Radio astronomers probe the sky for mysterious sources of radio energy. The search for signals from distant pulsars, quasars and galaxies demands powerful new electronic tools. Interferometer antennas, on-line computers and sensitive autocorrelation receivers are helping scientists to map the universe. For details, see p. 25
If it only were so!

Wouldn’t it be nice if all you needed to make your measurements was one instrument? The modern oscilloscope comes as close as possible. Scopes today, for example, are being used as voltmeters, frequency meters, spectrum analyzers and a multitude of other instrument functions.

But… much as we hate to admit… it is not the universal instrument we’d like it to be! Occasionally, you need to use the 180 with other instrumentation.

How many times have you been frustrated matching a balanced input with an unbalanced output? Didn’t work too well, did it? This happens time and again when you use your scope as the core of your instrumentation set-up with several manufacturers supplying your instruments.

You won’t find this condition with the HP 180 system and HP manufactured equipment. Your HP field engineer has a complete line of more than 1500 compatible instruments from which you can design your measurement system.

For example, if you’re interested in low frequency wave analysis, ask your HP field engineer about the HP 3590A with automatic sweeping plug-in. It’ll make distortion, filter, noise, sideband, and spectrum measurements previously unattainable. You can see the results on your 180 CRT—and you can get a permanent plot of what you’ve seen with an HP X-Y plotter.

As you know, the accuracy and reliability of your measurement system depends on the quality and compatibility of your scope and your signal source. Your HP field engineer has any type of signal source you may need—power supplies, oscillators, pulse generators and function generators—sine, square, sawtooth signals.

Pick up your phone and talk to your local HP field engineer. Why? Because he’s a complete instrumentation analyst who can do a lot more than recommend a scope. He can recommend from a group of over 1500 electronic measuring instruments. Much as we both would like, the real measurement world is not supercalifragilisticexpialidocious—it’s seldom a simple one instrument buy. It may focus on a scope, but odds are you will need peripherals to make your system complete.

When your job depends on your measurements, when your reputation rests on your purchases, when you want maximum performance per dollar invested, your HP field engineer is a man you can rely on. Call him today.
Break Performance Bottlenecks

When you're looking for every bit of precision from a coaxial system, ordinary connectors become the limiting factors. You can break these performance bottlenecks with the GR900® connector and its family of precision components.

The GR900 connector, with unexcelled electrical characteristics in the dc-to-8.5 GHz frequency range, meets all specifications of IEEE 287, Standard for Precision Coaxial Connectors (50-Ω, 14-mm size). VSWR is guaranteed to be no greater than $1.001 + 0.001f_{GHz}$ for both single connectors and calibrated pairs. Its excellent VSWR and insertion-loss repeatability (typically within 0.03% and 0.002 dB, respectively, for a pair of connectors) allows extremely high accuracy in attenuation and other substitution measurements. It has a precisely defined electrical reference plane, an important feature for phase and impedance measurements. And its leakage of better than 130 dB below signal level makes it the "coolest" coaxial connector in use today.

GR900 stands for more than just a precision connector. It also designates an ever-growing family of precision coaxial components that includes adaptors, terminations, reference lines, attenuators, impedance standards, and tuners. Sixteen precision adaptors mate the GR900 to 10 other popular connectors, with even lower VSWR than found in their "natural" matings. They make it possible to take advantage of GR900 precision in measurements on systems and components fitted with other connectors. An immittance bridge and a slotted-line/recorder assembly bring GR900 precision to routine microwave measurements.

It's no wonder that so many GR900 connectors are replacing bottlenecks ... try them in your most demanding coaxial requirements.

For complete information, write General Radio Company, West Concord, Massachusetts 01781; telephone (617) 369-4400. In Europe: Postfach 124, CH 8034, Zurich 34, Switzerland.
Until now you couldn't make simple, automatic frequency measurements from 100 to 300 MHz without a special VHF plug-in. The extra plug-in was clumsy in the lab. And when switching plug-ins was impossible—as in automatic console systems—the VHF gap was unavoidable. Now two self-contained Systron-Donner counters span the VHF gap, operating automatically from DC to the microwave region.

Non-stop DC to 12.4 GHz. The VHF gap is filled by a built-in prescaler in this new Thin Line counter. The instrument operates just like a simple frequency counter across the board from DC to 12.4 GHz. You merely connect the signal and read the final answer on the display. Built with IC's to take only 1-3/4” of rack space and operable by remote control, it is the ideal instrument for automatic systems.

Non-stop DC to 3 GHz. New ACTO® plug-in with built-in prescaler carries this counter across the VHF gap to 3 GHz with fully-automatic operation. The new broadband plug-in can be replaced by others to raise the frequency range to 40 GHz, to measure very noisy signals, to measure FM and pulsed RF, to read time interval, etc. This is the best available wide-range laboratory counter—the root of a system that can accomplish nearly everything possible with counter instrumentation.

...two more reasons to check with Systron-Donner before you buy.

Send for Catalog.

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Information Retrieval Service Card inside back cover
The basic HP 3450A digital multifunction meter measures dc voltage and **true four-terminal** dc ratio. From there you make up your own unit with options to fit your needs now—then add other field-installable capabilities later to make your unit a complete “dodecameter” with five digit plus overrange digit readout for dc, ac and ohms measurements. Full autoranging capability for all functions is standard.

Add the AC Option and you can make **true RMS** ac measurements from 45 Hz to 1 MHz—and true four-terminal ac ratio. Add the OHMS Option for six four-wire ohms ranges including a 100 Ω range and ohms ratio. Put in the LIMIT TEST Option and you have HI GO LO and digital readout with two preselected limits for dc, ac and ohms— and ratio limit tests for ac, dc and ohms. That gives you a total of twelve measurement functions. But, that’s not all! Add the DIGITAL OUTPUT Option for nine columns of digital output to a printer. With the addition of the REMOTE CONTROL Option, you have added full programmability for systems use. The only option that must be factory-installed is the REAR INPUT Option for isolated front and rear input capability!

All this capability is contained in a rack-mountable cabinet only 3½ inches high. All-solid-state construction—including more than 220 integrated circuits—gives you increased reliability and lower maintenance. Turn the instrument on, and in seconds it’s ready to operate.

Call your nearest HP Sales and Service Office to learn how you can save time and reduce bench clutter with the one multi-function meter with twelve measurement capabilities. For full specifications, write to Hewlett-Packard, Palo Alto, California 94304. Europe: 1217 Meyrin-Geneva, Switzerland.

**DC VOLTAGE and DC RATIO**
DC voltage and dc ratio capabilities are contained in the basic unit. The 3450A uses a dual-slope integration technique and is fully guarded for excellent noise immunity at 15 readings per second on all five dc voltage ranges (100 mV to 1000 V). Input resistance is \(>10^{10}\) Ω on the lower three ranges and \(10^7\) Ω on upper ranges to minimize the effects of resistive loading of your sources. The four-terminal ratio on the 3450A gives you complete isolation between X and Y inputs so you can measure the ratio of two independent dc voltages. Four ranges (1:1 to 1000:1) of true four-terminal dc ratio are provided. Price of basic 3450A, $3150.

**AC VOLTAGE and AC RATIO**
(Option 001)
The 3450A with ac option is the only true RMS digital voltmeter with five-digit resolution for ac measurements...
from 45 Hz to 1 MHz. This greatly increases the capability previously available in a digital meter. You get true RMS responding measurements on four ranges (1 V to 1000 V). And the 3450A has a ±0.05% midband accuracy!

Adding the ac converter (Option 001) to your basic 3450A provides ac voltage and true four-terminal ac ratio. Price Option 001, $1250.

OHMS and OHMS RATIO (Option 002)
Six ranges (100 Ω to 10000 kΩ) of four-wire ohms measurements at 15 readings/sec are available when you add the ohms converter to the 3450A basic unit. A maximum of 1 mA signal current reduces self-heating in the resistor under test. The ohms converter also adds four ranges of ohms ratio. Price Option 002, $400.

LIMIT TEST (Option 003), DIGITAL OUTPUT (Option 004)
Install the limit test converter in your 3450A. Then you can use contact-closures-to-ground to preset two four-digit limits (with an additional digit for 20% overranging) and polarity for dc and dc ratio limit tests. When your 3450A has ac and ohms capability, plus the limit test option, you have ac limit and ac ratio limit tests, ohms limit and ohms ratio limit tests. HI, GO, LO front panel lights clearly indicate results of a test.

With the digital output (Option 004), you get 9 columns of information including HI, GO, LO limit test decisions in 1-2-4-8 “1” state positive BCD form. Buffered BCD output stores previous reading until printer can record it and allows DVM to immediately make another reading. Price Option 003, $350; Option 004, $175.

REMOTE CONTROL (Option 005)
For systems applications, remote control option installed in the 3450A allows full programmability. All programmable front panel controls can be locked out in remote operation. Price Option 005, $225.

REAR INPUT TERMINALS (Option 006)
Addition of this option provides a set of rear input terminals and a FRONT/REAR INPUT selector switch on the front panel. Price Option 006, $50.

