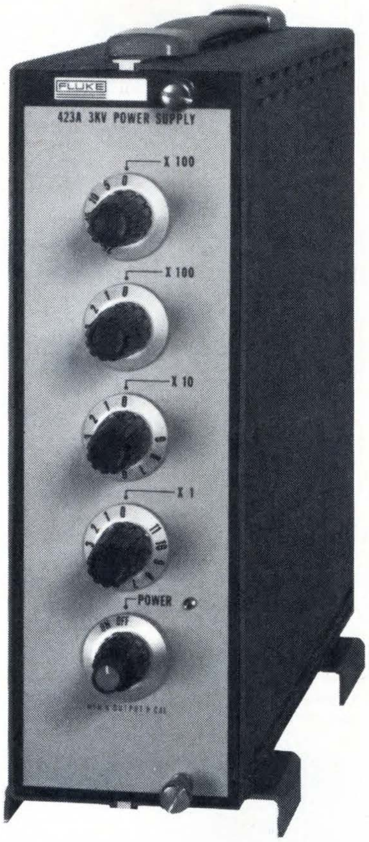
Test Equipment

1-MHz automatic capacitance bridge, C403, with 25-ms balance time and measurements in % deviation from nominal. Capacitance measurements from 1 to 2000 pF. Deviations from −100% to +159.9%. Dissipation factor to 15%. Range and nominal value programmable. BCD output. $5850. TERADYNE. **538**

Digital L-C meter, 9400L-C, with 4-digit (in-line) display. Inductance reso-

(Continued on page 82)

Even in power supplies, somebody makes progress once in a while. This is the new NIMS high voltage power supply.



It's a Fluke.

Fluke's new NIMS (nuclear instrument module system) high voltage power supply is priced about the same as the three major competitors, $460. That's where the similarity ends.

In every other pertinent spec, the new Fluke 423A exceeds or at the very least meets the competition. And, in addition, it offers some exclusive features all its own. Let's go down the list. Only Fluke offers a full 0 to 3000 volts, line and load regulation of 0.001 and 0.002 percent across the board. Only Fluke offers portable bench case or NIMS bin module. Only Fluke offers remote analog slewing of the output or manual operation. Only Fluke offers a current limit of 15 ma. Other specifications are output current, 0 to 10 ma, Resolution, 100 mv. Accuracy, 0.25%. Ripple and noise, 5 mv peak-to-peak (10 Hz to 1 Mhz). Polarity is reversible at the rear panel. Size is 2.7" x 8.7" x 9.7". Price with case is $495.

For full details, see your Fluke sales engineers or contact us directly.

FLUKE®

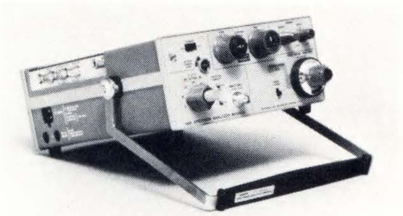
Fluke, Box 7428, Seattle, Washington 98133. Phone: (206) 774-2211.
TWX: 910-449-2850. In Europe, address Fluke Nederland (N.V.), P.O. Box 5053,
Tilburg, Holland. Phone: (04250) 70130. Telex: 884-50237. In the U.K., address
Fluke International Corp., Garnett Close, Watford, WD2 4TT.
Phone: Watford, 27769.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

Circle 215 on Inquiry Card

lution 0.1 μH and capacitance resolution 0.1 pF. Accuracy ±1% f.s. ±1 digit. Cap ranges 100 pF to 100 μF in 7 decade steps. Inductance ranges 100 μH to 100 mH in 4 decades. BCD output. $550. SYSTRON DONNER. **539**

Analog filter, 1100, for a range of 10 Hz to 1.1 MHz. Band-pass, low-pass and high-pass modes. Digital frequency selection. 24 dB/oct slope. 5% accuracy. Butterworth or Bessel response. $690. ROCKLAND SYSTEMS. **540**

Spectrum Analyzer Module, 1401, for use with Sony/Tektronix 323 or any other scope. 1 to 500-MHz display. Up to 1-MHz resolution bandwidth. 60-dB log dynamic range. Power from ac line, 6-16 Vdc or int batteries. TEKTRONIX. **541**



Low-cost DVM, DVM-110, with 3½ digits. Dc ranges 1.5, 15, 150 and 1000 V. 33% over-ranging on all scales. Incorrect voltage polarity causes readout to indicate zero. Automatic overload protection. Input Z 0.2 MΩ (1.5-V range) and 10 MΩ all other ranges. Accuracy 0.5%. Ac operation. $189.50. ALCO. **544**

Wideband wattmeter/analog multiplier for complex waveforms. 0.25%-multiplication accuracy. DVM reads watts, kilowatts or megawatts. Voltage inputs to ±1000 V. Current range to ±25,000 A. Two voltage outputs, filtered and unfiltered. HALMAR. **546**

Function Generator, 745, with 6099-digitally adjustable frequencies from 0.01 Hz to 1.099 MHz. Triangle, square and sine wave mode. Tone burst, synchronization and fm of all waveforms. 20 Vpp from two isolated 50-Ω terminals. Sine wave amplitude variation 0.05 dB. Distortion 46 dB. Square wave rise time 50 ns. 3 digit control of frequency. At 25°C freq resettability ±1 digit. Freq acc ±0.4% and ±2 digits. $425. CLARKE-HESS. **547**

Display Devices

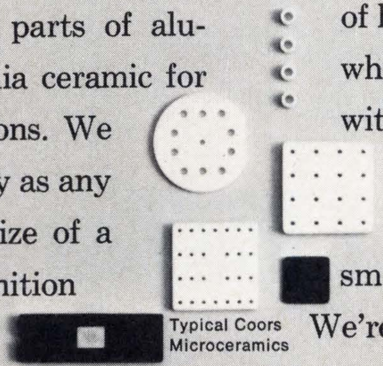
CRT-bargraph display, MS20D, for displaying up to 50 channels of data. Provides 4-digit readout of any selected channel or high and low alarm levels on that channel. 20 in. CRT with electronically-generated no-parallax grid. Transducer input 5 mV to 5 Vdc. Can be interfaced to line print-

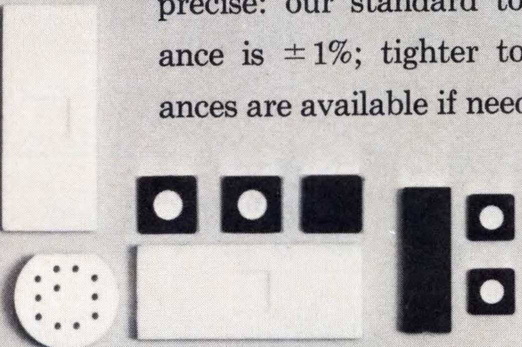
(Continued on page 84)

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

Q. WHAT ARE COORS MICROCERAMICS ANYWAY?

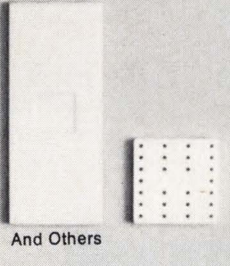
A. Glad you asked. They are small, precise parts of alumina or beryllia ceramic for microelectronic applications. We define small rather loosely as any part between, say, the size of a dime and a BB. The definition of precise is more precise: our standard tolerance is ±1%; tighter tolerances are available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

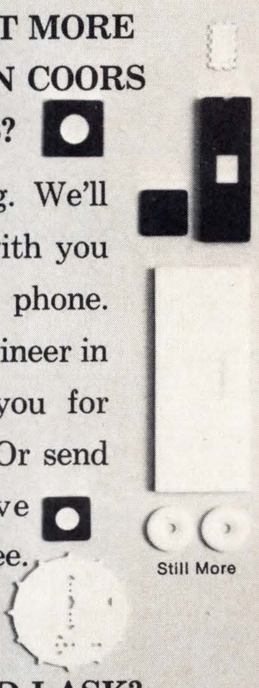

And Others

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?

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Coors/CERAMICS
the tough stuff

CP-137

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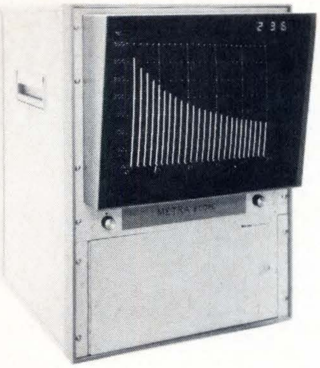


er, computer, or other digital equipment. $4,375 plus $40 per channel monitored. METRA INSTRUMENTS. **528**

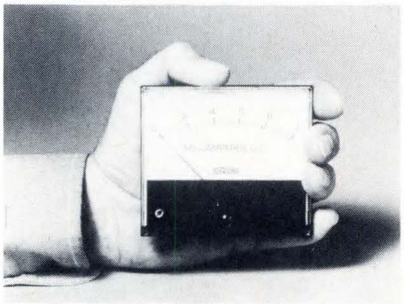
Hexadecimal Display, series 30, with 9-bar readout for translating 8-4-2-1 BCD into a display of 16 non-ambiguous characters, 0 through 9 and A through F. Character height is 0.32 in. $26. LUMINETICS. **529**

DPM, 332, with bipolar operation and automatic zeroing. 3 1/2 digits plus neon minus sign. All functions programmable. Zin 100 MΩ. Ranges: 1 to 1000 V, lk to 10 MΩ and 100 μA to 1 A. 100% overrange. Acc 0.1% f.s. ±1 digit. $184. DIGILIN. **530**

Digital tachometer, D9000, with 3 1/2-digit display. Displays rpm or any other rate information. Inputs from mag pickups, photocells, or shaft encoders. Input 15 mV to 30 Vrms. Input Z 4 kΩ. Frequency from 0-50 Hz to 0-20,000 Hz. Linearity 0.1%. Waveshape: Pulse, sinusoidal, square or triangular. $354. DYNALCO. **531**

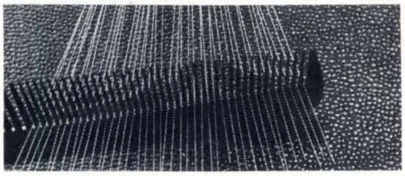
Low-cost decade counter, DC-10-1, with integral neon display. Counting rate 10 MHz over +10 to 50°C. Input, carry, output and clear are TTL logic levels. Mounting tab and etched edge connector. Power in: 5 Vdc ±5% at 75 mA and 105 Vdc ±15 V at 4 mA. $16.95. DISPLAY ELECTRONICS. **532**