THE INCREDIBLE DODECAMETER

Start with the basic meter...Order what you need now...
Add what you want later!
The listing below is the broadest line of single and dual MOS-FETs available anywhere. It is another example of our great "hang up"—which is to constantly extend General Instrument’s recognized leadership, not only in complex integrated circuitry and LSI, but in MOS-FETs.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>CHANNEL</th>
<th>DESCRIPTION</th>
<th>TEMP RANGE</th>
<th>CASE #</th>
<th>I(FORST) (VOLTS)</th>
<th>I (DRAIN) (VOLTS)</th>
<th>RDS (ON) (ohms)</th>
<th>ID (MA) @ 200 MHz</th>
<th>NF (dB) @ 200 MHz</th>
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</thead>
<tbody>
<tr>
<td>MEM511</td>
<td>P</td>
<td>Enhancement Power MOS-FET™</td>
<td>-65° to +125°C</td>
<td>TO-72</td>
<td>-4.0 -6.0 -0.2 -30</td>
<td>2,500 2.0 150</td>
<td>*</td>
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<td>-65° to +125°C</td>
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<td>-4.0 -5.0 -1.0 -30</td>
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<td>-1.5 10 *</td>
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<td>8.00 5.35</td>
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<td>-4.0 -7.0 -0.1 -50</td>
<td>950 0.3 700</td>
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<td>-2.0 8.0 *</td>
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<td>3,500 3.0 100</td>
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<td>1.5 15 0.5 20</td>
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<td>0.3 150</td>
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<td>0.3 150</td>
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<td>TO-72</td>
<td>1.5 40 1.0 20</td>
<td>7,000 @ 10 mA</td>
<td>0.3 50</td>
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<td>7,000 @ 10 mA</td>
<td>0.3 50</td>
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<td>20,000 .32 200</td>
<td>17 @ 200 MHz 3.0 @ 200 MHz</td>
<td>1.75 1.15</td>
<td></td>
</tr>
</tbody>
</table>

* With Gate Protection; ** Not Applicable

Contact your authorized GI distributor for complete information on General Instrument’s full line of MOS-FETs.

GENERAL INSTRUMENT CORPORATION • 800 WEST JOHN STREET, HICKSVILLE, L.I., NEW YORK

Start solving your FET “hang ups.” — Send for your copy of General Instrument’s free, colorful MOS-FET wall chart. Write to General Instrument Corporation, 600 West John Street, Hicksville, L.I., N.Y. 11802. (In Europe, to General Instrument Europe S.P.A., Piazza Amendola 9, 20149 Milano, Italy.)

INFORMATION RETRIEVAL NUMBER 8

THE GREAT MOS-FET "HANG UP"
From Monsanto:

130,000,000 discrete frequencies with almost perfect purity.

New “4th generation” digital frequency synthesizer achieves new level of perfection in signal generation with computer-aided design and I-C construction.

Monsanto’s new Model 3100A Digital Frequency Synthesizer obsoletes just about every present concept of general purpose signal sources.

Pick your frequency from 0.1 Hz to 1.3 MHz in 0.01 Hz steps. The result—signal purity you can get only from Monsanto, with a stability of one part in $10^9$ per day.

Other refinements include: internally supplied rapid or slow sweep and provision for external sweep; continuous control of output level over a 90 db range; provision for both amplitude modulation and frequency modulation or both, simultaneously; in the remotely programmable version, switching time is less than 20 microseconds.

You can put this better way of signal generation to work for you for only $3950.00, FOB West Caldwell, N. J.

For a demonstration, or for full technical details, call your local Monsanto Field Engineer now or contact us directly at: Monsanto Company, Electronic Instruments, West Caldwell, New Jersey 07006, (201) 228-3800.
FEATURES OF THE HIGH PRECISION POWER DIFFERENTIAL VOLTMETER

DRAW POWER AS YOU MEASURE VOLTAGE

The first and only differential voltmeter to furnish high stability power output while being used as a voltmeter... no need for a separate power supply.

PLUS ALL POWER SUPPLY SPECIFICATIONS

FEATURES OF THE METERED HIGH PRECISION POWER SOURCE

0.0005% PLUS 100 µV REGULATION

Best of any high stability power supply in this price range.

RIPPLE

35µV rms; 100µV p-p.

ACCURACY

0.01% + 1mV

2 METERS

Monitor both voltage and current simultaneously and continuously.

GUARANTEED FOR 5 YEARS

The only 5-year guarantee that includes labor as well as parts. Guarantee applies to operation at full published specifications at end of 5 years.

MULTI-CURRENT-RATED

for 30°C, 40°C, 50°C, 60°C— Covers temperatures most often encountered in laboratory work.

5 MODELS

With ranges of 0-10, 0-20, 0-40, 0-120, 0-250VDC— Wide selection of ranges to suit your specific needs.

ILLUMINATED DIGITAL READOUT MILLIMETER GANG DIALING

5-digital voltage dials with automatic decade switching provides convenient precise adjustment (200µV resolution over entire range).

MOUNT IN RACK ADAPTERS

LRA-1 ($60.00) or LRA-2 ($35.00). Rack adapter LRA-1 only is available with chassis slides mounted. Add suffix "CS" to rack adapter model number and $50 to price.

With this plug-in it becomes a ... High Precision Power Differential Voltmeter

With this plug-in it becomes a ... Metered High Precision Power Supply

LAMBDA'S LS SERIES

IS TWO INSTRUMENTS IN ONE

TWICE THE POWER

in a convenient ½-rack package.

ONLY 9½ HIGH

convenient half rack size for rack or bench use.

STABILITY

0.001% + 100µV for 8 hours

ALL-SILICON DESIGN

for maximum reliability

CONVECTION-COOLED

for convenience and reliability... no blowers or heat sinks.

REMOTE PROGRAMING

by changes in voltage or resistance for convenience in systems, test equipment and automatic equipment applications.

AUTO SERIES/AUTO PARALLEL

with Master-Slave tracking.

CONSTANT I/CONSTANT V

by automatic crossover

COMpletely PROTECTED

short-circuit proof; continuously adjustable automatic current limiting.

OVERVOLTAGE PROTECTION

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AC INPUT

105-132VAC, 47-440 Hz (derate dc output current 10% at 50 Hz). 205-265VAC at no extra charge. ("-V" option)

<table>
<thead>
<tr>
<th>Basic Non-Metered Model</th>
<th>Voltage Range</th>
<th>Max. Amps at Ambient of (1)</th>
<th>Metered Accessory Model</th>
<th>Metered Accessory Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS-511 0-10VDC</td>
<td>30°C 40°C 50°C 60°C</td>
<td>2.8A 2.5A 2.1A 1.7A</td>
<td>LS-FM1</td>
<td>$55</td>
</tr>
<tr>
<td>LS-512 0-20VDC</td>
<td>1.6A 1.5A 1.3A 1.1A</td>
<td>1.8A 1.6A</td>
<td>LS-FM2</td>
<td>$55</td>
</tr>
<tr>
<td>LS-513 0-40VDC</td>
<td>0.6A 0.5A 0.35A 0.25A</td>
<td>1.0A 0.9A</td>
<td>LS-FM3</td>
<td>$55</td>
</tr>
<tr>
<td>LS-515 0-120VDC</td>
<td>0.02A 0.025A 0.025A 0.025A</td>
<td>0.33A 0.25A</td>
<td>LS-FM5</td>
<td>$55</td>
</tr>
<tr>
<td>LS-516 0-250VDC</td>
<td>0.009A 0.008A 0.008A 0.007A</td>
<td>0.1A 0.09A</td>
<td>LS-FM6</td>
<td>$55</td>
</tr>
<tr>
<td>LHOV-4 3-24 3-24 3-24 3-24</td>
<td>0.09A 0.08A 0.07A 0.07A</td>
<td>0.1A 0.09A</td>
<td>LS-FM6</td>
<td>$55</td>
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<tr>
<td>LHOV-5 3-47 3-47 3-47 3-47</td>
<td>0.09A 0.08A 0.07A 0.07A</td>
<td>0.1A 0.09A</td>
<td>LS-FM6</td>
<td>$55</td>
</tr>
</tbody>
</table>

Notes: 1. Current rating applies over entire voltage range. Ratings based on 55-65 Hz operation. Derate current 10% for 50 Hz.
2. This price is for non-metered Precision Power Source. Addition of Metered Accessory Plug-In (next two columns) is necessary to have Metered High Precision Power Supply. Addition of Differential Voltmeter Accessory Plug-In to the basic model is necessary for the unit to function as a High Precision Differential Voltmeter.

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For further information on meetings, use Information Retrieval Card.

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MOS DELAY LINES

Integrated delay lines let digital system designers escape one of nature's small tyrannies—finding a match between system timing and the prefixed delay set by a glass or wire line's length, or a drum's rpm. In contrast, the input-output rates and storage time of an MOS shift register can be controlled individually to mate with any part of the system, be it instrumentation, data link, or computer.

The simplest, smallest, and least power-hungry delay lines are those made with MOS dynamic shift registers. Each silicon chip contains up to 200 storage nodes and the digital equivalents of input transducers and output detectors. All the designer supplies is a few microwatts of power per bit, clock signals, and data. Data can be shifted through the register at rates from near DC to greater than 15 MHz.

Lines that store only a few hundreds or thousands of bits are less expensive to build with MOS. The line in Figure 1a is just the series-connected halves of an MM506 dual 100-bit dynamic register and a few pull-down resistors. A dynamic register is run with a two phase clock, static registers require a single clock. At 700 KHz or less the clock driver (Figure 1b) can drive three or more MM506's or more than a dozen dual 16-bit static registers.