Low-cost panel meters, Stellar 1, with standard sizes from 1 1/2 to 4 1/2 inches. Shielded permanent-magnet moving coil mechanism. Optically clear plastic windows, antistatic treated. Acc ±2% or 1% f.s. Meets ASAC 39.1. $4.50 to $5.00. PHAOSTRON. **533**



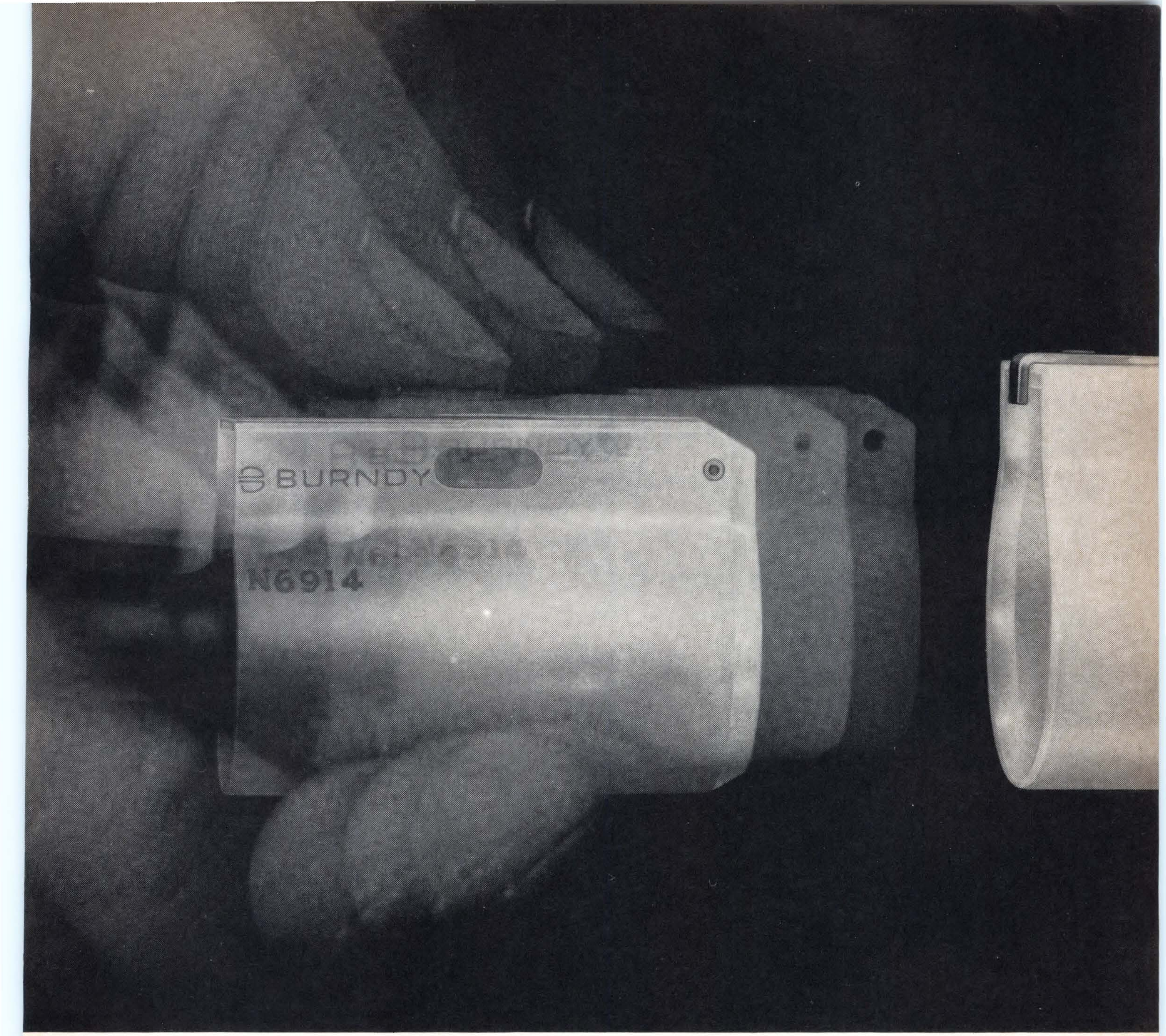
Special Products

Plated wire, NW-100 for NDRO memory applications. Consists of 5-mil beryllium-copper wire, electroplated with 30 μin. layer of magnetic permalloy. Switching speeds as low as 10 ns allowing construction of memories having five times the speed of core memories. Available in 15-in. lengths. $0.10 per in. (qty of 100,000 wires or more). NEMONIC. **525**



High-torque stepper motor, VR2490-15, with low rotor inertia. Stall torque 90 in.-oz. Rotor inertia 20 × 10^{-6} lb. in.-s^2. Stepping response time 2 ms. Step angle 15°. Positioning accuracy ±18 min. Rated input 24 Vdc at 13 A. 3.28 in. dia × 4.87 in. Shaft dia 0.25 in. BULOVA **526**

Tiny low-cost tachometer, 220/210T, with unique ironless skewed-winding rotor that minimizes ripple and output non-linearities. Output gradient 3.4 V/1000 rpm. Linearity 1%. 1.02 in. dia × 1.6 in. 5 oz. $25.40 (sample qty) or $16.20 (100 up). Stock to 4 wks. MICRO-MO **527**



Fastest disconnect in the business

(And practically indestructible.)

Apply gentle pressure on the locking latch of this coupling connector and the ejector spring pops the plug assembly into your hand.

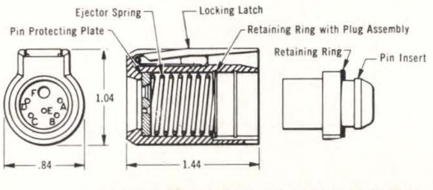
It's the MB6 series, and it connects easily, too, especially in limited access areas. Manipulation for blind mating is convenient and safe, and a dead-front pin-protecting plate makes the plug "more than scoopproof". When inserted, a quick "click" lets you know it's connected . . . securely.

Burndy uses resilient nylon for both the plug and receptacle. Lightweight, reliable and low-cost, it will withstand many times more disconnects than a metal connector, without any wear or galling. Even if accidentally stepped on, it cannot be deformed.

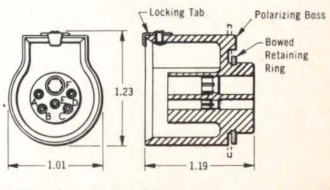
Unaffected by humidity, the MB6 is rated for temperatures from −55°C to +100°C and is shock and vibration resistant. Uses standard copper alloy gold-plated contacts installed with standard tools.

Burndy has more connectors like this, with and without the self-ejecting spring feature. Write for complete information, including test results.

Plug Assembly Type MB6P-



Receptacle Assembly Type MB6R-



Accepts five standard contacts for No. 24-20 wire, plus either one standard contact for No. 14-12 wire, or one coaxial cable contact.

BURNDY

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70–26

New Literature

Rf connectors in comprehensive 161-pg Bendix catalog. **400**

Numeric readout tubes, zero-voltage switching, handling and mounting plastic semis, thyristor characteristics and applications, gate-oxide protection circuits and astables and monostables using DICs in 6 RCA app notes. **401**

Switches of many types in Alco 24 pager. **402**

"Digital Fourier Analysis," fine tech article in "Hewlett-Packard Journal." **403**

Rf coax cable in Times Wire 44-pg handbook. **404**

Solid-state timers in Syracuse 30 pager. **405**

Miniature switches and terminations in Grayhill 92 pager. **406**

IC circuits in 6 Sprague app notes. **407**

D/A and A/D conversion in Burr-Brown 16 pager. **408**

Digital readouts in Instrument Displays catalog. **409**

Connectors of many types in Cinch 28 pager. **410**

Silicones for electronics in Dow Corning 20 pager. **411**

Broadband VSWR measurements in first issue of "Wiltron Technical Review." **412**

Economy pushbutton switches in Oak data. **413**

Tape recorders in three Leach catalogs. **414**

Photographic information in 32-page Kodak 1970 index. **415**

Solid-state control modules in Mullard 12 pager. **416**

Linear ICs in 88-pg Fairchild pocket catalog. **417**

Beryllia and alumina properties in National Beryllia tech bulletin with 11 × 17 wall chart. **418**

Pulse, wideband, video power amplifiers in C-Cor short form. **419**

Byte generators in Adar data. **420**

Mercury-film relays and switches in Fifth Dimension brochure. **421**

Transistors for vhf to S band band in KMC "Design Aids." **422**

Automatic measurement in Vidar 16 pager on computer-controlled, digital data acquisition. **423**

Digital cassette tape drives in Ampex data. **424**

Flexible flat cable in Teledyne 24-pg design guide. **425**

Wire-Wrap formats and services in two Raytheon brochures. **426**

Monolithic ceramic capacitors in San Fernando 24 pager. **427**

Instrument rental in 22-pg Beckman bulletin. **428**

Solid-state microwave products in Varian 36 pager. **429**

A/D conversion in Analogic packet including reprints of "Bernard Gordon Speaks Out on What's Wrong with A/D Converter Specs," "Digital Sampling and Recovery of Analog Signals" and other tech articles. **430**

Unusual Literature

How to Select The Optimum Fan For Your Application

Pamotor

It's just superb. In this series of six pocket-sized booklets we find some of the best written, clearest, down-to-earth material on selecting the optimum air mover for cooling electronic equipment. The author starts immediately with the Ohm's Law analogy to cooling systems, then promptly shows where the analogy falls down.

Practical throughout, he shows the approximations we can make and the dangers that confront us. He mentions the "exact" mathematical formulas available, but scarcely uses them. He recognizes that, in real life, there are many measurements that simply aren't practical. As an example, he points out that "determining (or at least estimating) the resistance to airflow is the greatest practical difficulty you face." Then he shows what we can do — practically.

He warns us of matters we have to worry about but he tells us, too, about things that need not concern us — like the type of fan or blower — which should remain the province of the fan designer, not the electronics designer. And he pulls no punches in calling nonsense nonsense.

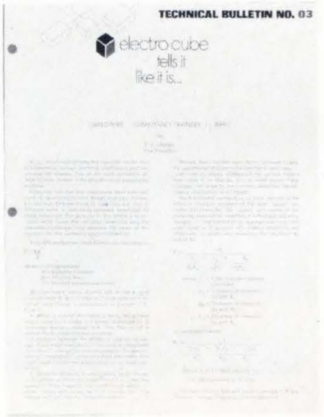
His style, completely informal, is so fine that we scarcely notice it. Instead, we get the feeling, throughout, that a good engineer who knows his stuff, is giving us some handy tips and procedures.

For a copy of the six-booklet series, circle **460.**

Capacitors . . .