Delay duration is the product of the clock period and the number of bit-storage nodes in the registers. At 1 MHz, for instance, 200 bits would be delayed 200 microseconds. The longest delay possible in a dynamic register is determined by the minimum operating frequency, which ranges from about 10 to 25 Hz at 25°C to 10 KHz at 125°C. If the designer wants a shift rate in the megahertz

**FIGURE 1a. Series-connected Delay Line.**

**FIGURE 1b. Line Driver.**

**FIGURE 2. High-speed Register Uses TTL Logic to More Than Double MOS Shift Rates.**

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range, but wants to delay the data much longer than microseconds, he can inhibit the clock between loading and unloading of the register, or recirculate the bits at low frequency within the register while reading in and out at high speed. To overcome a data synchronization problem, data can be shifted in at one rate and out at another.

Dynamic registers would lose data if the clock is stopped indefinitely, since they don’t contain latching devices. Static registers do have latches, and can therefore operate at DC clock rates at any temperature. Their clocks can be stopped, allowing indefinite delays. The price of latching and other special features of static registers is less bit capacity per chip than dynamic registers.

Clock rates much higher than the normal MOS speed limit of 1 to 5 MHz can be achieved by operating registers in parallel or interfacing them with TTL logic. Both methods are combined in the Figure 2 delay line, which has been clocked at 16 MHz. The high-speed clock and data inputs are distributed among the registers so that the upper MM506 transfers and delays bits numbers 1, 5, 9, 13, etc., of the data. The next two MM506 halves handle bits 2, 6, 10, 14, etc. The bits flow through the registers at a 4 MHz rate. When the four bit streams are reassembled in the DM8020 NAND gate, the data rate of 16 MHz is restored.

In an all-MOS system, an MM506 register could be clocked at 1 or 2 MHz. The limit is largely imposed by RC time constants raised by the high impedances of adjoining MOS elements. The register runs at 4 MHz in the Figure 2 configuration because TTL gates are fore and aft of each MM506 half. Thus, each register is driven at its input by a low-impedance source and each output terminates in a low impedance, low level sensor, making the outputs more easily detected. The TTL-MOS interfaces are simply pullup resistors at the register inputs and pull-down resistors at the outputs.

Parallel series of registers also make a fine “drum” memory—that is, a rectangular array of synchronous delay lines (Figure 3). When less than about 200,000 bits of storage are needed, MOS drums are less costly than electromechanical drums. An MOS multiplexer (MM582) does the gating required to write a word into a register, recirculate it and access it upon command. With counter addressing, the contents of a specific register in a series can be read out without disturbing the contents of other registers.

If the data stored in a line is recirculated within several minor loops in each line, the access time will be reduced proportionately. The recirculating loops in Figure 4 were designed to allow the continual shuttling of data from TTL logic into the MOS delay loops, and back out into TTL logic. The loop lengths should be kept to multiples of one another—say 100 or 50 bits—to avoid clocking complications. Here, too, the few additional TTL gates and resistors allow the registers to be clocked at up to 4 MHz.

Since each register in a delay line can operate independently, almost any combination of the basic operating modes in different segments of a line can be used. For instance, assemble a delay line with variable taps, build buffer memories with selectable delays to facilitate time-shared processing of data from several sources, or match low-speed sensor data to relatively high-speed logic circuits. Numerous specialized design-options are also available, such as clock formats that permit asynchronous operation of registers in a line or keep power dissipation well below the normal levels.

Write for data sheets on MOS and TTL devices used in delay lines.

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<tr>
<th>Type 145D</th>
<th>Type 109D</th>
<th>Type 130D</th>
<th>Type 137D</th>
</tr>
</thead>
<tbody>
<tr>
<td>For operation to +85°C</td>
<td>For operation to +125°C</td>
<td>For operation to +175°C</td>
<td></td>
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<tr>
<td>Volumetric efficiency up to 210,000 µF-volts per cubic inch. For use in miniature commercial/industrial printed wiring boards, packaged circuit modules, and wherever else cost and space are prime considerations. Elastomer end seal capped with plastic resin insures against electrolyte leakage and lead breakage. Available in voltage ratings from 6 to 75 VDC.</td>
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For complete information on Type 145D Capacitors, write for Engineering Bulletin 3750 (Type 109D, Bulletins 3700F and 3700.2; Type 130D, Bulletins 3701B and 3701.2; Type 137D, Bulletin 3703A; Type 200D and 202D, Bulletin 3705B) to the Technical Literature Service, Sprague Electric Company, 347 Marshall St., North Adams, Mass. 01247.

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INFORMATION RETRIEVAL NUMBER 14

Electronic Design 26, December 19, 1968
Paraboloid antennas, such as these at the National Radio Astronomy Observatory, enable scientists to tune in on signals from galaxies $10^{10}$ light years away. P. 25

Voskhod spacecraft is a forerunner of the third-generation Soyuz spacecraft, which many believe will take Soviet cosmonauts on a trip around the moon. P. 36

Also in this section:

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Weight ............................................. 0.1 oz.
Temperature Range ........................... −25°C to +125°C
Resistance Tolerance .......................... ±20%
Element ......................................... Cermet
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News Scope

Senator Stennis predicts boost in military R&D

Military R&D programs that have been limping along on token funds for years should have easier financial going in fiscal 1970.

This is the conclusion drawn from remarks made by Sen. John Stennis (D-Miss.) in an exclusive interview with ELECTRONIC DESIGN.

The Senator is chairman of the Preparedness Investigating Subcommittee.

Asked to forecast the fortunes of specific military development programs that, for years, have been dragging along on limited funds, Stennis began by saying:

"The Nixon Administration will strongly support the military strength concept . . . particularly [for] new weapons." This is a concept the Senator has long supported.

Concerning strategic offense, Stennis says he will advocate accelerating research on the Advanced Manned Strategic Aircraft.

The program got a token award of $5 million in fiscal 1969—but no authorization for a contract-definition phase.

As for funding any new family of ICBMs, Stennis does "not think the time has come yet [to go beyond the research stage]. We have an abundance of Minuteman and Polaris missiles deployed," he says.

Concerning tactical warfare and continental defense, he says "We need the FX."

This is the high-speed Air Force fighter that will be designated the F-15. The new plane will succeed the McDonnell Douglas F-4 and will compete with the Soviet Union's Foxbat—rumored to be the world's fastest (Mach 2.8) operational fighter (see ED 16, News Scope, Aug. 1, 1968, p. 21).

Asked about the proposed Navy fighter, the VF-X, Stennis says: "The VF-X has a high emergency rating. It is needed to take the place of the canceled F-111B."

The five industry teams that have been preparing studies for the VF-X—which will eventually be designated the F-14A—will be narrowed to two this month. Cost of producing the F-14A will probably hit $2 billion. Follow-on models, plus a reconnaissance version, could put the entire program into the $10 billion class.

Concerning surveillance, Stennis says he plans to ask for money to revive production of the YF-12A interceptor. Only two of these Mach-3 planes, as far as is known, exist. A reconnaissance version of the Lockheed-built plane is being flown by the Strategic Air Command, under the designation of SR-71. The YF-12A could be used to collaborate with the proposed airborne watchdog, Awacs, that will be equipped with down-looking radar to detect incoming enemy bombers.

Concerning electronic warfare, Stennis says more electronic countermeasures are needed, on planes "that we use in several places, in- cluding the Mediterranean."

Asked about the Grumman EA-6B Intruder, which was not funded in fiscal 1969, he says: "It will move. It's something that's really needed."

The EA-6B is equipped with a pod-mounted tactical jamming system that generates false signals and jams enemy radars as it escorts fighters and bombers to their targets. The twin turbojet is designed for both carrier and advanced-base operation.

Concerning naval superiority, Stennis' reaction to the Soviet fleet's presence in the Mediterranean is that the U.S. "must be there, quick, with a large, strong fleet that leaves no doubt about superiority. That's the way to avoid trouble." He points out that "more money will probably be needed for antisubmarine warfare" and that "more submarines are [also] needed in the Mediterranean." He says that he will advocate building "at least a few more attack submarines beyond those now planned, the last of which would be rolled out in 1970, unless more are ordered."

Looking beyond the "quiet" submarine, work on which has already begun by General Dynamics, Stennis says that a "fast" submarine is also under active consideration.

"I think a family of fast submarines will mature," he says. Concerning the cost of submarines: "They used to be about $30 million each. Now, we're projecting submarines that will cost $180 million each."

Concerning army hardware, Stennis reveals that he is enthusiastic about the new Main Battle Tank, MBT-70, being built as a joint U. S.-West German effort.

New king of computers unveiled in Wisconsin

The new king of computers, Control Data Corp.'s CDC-7600, is four to eight times faster than its predecessor, the CDC-6600.

Described as "the world's most powerful computer," the 7600 was unveiled at the company's laboratory in Chippewa Falls, Wis. It features a 27.5-ns logic clock cycle, compared with 100 ns for the 6600. It will execute instructions, on the
average, five times faster.

The 7600 has a hierarchy of memory: 65,536 words (60 bits) in a small central-processing-unit core memory and 512,000 words in a large core memory in the same unit.

The price for the new king is headier, too: It sells for $9 million to $15 million, or rents for $190,000 to $300,000 a month. This compares with $4.5 million and $85,000 a month for the CDC-6600.

Remarkably, the 7600 is made completely from discrete components.

"There's something basic you don't read in the ads for integrated circuits," super-computer designer Seymour Cray confided to reporters at the unveiling. "The process used in making ICs inherently compromises performance, mostly manufacturing tolerance and speed. The payoff should be cost, and that's why ICs are taking over in small- and medium-sized computers."

Tinted-blue glass panels and walnut metal trim distinguish the 7600 from other machines. It has 14 panels, only two of them being the central processing unit. There is no facility for the central processor to connect with input-output peripherals. Six peripheral units—separate computers—are provided for this.