F. L. Johnson
Electro Cube

Here's the beginning of a fine series of brief bulletins on capacitor subtleties that can still confuse. None of the information is really new, but because most engineers take capacitors so much for granted, they often run into snags because of things they should know, but don't.


TECHNICAL BULLETIN NO. 03

electro cube
tells it
like it is...

In one of the bulletins, "Capacitors . . . Capacitance Changes — Why?," author Johnson provides three handy charts showing variation of dielectric constant as a function of temperature for the most popular dielectrics (except ceramics) and for different capacitor impregnants. The information in the charts will come as a surprise to many users of very "stable" capacitors. The text goes further and discusses the effects of moisture, voltage and frequency.

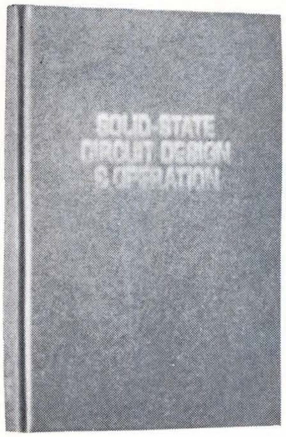
Another bulletin, "Capacitors . . . Insulation Resistance Can Be Confusing!" covers material that shouldn't confuse, but still does. The author sets up a straw man in a theatrical dialog and uses this vehicle as a method for clarifying megohm-microfarad ratings. Other bulletins cover other capacitor specs that are more or less well known.

Much of the information in these bulletins has already been widely disseminated. Yet there's material that can be new to many of us.

For a copy, circle **464.**

SAVE $2.00

on this special
Prepublication Offer!



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diodes, transistors, leakage, temperature, noise, FETs & MOSFETs, zener diode, thyristors, unijunction transistors.

SEMICONDUCTOR BIASING TECHNIQUES
limits for design, loop equations, voltage vs. current biasing, load lines, feedback biasing, fixed bias.

AC CIRCUITS & AMPLIFIERS
AC considerations, matrices, h, y, and s parameters, working problems, large signal circuits, thyristor applications.

PULSE & SWITCHING CIRCUITS
switching load lines, saturated and non-saturated switches, multivibrators.

LOGIC & DIGITAL ICs
And-Or functions, Nand-Nor logic, truth tables, basic Boolean equations, binary numbers, the Karnaugh map, And-Or negation, DTL and TTL.

OPERATIONAL AMPLIFIERS
basic amplifiers, working examples, opamp circuits, monolithic voltage regulators.

ARITHMETIC OF ELECTRONICS
math fundamentals, voltages and currents, series and parallel circuits, general networks.

SOLID-STATE CIRCUIT DESIGN & OPERATION

By Stanton Rust Prentiss

A Unique and Informative Guide to Semiconductor Circuit Analysis and Design of Value to Practicing Design Engineers

From diodes to integrated circuits — from FETs and MOSFETs to opamps — here is a truly practical guide to the design and operation of solid-state circuits. Containing numerous practical circuits designs, along with the solutions to a variety of basic circuit development problems, this all-encompassing work delves into operational problems frequently encountered in everyday design work.

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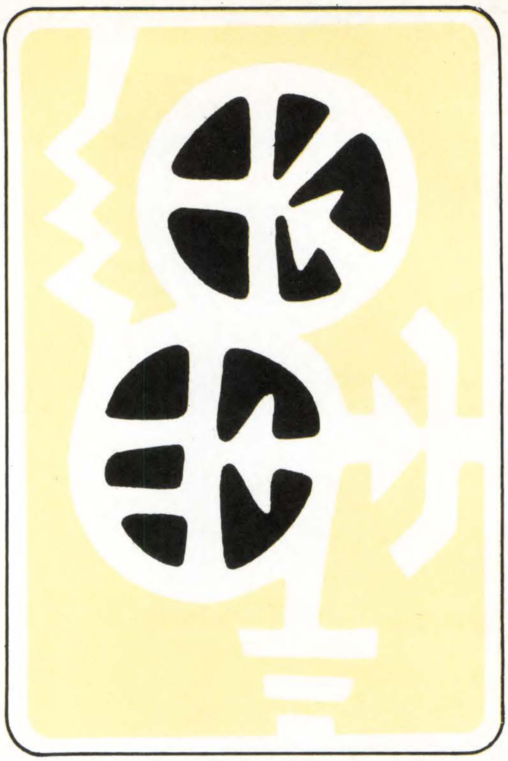


EEE readers have voted Stuart D. Culp winner of the $100 Savings Bond for July. The winning circuit design is "Crystal oscillator uses logic gates." Mr. Culp is with General Electric in Utica, N.Y.

High-efficiency, miniature decoupler

Circuit Design No. 14

by Gordon J. Deboo
NASA
Ames Research Center
Moffett Field, Calif.

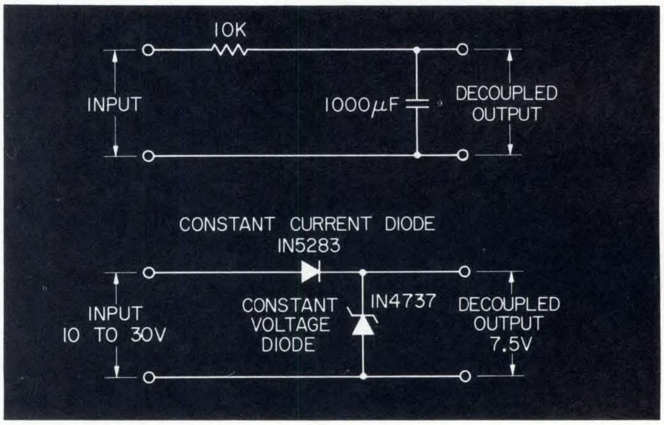
It's usually necessary to decouple the power supplies used with high-gain amplifiers to prevent oscillation due to feedback through the power lines. A disadvantage of the conventional network at the top of the figure is that decoupling is not very effective at low frequencies where good decoupling is often very important.

For example, a 1000-μF capacitor has a reactance of 160Ω at 1 Hz, so 1-Hz ripple is attenuated by a factor of only about 60. It is at frequencies of about 1 Hz that motor-boating oscillation occurs. Further disadvantages of this circuit are that it introduces phase shift, increasing the possibility of oscillation, and it requires physically large components.

The lower circuit in the figure overcomes all these disadvantages. The 1N5283 is a current-regulator diode, which is a two-terminal field-effect device with common source and gate as one terminal and drain as the other. The 1N4737 is a conventional regulator diode.

When used with a load requiring almost zero current, the attenuation of this circuit at 1 Hz exceeds 50,000 to 1 from dc to many kilohertz. The fact that attenuation is maintained down to dc is a significant advantage in preventing low-frequency oscillation. The circuit also uses small components.

Excellent decoupling from dc to very high frequencies can be achieved by adding an rf choke in series with the input to the 1N5283 and a capacitor across the decoupled output. Decoupling can be maintained for load currents that aren't negligible compared to the zener current by using an appropriate emitter-follower circuit as a buffer. ■



The conventional decoupling circuit at the top uses large components, yet it's not effective at low frequencies; it introduces phase shift and increases the possibility of low-frequency oscillation. The bottom circuit eliminates these problems, offering high attenuation from dc to high frequencies.

Versatile one-shot

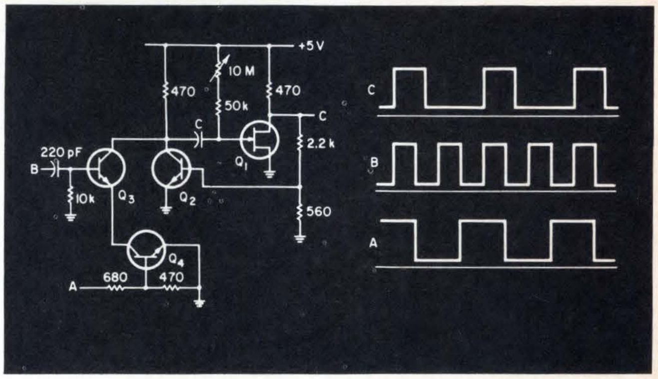
Circuit Design No. 15

by Ralph Tenny
Texas Instruments
Dallas, Texas

THIS CIRCUIT uses standard digital-IC voltage levels as inputs and can be inhibited or enabled at any time without causing an output. Duty cycle approaches 98 percent at trigger rates of 500 kHz.

Comparable IC monostables are limited to 50 percent duty cycle and are noise sensitive during long pulse times. Also, IC monostables may trigger on an inhibit command unless the inhibit occurs during the one-shot period.

The input gate (Q_3 and Q_4) is enabled with a logical 1 at point *A* and inhibited with a 0 at the same point. If the inhibiting function is not needed, the emitter of Q_3 should be grounded and Q_4 omitted. A logical 1 at point *B* starts a timing cycle. Q_1 is a 2N3819 JFET while all other transistors are 2N3704s. ■



Versatile one-shot mono may be enabled or inhibited at any time without a false output.

Gain-programmable amplifier

Circuit Design No. 16

by Karl Karash
Raytheon
Sudbury, Mass.

THE CIRCUIT in Fig. 1 enables the gain of a non-inverting op amp to be changed externally. The control device is a FET, which shorts feedback resistor R_3 to ground. Additional gain variation could be obtained by dividing R_3 into smaller increments and shunting each segment to ground with its own control FET. With the "digital input" at zero volts, Q_1 turns on but is held out of saturation by Schottky diode D_2. Q_1 then injects current into the gate of Q_2 through the reverse capacitance of D_3. Q_2 turns on, making its drain-to-source resistance about 10 ohms. This value is negligible compared to feedback resistors R_1 and R_2. The resulting op-amp gain is Eo/Ei = $(R_1+R_2)/R_2$. If R_2 is 1.13 kΩ and R_1 is 10 kΩ, the resulting gain is 10.

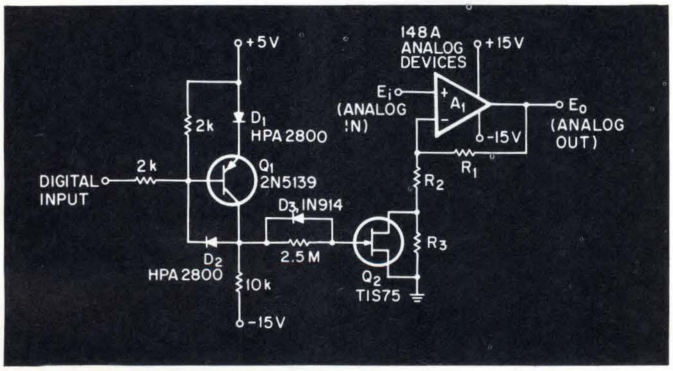


Fig. 1. This circuit's gain is programmable with standard logic levels.