Six 7600s have been ordered by Government agencies, and the first is due for delivery early next year to the Lawrence Radiation Laboratory at Berkeley, Calif.

Digital system speeds jetliner communications

Ordinarily it would take about a minute for the crew of a flying jetliner to radio to airline headquarters such information as the plane's identification number, its position, the engine performance and other data. A new air-to-ground digital communications system being tested by Pan American World Airways does the job in 0.6 of a second.

Called Digicom, the system is being tried out on a 707 jet on flights between New York and the Caribbean. Upon cockpit command, a binary-coded digital message in the form of a keyed, phase-shifted audio tone is transmitted from the airliner to a Federal Aviation Administration ground station at Avalon, N.J., and a Pan Am station at Kennedy International Airport. The message is then relayed by land line from the FAA station to Pan Am's message switching center in Cedar Rapids, Iowa, and then back to the Pan Am Building in New York. Here, the message is printed on a teletype and also displayed on a cathode-ray tube. A line from Kennedy Airport goes directly to the building.

In addition, analog data taken from engine sensors is converted to a binary-coded decimal signal and is also transmitted to the Pan Am Building for system evaluation.

11 telescopes in space offer new view of stars

The Orbiting Astronomical Satellite launched on Dec. 7 is the largest, heaviest and most automated scientific satellite ever launched by NASA.

The 11-telescope space package is expected to provide astronomers with data on young hot stars in the ultraviolet spectrum, and may also provide clues to the origins of the universe. The observatory was launched into a circular orbit some 480 miles above the earth.

In the past, acquisition of ultraviolet data from stars has been a time-consuming effort, mainly because the radiation does not pass through the atmospheric layer that surrounds the earth.

The 4400-pound satellite, which stands 10 feet tall and spans 21 feet with its eight solar panels extended, was built by Grumman Aircraft Engineering Corp., Bethpage, L.I.

The stabilization and control system, built by General Electric, Valley Forge, Pa., enables a telescope to lock onto a star by providing a course pointing accuracy of one minute of arc. This pointing accuracy, which must be maintained within 15 arc seconds for 50 minutes, is equivalent to zeroing-in on a person's eye from 500 feet, then holding steady for up to an hour and conducting a detailed study of its color and brightness.

The star-tracking system consists of six small telescopes which are capable of locking onto starlight and converting it into satellite-orienting commands.

Computers will link California crime net

The fight against crime in the state of California will soon be time-shared.

A $5-million police communications network, scheduled to be fully operational by October, 1969, will allow a policeman on duty anywhere in the state to check—by radio or land line—the legal status of suspects in both state and national crime files and to get back an answer at computer speeds.

The new California Law Enforcement Telecommunications System will link more than 450 state law-enforcement agencies to computer crime files in both Sacramento, the state capital, and Washington, D.C. It will replace a state teletype system that was established in 1931.

The centers of the high-speed system will be a complex of four RCA Spectra 70/40 computers, which will be placed in pairs at opposite ends of the state—Los Angeles and Sacramento—to protect the system against interruption by local disaster.

A policeman in the field will query his dispatcher by radio or telephone. The latter, in turn, will transmit coded inquiries over the network to data banks maintained by the state's Depts. of Justice, Motor Vehicles and Highway Patrol, and to the FBI's National Crime Information Center in Washington.

The computers will not only check their own files; they will also talk to each other. Information will be displayed at the dispatcher's terminal.

The system will be a cooperative effort: The state will provide the computers and switching-center personnel; the local agencies will set up the equipment that will link them to county terminals.
How to use the Singer model SSB-50-1 Spectrum Analyzer to monitor tone level in a multiplexed communications system

A high resolution spectrum analyzer allows monitoring of any number of multiplexed channels without repetitive meter readings or painstaking adjustments. As a first operating step, the analyzer's accurately calibrated frequency dial is precisely tuned to the center frequency of the channel.

A selector knob sets the frequency scale in one of five settings from 15Hz/division to 1.4KHz/division. Interlocked circuit functions in the analyzer automatically optimize the display for any setting of the frequency scale.

... but often a subcarrier level changes with a resulting communications malfunction. This display on the CRT shows that one subcarrier's level is down 12 db. Another is over the predetermined acceptable level.

Because the entire spectrum is continuously visible on the display, a lost channel shows up instantly... A frequency range of 10Hz to 40 MHz makes the Model SSB-50-1 an invaluable tool for this application and for general laboratory or field use.

The high resolution of the Singer Model SSB-50-1 provides this clear display of the multiplexed channel. The amplitude of each subcarrier is shown as a function of frequency. The display demonstrates complete operational readiness at a glance...

Model MF-5/CA-5-1 Spectrum Analyzer display section (features high resolution/low distortion and 70 db dynamic range)

Model TTG-3 Two-Tone Audio Generator 20-20,000 Hz frequency range and IM distortion of less than 70 db for testing single sidetband transmitters

Model REC-2 Range Extending Converter (extends the tuning range down to 10 Hz)

Model RF-8 Tuning Head (highly stable LO with coarse and vernier two speed tuning from 2 MHz to 40 MHz... usable to 200 MHz)
What could you do with a TO-5 size commercial relay?

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A brand new industry first from Deutsch-Filtors Industrial Products. The TC is a one amp, DPDT commercial relay with a clear dust cover, and sensitivity as low as 235 milliwatts. With a wealth of knowledge in relay design to back it up.

Are the ideas already coming to you? We'll see to it that a sample does too. Just drop us a line on your letterhead. And then see what you can do.

"Available immediately from COMPAR STOCK"
NEW AIDS FOR RADIO ASTRONOMY

Indirect design piercing celestial 'barriers'

'Brute force' approach to observation of universe is giving way to ingenious computer techniques

Elizabeth deAtley
West Coast Editor

The breakthrough, as Dr. Gerrit L. Verschuur recalls it today, was almost anticlimactic. It came shortly after 10 a.m. last July 4 while the noted radio astronomer was in his office at the headquarters of the National Radio Astronomy Observatory in Charlottesville, Va.

Dr. Verschuur was poring over a string of asterisks on a long strip of computer paper. For seven years he had been scanning readouts like this, looking for signs of a magnetic field in the Milky Way Galaxy. Suddenly his attention focused on a bulge in the pattern of asterisks.

"You know," he said quietly to two colleagues. "I think I've got it at last. There seems to be something here."

What he was looking at was a representation of radio waves emitted by hydrogen gas some 10,000 light years away. He saw a split in the absorption spectrum of the waves that would enable him to measure, for the first time in the history of radio astronomy, the strength of magnetic fields in our galaxy. It would enable radio astronomers everywhere to check their calculations of the strength of these fields and would give them new clues to how stars are born.

The delicate measurement was made possible by the development of a new 413-channel digital autocorrelation receiver. Before this receiver was put into operation at the observatory last May, no receiver anywhere was capable of resolving small enough bands of frequencies to detect such minute splitting in the radio waves.

Dr. Verschuur's discovery is typical of advances being made everywhere in radio astronomy through innovations in equipment design.

The old "brute force" solutions—building bigger antennas and more sensitive receivers—have reached practical limits. Now, electronic engineers are resorting to ingenious, indirect solutions, made possible by the computer. As a result, they are designing more sensitive equipment than ever before.

At the National Observatory installation in Green Bank, W. Va., for example, radio astronomers are taking radio intensity "pictures" of regions of the sky that are invisible to optical telescopes. At Cornell University's Ionospheric Observatory in Puerto Rico, they are resolving pulsar signals—those periodic pulses that come from unidentified sources in space—into subpulses of much higher repetition rate. In Europe and this country, scientists are synchronizing their telescopes in a single system trained on quasars—the very luminous radio galaxies that seem to be located at the outer reaches of the universe, some $10^{16}$ light years away.

Antenna arrays developing

The indirect engineering approach is yielding important results in antenna design. The resolving capabilities of a very big antenna dish can now be approximated by two or more small dishes spaced at intervals. The radiation collected at each spacing is processed by computer to produce a radio-intensity picture of the source at which the dishes were pointed. In other words, two small dishes and a computer can do the job of one enormous dish. The greater the separation between the dishes, the higher the resolution obtained. But until recently, the separation has been limited by the lengths of cables that link such installations.

This limitation has been dramatically overcome in the transcontinental or transocean long-baseline interferometer, developed by the National Radio Astronomy Observatory, the Massachusetts Institute of Technology, Cornell University and the Onsala Space Observatory in Sweden. In this type of system, measurements are made at two or more widely separated radio antennas that have no communication link between them. At each site the received signals are processed and digitally recorded. Atomic clocks, which provide equal frequencies for tuning the receivers and controlling the sampling rate, are synchronized by LORAN C pulses. These pulses are emitted at precise intervals from stations throughout the world. The information obtained from the various antennas is stored on magnetic tape and sent to a central computer for processing.

Up to four telescopes have been used in a common system: one at Westford, Mass., another at Green Bank, W. Va., a third at Hat Creek, Calif., and a fourth at On-
(Radio astronomy, continued)

sala, Sweden. An interferometer that spans the Pacific between the United States and Australia is planned for the near future. Thus the diameter of the earth now becomes the limit on baseline length. Radio astronomers are already studying methods for space-borne interferometers that could overcome this limitation.

Minute resolutions result

Existing long-baseline interferometers have increased the obtainable resolution by two orders of magnitude, and this is expected to jump to three with the longer baselines planned for the future. With telescopes in Sweden and West Virginia, resolutions of up to 0.0006 seconds of arc have been obtained. Radio astronomers compare this to the angle that would be subtended by a Volkswagen if the car were placed on the moon and viewed from the earth. To achieve comparable resolutions of optical wavelengths, the 200-inch telescope at Mount Palomar, Calif. —the world's largest optical telescope—would have to be several hundred feet in diameter.

Some remarkable discoveries are being made with these new systems. Consider the case of quasars, or quasi-stellar radio sources, which have puzzled astronomers since their radio emissions were first studied in 1962. They appear to be galaxies, possibly as far away as $10^{10}$ light years, with a luminosity equal to 1000 average galaxies. More puzzling yet, they seem to be considerably smaller than other galaxies—a few light years across, compared with a hundred thousand light years or more. They are so small and so far away, in fact, that their precise angular size has been impossible to determine. Now, with the long-baseline interferometer, these small, distant objects are being resolved. Recently, for example, it was found that most of the radio emissions from the 3C273—the brightest quasar and the first one discovered—come from a region in its center that subtends an angle of less than 0.0006 seconds of arc, and therefore seems to be less than a light year across.

The 1000-foot spherical dish at the Arecibo Ionospheric Observatory in Puerto Rico has a movable feed. It is being used for pulsar study because these strange pulsations, which extend from 40 to 2300 MHz, are strongest at the lower frequencies, for which this dish was designed. The observatory is operated by Cornell University under a contract from the Advanced Research Projects Agency of the Defense Dept.

Possible future applications for this new type of system are far-flung.

"Geologists may be able to check the theory that continents are drifting, by directly measuring the drift rate," says Dr. Kenneth Kellermann, a radio astronomer at the National Observatory who helped set up the long-baseline project. This measurement should be possible, he says, because the distance from one telescope to another can now be determined to within a few centimeters by taking the data obtained with a common radio source at the two telescopes and processing it in a central computer.

Today computers are being used to steer the telescopes, translate antenna position into convenient astronomer's coordinates, process signals, reduce and analyze data, and make theoretical models to describe observed phenomena.

The search for new pulsars has greatly accelerated this trend toward computerization.

"For the first time in the history of radio astronomy," says Dr. Sander Weinreb, head of instrumentation at the National Observ-

The origin of pulsars

Pulsars may be burned out neutron stars, according to Dr. Frank D. Drake of Cornell's Arecibo Ionospheric Observatory in Puerto Rico.

Theoreticians have long predicted the existence of these extremely dense stars and estimated them to be about 10 miles in diameter—much too small to be observed by existing optical telescopes. They have predicted that objects of such density and size would oscillate at a rate of about 100 Hz if set off by some kind of explosion—possibly in the surface gases. This rate—about 100 Hz—is the repetition rate of subpulses that are often observed traveling across the oscilloscope screen superimposed on the much larger main pulses.

The theory is that the neutron star is oscillating at 100 Hz and rotating typically once a second. One can imagine, then, that a hot spot on one side of the star is beamed at the earth once a second, making it possible to observe the 100-Hz oscillations of the star only at these times.

Neutron stars are believed to be remnants of a burned-out star whose internal pressure is no longer able to support its outer layers.
Normal Mode Noise Clouding Your Low-Level DC Measurements?

Not Here! The HP 3460B was introduced as a super accurate, 5-digit voltmeter. To make 0.004% of reading accuracy practical, a dual technique was utilized—integrating and potentiometric. The integration technique in itself gave a high common mode rejection of 160 dB at dc.

Now HP has added a filter option which is a programmable filter that cancels out frustrating noise picked up by leads and input devices. This filter effectively adds 26 dB of ac normal-mode rejection at 60 Hz to rejection provided by integration. Now you can accurately measure low level dc signals with as much as 100% of range (peak) ac riding on the measured dc signal.

Other features of the 3460B include a sixth digit for 20% overranging, automatic polarity selection, four ranges from 1 V to 1000 V, guarded inputs, 15 readings per second (without filter) fully programmable functions with BCD output for systems compatibility.

To make the 3460B a multiple function DVM, add the HP 3461A AC/Ohms Converter-DC Preamplifier. Measure 0.1 V dc voltages with 1 µV sensitivity, 50 Hz to 100 kHz ac measurements with 10 µV sensitivity, and resistance measurements from 1 kΩ to 12 MΩ with 10 milliohm sensitivity on lowest range.

If you're interested in a precision DVM, look up the 3460B in your HP catalog. If you're interested in adding the filter option to pick low level dc out of noisy environments, call your local HP field office. (Price HP 3460B, $3800; 3461A, $2400. 3460B Option 002 or 003 is required for operation with 3461A. Price option 002 or 003, $150. Filter option prices on request.) Or for a data sheet, write to Hewlett-Packard, Palo Alto, California 94304. Europe: 1217 Meyrin-Geneva, Switzerland.
(Radio astronomy, continued)

"the weakest signal that can be detected depends directly on the computer time available."

What are these strange pulsations, which come from regions in the sky where optical telescopes find nothing? Why does it require so much computer time to detect their presence?

A pulsar emits a series of pulses that occur at very precise intervals. Dr. Michael Davis, radio astronomer at the National Observatory, says that the average period of the first pulsar, which was discovered at Cambridge, England, about a year ago, "has not changed by one part in $10^{14}$—this is pushing even the hydrogen maser clocks to the limit of their accuracy."

The first pulsar occurs at intervals exactly 1.33730113 seconds apart. Ten other pulsars are now known, each with its own very precise pulse rate. In addition a new pulsar-like aperiodic pulse was detected in the Crab Nebula early in November. Individual pulsars have been measured over a very wide band of frequencies (40 MHz to 230 MHz).

The detection of pulsars is complicated by several factors:

1. Although typically pulsars occur at very precise intervals, the strength of the pulse may vary greatly from one interval to the next. At some intervals, the pulse is very strong and at others it is too weak to detect. However, when a pulse occurs at all, it occurs at the precise time interval that is characteristic of that particular pulsar.

2. Characteristically pulsars are much stronger at low frequencies than at high.

3. Individual pulses associated with a given pulsar may contain "sub-pulses" of much higher frequency (on the order of 100 Hz).

4. The velocity of electromagnetic radiation is slowed as it travels through ionized gas in interstellar space. The long wavelengths are slowed more than the shorter ones, and thus arrive at the earth later. This effect, known as dispersion, causes a differential delay in the arrival time of the same pulsar at different frequencies. At 2300 MHz this delay may be only a few microseconds, whereas at 40 MHz it may be as much as 40 seconds.

To identify a pulse repetition rate at a given frequency as a particular pulsar requires subtle cross-
Listen to what the new Bendix Model BHA-0002 audio amplifier can do for you.

This 1" x 2" x 5/16" package actually costs less to use than discrete components—and outperforms them as well. It has 25Hz-20KHz frequency response, a voltage range of 14 to 40 volts, power gain of 55db, THD less than 1%, high-power operation to 100°C case temperature, and 350 mV input for $P_o = 15$ watts.

The BHA-0002 offers some exciting possibilities for stereo amplifiers, transceivers, PA systems, phonographs, musical instrument amplifiers, intercoms and movie projector/sound systems.

It's one of a whole new family of thick-film power circuits from Bendix. These additions include two more audio amplifiers, 2W and 5W (see chart), plus a new Darlington, bridge rectifier and power driver module for industrial applications.

It's a lot of power for a lot of applications. From the real power in power: Semiconductor Division, The Bendix Corporation, Holmdel, New Jersey 07733.

### POWER AUDIO AMPLIFIER CIRCUITS

<table>
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<th>Part Number</th>
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<th>Input Voltage (mV)</th>
<th>Frequency Response (Hz)</th>
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<td>15</td>
<td>14 to 40</td>
<td>350</td>
<td>25 to 20K</td>
</tr>
</tbody>
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Would a 15W power IC audio amplifier be music to your ears?
(Radio astronomy, continued)
correlation techniques. As Dr. Weinreb puts it: "You have to correlate the signal with a possible pulsar having a certain rate and dispersion. You've got to do this for all possible rates—all the rates that are reasonable for pulsars and all the dispersions that are reasonable—and that is a very long computing job."

Not only is the computer being used more and more to help the radio astronomer search for and interpret signals that are buried in noise; it is also helping the equipment designer, by making it practical for him to use the indirect solutions to old problems.

The brute-force approach to the design of a good radio astronomy antenna is to build an enormous, very smooth paraboloid dish, freely adjustable in two coordinates and yet so rigid that it will hold its paraboloid shape to within a very fine tolerance as it tracks a point in the sky. Why is such a dish a good radio-astronomy antenna? What does it have that the dipole, for example, does not have?

For one thing, it has a large collecting area. This gives the big dish two essential qualities: high resolving power—the ability to distinguish two objects separated by a very small angle of arc—and high sensitivity—the ability to detect weak signals. Both resolving power and sensitivity are inverse functions of wavelength; so the dish should be even bigger for long-wavelength radiation than for short.

Although not all existing big dishes are paraboloids, this shape is desirable because parallel rays from distant radio sources will strike the paraboloid surface and converge in phase at the focal point. This paraboloid surface must be very smooth, because any slight irregularities in it will deflect the shorter wavelengths away from the focal point. For the same reason, if the dish bends slightly out of shape as it tracks a source in the sky, the shorter wavelengths will be deflected away from the focal point. Thus the smaller the wavelengths received, the more perfect the shape of the dish must be.

There are practical limits, of course, to the size of such a dish. The bigger it is, the heavier it is and the more it will bend out of shape when moved about.