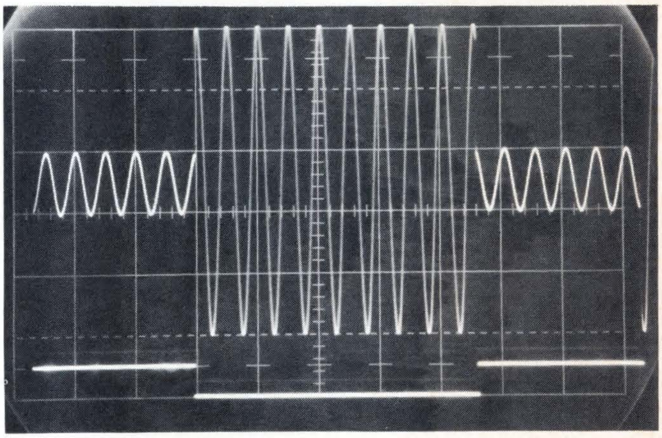


Fig. 2. Output voltage variation as a function of the digital control signal. Analog output voltage scale is 1 V/cm and the digital input voltage scale is 10 V/cm. The time scale is 200 μs/cm.

When the "digital input" is 5 volts, Q_1 is off and the gate of Q_2 is driven to -15 V. This negative gate bias causes the drain-to-source impedance of Q_2 to approach an open circuit. Now the gain becomes Eo/Ei = $(R_1+R_2+R_3)/(R_2+R_3)$. If R_1 and R_2 are still at 10 kΩ and 1.13 kΩ, respectively, and if R_3 is 8.87 kΩ, the resulting gain is 2. Fig. 2 shows the variation of the analog output as a function of the digital control signal. ■

Short-protected current limiter ignores inrush currents

Circuit Design No. 17

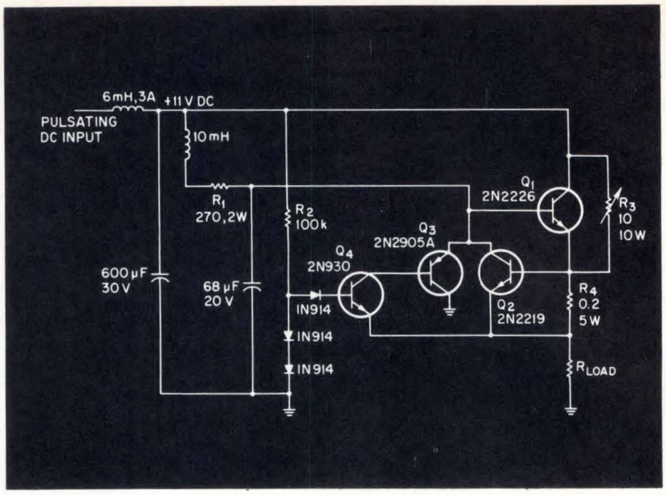
by L. G. Wright
Westinghouse Defense and
Space Center
Washington, D. C.

THE SIMPLE CURRENT limiter in the figure protects itself from overdissipation in case of a shorted output. It also distinguishes between a shorted output and capacitive or cold-filament loads which can momentarily look like shorts.

As soon as the current in the circuit exceeds the limit value, 3 A in this case, the voltage drop across the current-sensing resistor R_2 exceeds the cut-in voltage for the emitter-base junction of Q_2. This causes Q_2 to conduct, thereby limiting the base drive to Q_1.

If the load resistance is reduced to zero, Q_4 conducts and Q_3 saturates, thereby turning

(Continued on page 90)



Though protected against short circuits, this current limiter will deliver momentary high current to uncharged capacitors or cold filaments.

Q_1 off, and the current is limited by R_3 in series with R_2.

If the load is a filament, R_3 is necessary to allow the circuit to operate. If R_3 is omitted, then when power is applied, Q_4 conducts and Q_3 saturates, keeping Q_1 off. If R_3 is added, a "starting" current flows through R_3 and R_2 to the load.

R_3 is adjusted so the starting current is large enough to begin heating a cold filament. As the filament voltage increases to about 100 mV, Q_4 and Q_3 turn off, allowing the load current to rise to the 3-A limiting value. ■

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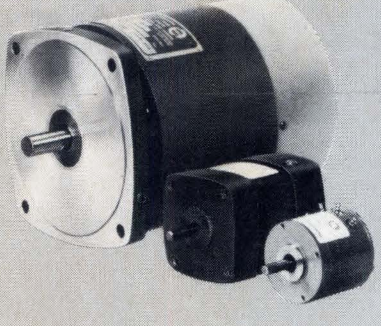