Scientists at the National Observatory estimate the maximum practical size for an antenna dish to be about 400 to 500 feet in aperture diameter. And, of course, the cost of building a fully steerable dish close to this theoretical limit is so high that no one has been willing to pay for it. The biggest fully steerable antenna in the world is a 250-foot-diameter paraboloid dish at the Jodrell Bank Observatory, University of Manchester, England. Most dishes like it are less than half its diameter. And, unfortunately, existing dishes provide far less resolving power than a good optical telescope (Fig. 1) and far less than the radio astronomer needs for many purposes.

The 'aperture synthesis' method

To solve this problem, the equipment designer is turning more and more to an indirect approach known as "aperture synthesis." In its simplest form, aperture synthesis is a method of synthesizing the collecting area of a large dish by measurements with an interferometer which consists of two dishes, one fixed and one movable.

In the case of the big dish, the incoming waves that fall on each elemental area add at the focal point. In the aperture-synthesis approach, the measurements made with the two dishes in different positions are summed by a computer.

The two antennas of the radio interferometer are separated by a base line of given length. Radio waves impinging on the antennas are fed to a summer and integrator. The phase difference in the waves from the two antennas, as they arrive at the summer, produces fringe patterns analogous to those of an optical interferometer. These fringe patterns vary, depending on the base line length, the position of the source and the distribution of radio intensity across the source.

A source is tracked over a period of time, fringe patterns are recorded at frequent intervals during this time, and this information is processed by computer. A radio intensity contour map of the source (see cover photo) can be obtained by repeating this procedure for many different base line lengths and by taking the Fourier transform of all data collected.

The more dishes there are in an array, the faster the data can be collected. For this reason, multi-dish arrays are becoming more and more popular.

36-antenna array planned

One of the largest—now in the design and proposal stages at the National Observatory—is an equiangular Y configuration of 36 paraboloid antennas, each 82 feet in diameter and transportable on railroad tracks. Each arm is 15 miles long. The system includes 630 receivers—one for each pair of antennas.

In eight hours this array will make a radio-intensity contour map containing 14,000 dots at any of four different resolutions: 1, 3, 9 or 27 seconds of arc, depending on the size of the map. For example,
LOGIC FOR TUNG-SOL DIGIVAC S/G

This is a monolithic integrated MTOS circuit. It contains (1) decade counter, (2) storage register, (3) decoder/driver, and (4) appropriate input, output, and command terminals. Two important features are provision for leading zero blanking and false count indication.
Doppler shifts are the key

Mapping the brightness distribution of a source and pinpointing its location in the sky are essential to an understanding of the nature of the source. However, this information tells the radio astronomer little about its contents and nothing about its speed toward or away from the earth. To determine these things, he must study the Doppler shifts in radio frequencies. Radiation from a source that is moving away from the earth, for example, is Doppler-shifted toward the longer wavelengths by an amount that is proportional to the speed. Like the spectral line of optics, certain radio frequencies are known to be emitted or absorbed by certain elements or molecular compounds under certain conditions. If the radio astronomer can identify one of these known emission or absorption frequencies, he can determine the amount of the shift and thus the velocity of the source.

The first line detected in the radio wavelengths was the H line, which is emitted or, under certain conditions, absorbed when the magnetic fields of the hydrogen proton and electron change their relative directions. This was a discovery of great importance to radio astronomy, since neutral hydrogen constitutes a major portion of interstellar matter and it is invisible to optical telescopes. Since that time several other spectral lines have been isolated in the radiofrequency range. Many such lines coming from sources at various distances from the earth, traveling at various speeds, appear as a bulge on the frequency spectrum (Fig. 2).

For spectral line analysis, the radio astronomer needs a receiver that can determine the average power in each of a number of very narrow bandwidths that make up a larger bandwidth of interest. The power in each narrow band varies, first of all, because of noise from the atmosphere and the receiver itself. It varies further because the atomic and molecular transformations that emit a particular frequency fluctuate randomly about that frequency. The receiver must average the power at each narrow bandwidth and plot this average power over the desired larger bandwidth. In attempting to design such a receiver, designers first used a brute force approach: the multi-filter receiver. In this type of receiver, the output from the superhet is fed to several narrowband filters in parallel. The output of each filter is averaged and displayed as a single point on the frequency spectrum.

The trouble with this technique is that some frequency bulges are wider than others, and most are Doppler-shifted by an unknown amount. Thus the radio astronomer needs to observe over a wide band of frequencies to locate the spectral bulges before he closes in on one or more for scrutiny. For this work, he needs different amounts of resolution and therefore, with the multi-filter receiver, a different set of narrowband filters for each bandpass.

Plainly some more versatile approach was needed, and Dr. Weinreb of the National Observatory looked to the autocorrelation function, digital processing and computer techniques to build the first radio astronomy autocorrelation receiver in 1961.

In this type of receiver, the desired resolution is obtained not by expanding the frequency spectrum directly, but by forming the expanded autocorrelation function in the time domain and converting it to the frequency domain by Fourier transformation.

The incoming signal is sampled at a certain rate that is inversely proportional to the desired resolution. These samples are used to create the autocorrelation function. Assume a receiver with N channels at the output (Fig. 3). The incoming signal is divided into separate pulse trains: One contains frequency information, and the other amplitude information. The pulse train that contains frequency information is sampled at a rate of 1/\tau per second (see point X in Fig. 3). Every \tau seconds a sample is stored in an N-bit serial-to-parallel shift register until N such samples have been accumulat-
ed in the register. The \( N + 1 \)th sample—call it \( f(t) \)—is multiplied simultaneously by each of the preceding \( N \) samples. Then \( f(t) \) is stored in the first shift register bit. This process of multiplying the present sample by the \( N \) preceding samples is repeated over a 10-second interval, during which the products are summed and averaged. The amplitude information is then added, forming the autocorrelation function of the signal 
\[
\int f(t)f(t+\tau)\,dt
\]
expanded in the time scale by an amount that depends on the sampling rate. For example, if the sampling rate is 20 MHz, the period \( \tau \) between samples is 50 ns. If we assume the number of channels (\( N \)) is 400, the scale of the autocorrelation function is 400 x 50 ns = 20 \( \mu \)s. If the sampling rate is reduced to 10 MHz, the period \( \tau \) is 100 ns and the scale of the autocorrelation function becomes 400 x 100 ns = 40 \( \mu \)s. The autocorrelation function is then converted to the desired power spectrum by Fourier transformation.

The square-wave generator and sync detector are used to subtract the background radiation, so that the desired spectral radiation will be displayed on a base of zero (Fig. 2).

The latest model, a 413-channel receiver designed by Arthur M. Shalloway and Robert Mauzy of the National Observatory, can display simultaneously the entire bandwidth of interest in 29 channels plus a narrowband of interest, much expanded, in 384 channels, or two bands in 192 channels. This receiver is considered by officials of the observatory to be the fastest digital system of its size ever built. Its maximum sampling rate is 20 MHz.

Bibliography:
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The key CTµ,L characteristic is non-saturating logic. That means you get fast gate propagation delay (typically 3nsec) with slow rise and fall times (typically 6nsec). So, there's no need for transmission lines or complex packaging. You can build an entire computer with normal two-sided circuit boards. Also, CTµ,L can handle signal swings as large as 3V. It also provides typical noise immunity of 500mV.

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MSI CTµ,L will be out before the year ends. CTµ,L-II will be out even sooner, offering improvements like gate propagation delay of 1.5nsec. (typical, loaded) and a buffer and
An inverter with propagation delays of 5nsec, compared with 12nsec in standard CTµL. And, the new MSI and CTµL-II circuitry will interface beautifully with all these standard CTµL devices:

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<th>Device</th>
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<td>9953 Triple AND Gate</td>
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If you want CTµL-II in sample quantities, call Fairchild. If you want standard CTµL in production quantities, call a Fairchild distributor. He has everything you need to build any computer, Even a Computer.

Fairchild Semiconductor / A Division of Fairchild Camera and Instrument Corporation / 313 Fairchild Drive, Mountain View, Calif. 94040 (415) 962-5011 / TWX: 910-379-6435

of LSI admits there's another way:
Three ways to put a Russian on the moon

Craft may be sent directly, be assembled in space or employ a lunar-surface rendezvous approach

Charles D. LaFond
Chief, Washington News Bureau

Space scientists in the United States have believed for some time that the Soviet Union has three options anytime it wants to send a man to the moon.

It can, with a limited-thrust launching vehicle, send the moon craft aloft in sections and assemble the sections as they orbit the earth. Once assembled, the craft would have sufficient thrust to carry it to the moon and back.

A second approach, suggested in October by Dr. Wernher von Braun, director of the Marshall Space Flight Center, Huntsville, Ala., calls for a lunar-surface rendezvous.

The Russians would first launch an unmanned vehicle to the moon and soft-land it. It would have stored propulsive power on board, and once it is checked out by telemetry, a second vehicle, with cosmonauts, would be sent to the moon. Landing close to the first spacecraft, the cosmonauts would explore the lunar surface, then board spacecraft No. 1, ignite its propulsive unit and return to the earth.

The third approach is probably the simplest, but it requires an enormous boost capability—on the order of 10 million pounds of thrust or more. It calls for a direct manned flight from the earth to the lunar surface, without any intervening rendezvous.

The flights of Soyuz 2 and 3 last Oct. 26-30 are viewed by some U.S. authorities as attempts to begin preparations for the subsequent assembly of lunar craft in sections while the latter orbit the earth.

Soyuz 3 was described in several Soviet newspapers, including Pravda, as a three-compartment vehicle designed primarily for use as part of a much larger manned orbiting laboratory. U.S. space experts believe it can also serve as the nucleus for a spacecraft that can carry Russians to the moon.

Spacecraft has extra room

According to the description, the Soyuz has two crew cabins, compared with one, in the U.S. Apollo. In addition there is a rear unit that houses instruments and rocket engines, much like Apollo's service module.

During launching and the return to earth, as well as during such key maneuvers in space as rendezvous with another ship, the cosmonauts are seated in the middle compartment, a small, pressurized capsule protected by heat shielding and containing most of the navigation instruments.

Most of the time while the cosmonauts are in orbit, they live and work in the roomier compartment up front in the nose. To get there, they open a hatch and climb through a passage. In the forward cabin the cosmonauts have room for eating, sleeping, exercising and conducting scientific experiments. Altogether the two cabins are reported to have 318 cubic feet of space for the cosmonauts to move about in, compared with 210 cubic feet in the Apollo crew cabin.

The Soviet says Soyuz is equipped with four TV cameras, two inside the cabin and two mounted outside.

Soyuz also has two large, wing-like panels extending from either side of its midsection. These contain solar cells to power the spacecraft's instruments. Apollo relies for power on fuel cells housed in its service module.

Soyuz is designed to use the atmosphere's braking properties and to make a partial gliding re-entry. This capability was also tested, apparently successfully, with the circumlunar flight of the unmanned Zond 6 last month.
Meat-ball or no meat-ball, the decision to commit or wave-off rests with the Landing Signal Officer. And he must see to decide— even on low, overcast nights. So meet the unique Westinghouse TV sensor package. The first in the industry to give an un-blurred picture of a moving object in the total dark. This "off the shelf" package WX-32000 consists of a new Image Intensifier perfectly mated to our exclusive Secondary Electron Conduction camera tube. The Intensifier gives you a brightness gain of 200 with low background, minimum distortion, and good resolution. Together they make a compact unit that gives you crisp, fast-motion, halo-free images at 10⁻⁵ foot candles. For full details on our night-seeing, non-blurring TV Sensor Package, write Westinghouse Electronic Tube Division, Elmira, New York 14902. Then we'll talk you in!
support the lunar mission plus the addition of a much larger propulsion unit. The first test of Soyuz 1 encountered early attitude control instability in orbit and ended in tragedy 25 hours after launching. Following re-entry, the craft’s parachute failed to open properly, and Col. Vladimir Komarov, the cosmonaut on board, died in a crash landing.

The result was an over 18-month delay before the next Soyuz 2 and 3 flights. It might have been expected that the second Soyuz flight would have been a repeat of the first, to check out the modified or improved onboard systems.

Instead, Soviet space officials launched Zond 5 the middle of September and Zond 6 two months later in flights around the moon, with living specimens in the spacecraft. The Zond vehicle is believed to be the command capsule portion of the Soyuz. In fact Tass, the Soviet press agency, admitted that the Zond flights were made as tests for a manned space ship to be sent to the moon.

The Tass disclosure indicated the Soviet Union may be close to trying a manned moon flight, perhaps before the United States launches Apollo 8 on Dec. 21.

Between the two unmanned shots the Soviet proceeded with the difficult task of launching on Oct. 26 one manned and the following day one unmanned Soyuz into earth orbit. Thus in less than 30 days the Russians exhibited an immense competence in both automatic flight controls and launching capability.

As a matter of fact, it is doubtful that the U.S. has achieved such a capability with automated flight systems. Even Dr. Thomas Paine, NASA’s Deputy Administrator, in commenting on the Soviet unmanned automatic-mode operational achievement, says: “It’s a rather shifty question as to whether or not at this particular point in time we would indeed have had that capability.”

The question, however, is moot, since the U.S. approach has never included such a degree of automatic control; rather, man has always been considered an integral part of the spacecraft systems loop.

A heavy use of telemetry

As a starting point in any speculation concerning Soviet manned-spacecraft onboard systems, U.S. scientists assume that its vehicles provide functions equivalent to those of U.S. spacecraft. It is apparent that the Russians have very effective data and voice communications systems and an adequate but limited ground-communications supporting network. They make heavy use of telemetry for data retrieval and provide a high concentration of biological and medical observations.

They apparently use an inertial autopilot and a good attitude control system but may not employ a complex inertial-guidance and navigation system, possibly due to an early decision to use radio command and control from a central earth station. Navigation and control computations are believed to be performed by a very large, high speed digital computer at the control center in Moscow. There must be at least one small digital computer in the spacecraft with reasonably large storage capacity.

The Zond 5 and Zond 6 missions appear to have successfully tested all the systems necessary to support a manned circumlunar flight. Communications were maintained throughout the flights, and there is evidence that even the voice links were exercised, either through direct relay of a ground transmission or from an onboard tape. The guidance and navigation systems appear extremely accurate, since only very minor firings were needed as mid-course corrections on the flights to and returns from the moon. Finally, the re-entry guidance and control systems brought the spacecraft well within planned landing corridors, according to Soviet officials. Zond 5 landed and was recovered in the Indian Ocean. Zond 6 is presumed to have come down in Kazakhstan, Central Asia.

Only one cosmonaut per Soyuz

The Soyuz 2 and 3 missions still offer some consternation to U.S. space experts, principally because there seems no practical explanation for the Soviet use of only a single cosmonaut. It can be presumed that in addition to the normal checkout of flight hardware, a principal experiment was the accomplishment of both automatic and manual space rendezvous of the two vehicles. The flight could also have tested docking procedures; yet the two craft were never physically joined.

The Russians had previously performed automatic rendezvous and docking procedures last April with the two unmanned Cosmos 212 and 213 satellites. Thus the closed-loop rendezvous radar and the control...
A sampling

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<tr>
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systems had already been proved in the automatic mode, and the performance of manual docking might have been anticipated in the recent flight.

However, with only one cosmonaut involved, it has been suggested that actual docking would have been a dangerous maneuver. If the two craft had locked, it might have been necessary for a cosmonaut to leave the vehicle and physically assist with vehicle separation—but this would require at least one more cosmonaut.

That the Russians lay great stress on automatic rendezvous and docking was revealed in New York last October during the 19th Congress of the International Astronautical Federation. Dr. Victor P. Legostaev, an associate professor at the Academy of Sciences in Moscow, emphasized that unless the need for cosmonauts is required for other functions, the automatic mode for assembling vehicles in space is the more rational approach.

The Soviet automatic technique applies a passive role to one vehicle, an active role to the other. Each is placed in roughly the same orbital plane at an altitude of from 125 to 155 miles. Both vehicles carry search radars to detect and lock onto the other vehicle. Rendezvous radars are gimbaled to provide directional maneuverability.

After acquiring its target, the active spacecraft maneuvers to within roughly 1000 feet of and into the same plane as the target vehicle. In the meantime each vehicle has automatically self-aligned itself, so that the docking elements can be mated. The closure rate at this time is about 6.5 feet a second.

Each vehicle then stabilizes itself spatially, reducing roll to zero. As the two vehicles approach for docking, the closure rate is reduced to about 1.5 feet a second until mating occurs.

According to the Soviet scientist, the entire operation—which includes radar range and range rate sensing and computation and all the control procedures—is performed with onboard subsystems, not by ground control.

Automatic docking with radar

In the Soyuz 2-3 missions this fully automatic maneuvering (but without actual docking) was achieved first automatically and later manually by cosmonaut Col. Georgy Beregovoy. The automatic approach, according to Soviet reports, brought the two vehicles to within 650 feet. Radar lock-on for the automatic approach, they say, occurred when the two craft were separated by several kilometers.

Under manual control, Beregovoy is reported to have brought his vehicle to within several hundred feet of the other with a closure rate of about 1.5 feet a second. It has also been reported by the Soviet that the two vehicles flew in formation for some time at the same speed.

Communications satellite used

Because of the sparsity of Russian ground tracking stations, performance data were stored for as long as 10 hours before they were released through the telemetry link as the spacecraft passed over a receiving facility. As has been done before by the Russians, live television pictures from within the spacecraft were transmitted to ground successfully. These were relayed from the tracking centers through the Molniya communications satellite system to Soviet broadcast stations for transmission to the public.

There were reported improvements in the Russian tracking network for the latest series of flights, compared with what was available in 1967. The Soviet is believed to have instrumented six tracking ships in addition to its land bases, the latter largely in the Soviet Union. In addition a permanent tracking station has been set up in India to support Indian Ocean landings.

It should be pointed out, however, that while the U.S. space program has always employed the concept of soft landing and recovery by water, the Russians, with their large land mass, have favored soft-landing techniques on solid ground. The Zond 5 flight indicates the Russians are learning the techniques of water recovery.

There had been some speculation that Zond 5 missed its landing target and may have come down so hard that any life on board would have been injured. All the Russians conceded was that turtles in the craft had suffered spleen damage.
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<td>watts</td>
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Spiraling C-5A costs revealed

Testimony before the Senate Subcommittee on Economy in Government (see this column, ED 25, Dec. 5, 1968), continues to describe the tendency of large defense-contract costs to seriously inflate in time. While the rising costs for the Minuteman ICBM series, in the years from 1958 through 1966, and the unusually high profits that were obtained grabbed headlines, the most serious discussion before the Subcommittee focused on ballooning development costs for the Air Force C-5A Galaxy, the world's largest aircraft.