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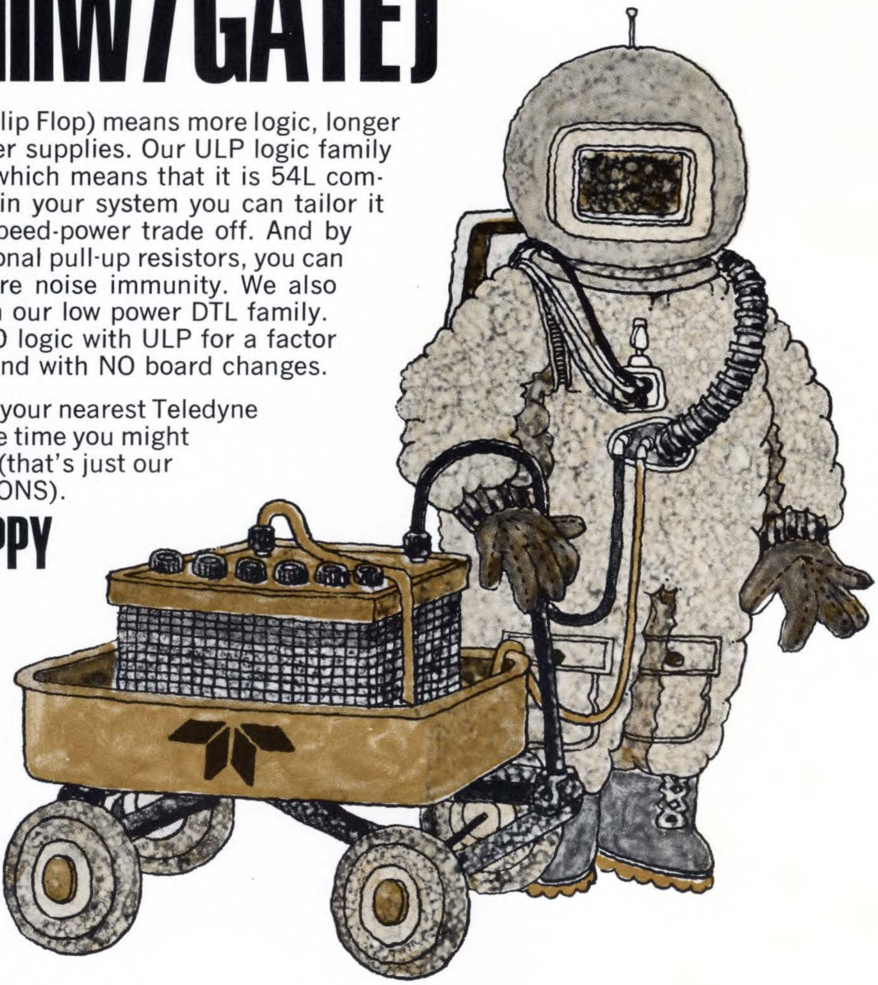

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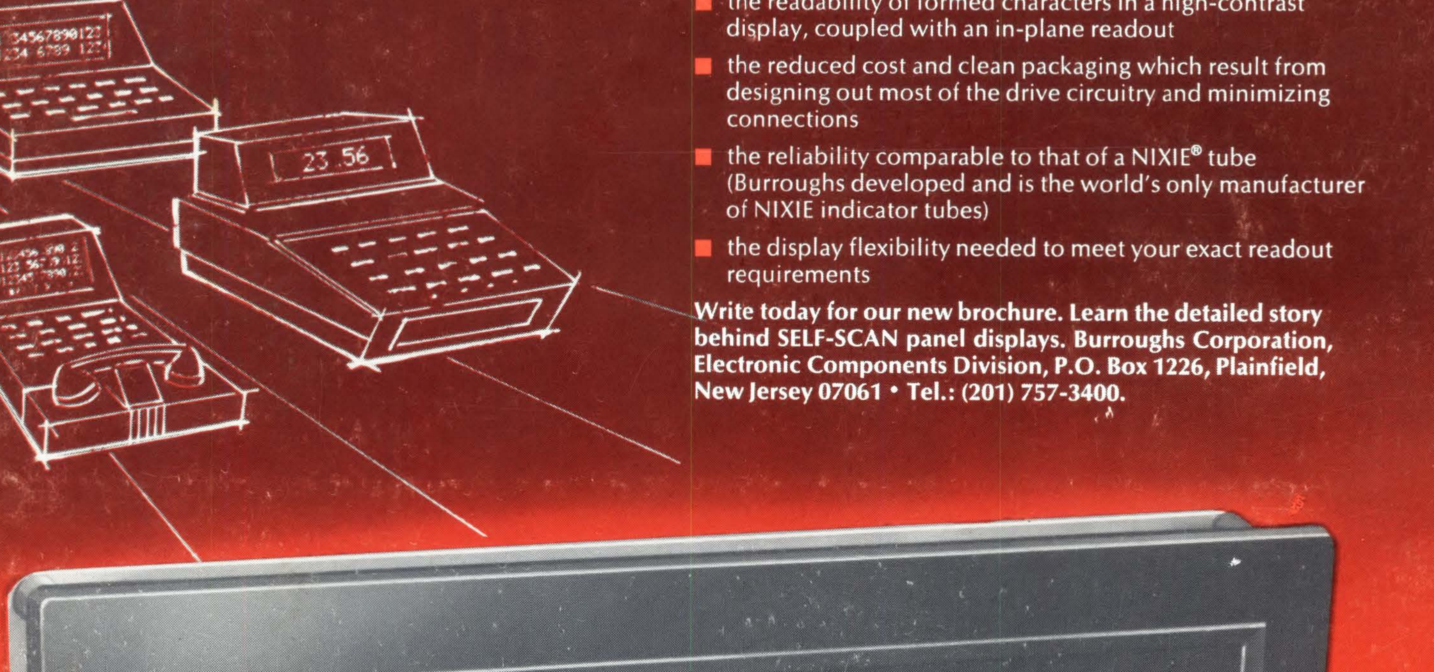

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