The reason for dismay over the rapidly rising expenditures of the C-5A, as compared with those of the Minutemen, is understandable. The Minuteman effort culminated a massive missile build-up in this country, during which time three major ICBM series, the Atlas, the Titan and the Minuteman, were developed and deployed concurrently. It was expected, then, that realistic cost estimates would be impossible, because of duplication and the application of state-of-the-art technology to highly sophisticated and complex weapons systems. However, under the McNamara regime, the C-5A program was intended to serve as a model for the concept of "total package procurement" on a rigid, fixed-price basis. The argument advanced then, when Lockheed-Georgia Company won the multi-billion dollar prime contract, was that all of the technology required to build the monstrous aircraft was available and that, therefore, the problem was largely a problem of engineering. Something obviously went wrong.

The program began three years ago when the Air Force estimated that the total development and production cost for the first 58 of the C-5A aircraft would be $2.3 billion. The firm also was given to understand that it would most probably produce a second batch, numbering 57 aircraft, and that the Air Force held an option to buy 85 more. In contrast, current estimates, according to Pentagon officials, indicate that the first 58 aircraft will cost a total of at least $3.25 billion and that successive aircraft procurements will be correspondingly higher.

Looking back, informants here recall that Lockheed won the contract with an unusually low bid, compared to cost proposals submitted by Boeing and Douglas Aircraft, its competitors. At that time, to many observers, it looked like Lockheed expected to recover the losses it incurred in the first aircraft purchase—hopefully through succeeding procurements.

As it stands now, Lockheed will probably have to absorb a $970 million loss. It will have to seek recompense in its negotiations with the Air Force for the second batch of 57 aircraft. It is also anticipated that in the 91st Congress legislation will be sought to further tighten control over defense contracting.

Astronauts defend circumlunar flight

Late last month, the Apollo 8 astronauts vigorously defended their circumlunar mission plan. The flap grew out of comments made by Sir Bernard Lovell, director of Britain's Jodrell Bank Observatory. He had been quoted as saying that: "On a scientific basis this project is
wasteful and silly. We've reached the stage with automatic landings when it's not necessary to risk human life to get information about the Moon.”

NASA officials quickly took issue. They said that at no time had the mission's purpose been declared to be scientific; it was, they said, the next operational test needed to develop lunar-landing capability. In voicing the disagreement with Lovell that was shared by all three Apollo 8 crewmen, astronaut Maj. William A. Anders stressed that the lunar-orbital mission will strongly support future Apollo flights by collecting finer photographs of lunar landing sites, by area mapping and by gaining necessary operational experience in actually performing such a flight.

Astronaut Anders stressed that in addition to obtaining detailed color photographs of the Sea of Tranquility—considered to be the prime landing area—more tracking data are urgently needed for future lunar-landing missions. Ground trackers today, he said, are still not certain of the precise orbit path that will be taken by Apollo spacecraft, because of insufficient data on the Moon's sphericity; this could lead to landing errors of as much as 45 miles. He also declared that: “The more we learn about the Moon's gravitational field and how to navigate in it, the less will be our error when astronauts try to land.”

**Warning on manpower cutbacks**

William G. Torpey, a top manpower specialist in the Office of Emergency Planning, admonished the Government to very carefully consider manpower displacement problems before cancelling major defense contracts. His concern, as he expressed it in the November issue of Personnel Journal, is principally with changes in the nation's defense posture and the effects that such cancellations may have on the nation's existing scientific and engineering manpower pool.

Torpey points out that the defense industry today directly employs 215,000 engineers and that a great number of these are employed by small R&D firms as well as by large prime contractors. Personnel cutbacks, he asserts, more often affect engineers, rather than lesser technicians, because engineers possess specialized skills in narrow technological areas.

He also notes this irony in the situation: although a distinct need exists today for engineers in the civilian economy, it is often difficult to match many engineers with existing nondefense job opportunities because of their high degree of specialization on defense contracts.

**Communications policy release imminent**

The long-awaited Communications Policy Report, due to be made by a Presidential Task Force and which was expected to reach the White House late last month, may be delayed again because of the impending change in administration.

Nevertheless, Electronic Industries Association officials believe that many of the recommendations made in the EIA/IEEE Joint Technical Advisory Committee Report, “Spectrum Engineering—The Key to Progress,” will be included in the Task Force study. The joint report strongly recommended that a carefully planned centralized approach be taken for solving the problems of managing the communications spectrum. It urged establishment of both a pilot project and a central data-clearing house to implement a long-term frequency-selection and experimental-operations program.
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**Letters**

**Sharp-eyed author corrects our typo**

Sir:

The author of Reference 2 in my article "Count Your Foot-Candles with Photodiodes" (ED 17, Aug. 15, 1968, pp. 206-209) should be George T. Daughters III and not G. I. Laughters III, as printed.

Howard Murphy
Optoelectronics Section
Device Development Dept.
Fairchild Semiconductor
Palo Alto, Calif.

**Accuracy is our policy**

**Electronic Design 21**

In Vietnam, seeing in the dark often means life or death. This Starlight Scope (below), a direct view-finding device, helps protect the air base at Da Nang. Elsewhere, low-light-level tv and line scanners help airborne observers find their targets. For a look at these new devices and how they are designed turn to page 21.

Photographs of the Starlight Scope, shown on our Oct. 10, 1968 cover and on page 26 of the same issue, were made for the Army by Varo, Inc., of Garland, Texas. We regret the omission of these picture credits. Varo is one of the leading makers of night-vision equipment in the field.

In the Idea for Design "Counter divides by either 3 or 4" (ED 21, Oct. 10, 1968, p. 114), the state of flip-flop Y produced by clock pulse 3 was erroneously given as \( J_Y = K_Y = 1 \). It should be \( J_Y = 0 \) and \( K_Y = 1 \).
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INFORMATION RETRIEVAL NUMBER 32

SIDELIGHTS OF THE ISSUE

Big stories from little press releases . . .

Sometimes—and we're sure you're familiar with this—you notice a small object or idea, and the more you examine it and explore it, the larger it becomes—until you've uncovered a giant phenomenon. Iceberg hunters are aware of this; they know that the hidden potential of what they observe is likely to be far greater than what meets their eyes. And, in her own quiet way, Elizabeth deAtley, ELECTRONIC DESIGN's new West Coast editor, has just spent two months proving the point again. The result is a new glimpse of the universe for ED readers, a comprehensive survey of electronics for the radio astronomer.

It began with a press release. A builder of integrated circuits was announcing briefly that its circuits had been installed in a new autocorrelation receiver. "Autocorrel-what?" Elizabeth asked herself. Autocorrelation receiver at the National Astronomy Observatory, she learned. A phone call to Dr. Sander Weinreb, the observatory's head of instrumentation, and Elizabeth was off on a trip to the world of quasars, pulsars, interferometers and . . . "the hairiest hairpin mountains I've ever seen" in a night drive to the observatory installation at Green Bank, W. Va. She asked hundreds of questions.

In the process, she uncovered a developing trend in electronics: The "brute force" approach to piercing outer space—the radar dish the size of a football field—is nearing the point of impracticality; designers are turning to clever, indirect ways to achieve their goals. For a glimpse at some of these ways, start reading on page 25.

Before joining ED, Elizabeth worked as an applications engineer for Philco-Ford's Microelectronics Div. in Santa Clara, Calif. She has a degree in physics from Stanford University.
Being an HP Frequency Synthesizer is a tough life.

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<th>MODEL</th>
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*Includes required 5110B Driver ($4350) which operates up to four synthesizers.
**Dual range unit; has internal driver.

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Electronic Design 26, December 19, 1968
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Also in this section:

A practical guide to a/d conversion, Part 2. Page 57
Ideas for Design. Page 98
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Part 2

Written by: Hermann Schmid, Senior Engineer, General Electric Co., Binghamton, New York
Edited by: Frank Egan, Technical Editor

Part 1 of this design guide covered parallel- and serial-feedback a/d converters, their performance criteria and design considerations. Part 2 continues with additional converter types—namely, indirect a/d converters and high-speed, high-accuracy a/d converters. Within these broad categories, the following specific converter types are covered:

- Indirect a/d converters ...................................................... 58
  Simple ramp-comparison type
  Precision ramp-comparison type
  Up/down integration type
  Precision type without precision components

- High-speed, high-accuracy a/d converters .......................... 67
  Cascade, analog-to-pure-binary type
  Cascade, analog-to-Gray-code type
  Variable-reference cascade type
  Multi-threshold type
  Partially-cascaded type
Indirect a/d converters require few critical components. Their conversion speed, though, is low.

Parallel-feedback and serial-feedback a/d converters can also be classified as direct encoders because they convert directly from analog signals into digital signals. In contrast, the a/d converters described here can be classified as indirect decoders, because they convert the analog signals first into intermediate signals, which are half-analog and half-digital. The intermediate signals are then converted into pure digital signals.

Indirect a/d converters have several distinct advantages. They offer circuit simplicity; they employ mostly noncritical components, and they exhibit none of the high-speed problems that are common to serial-feedback converters. The penalty for these advantages, though, is a lower conversion rate.

To count, for example, from 0 to $2^{12}$ with a 1-MHz clock frequency requires $4096 \mu s$. Hence the conversion rate is only about 250 per second. This is slow by successive-approximation standards, but is still fast enough for many control applications. Moreover, when higher speeds are required, there are several techniques for obtaining them.

The first approach is to raise the clock frequency, $f_c$, although there are, of course, limitations on how high $f_c$ can be made. The second approach is to use fewer bits in the digital word. The designer, however, usually has little control over this.

1. Simple ramp comparison a/d converter

The ramp-comparison technique is the fundamental principle of all indirect encoders. However, although it is conceptually very simple, the technique has never been used extensively. The reason for this is that it has been generally assumed that the ramp-comparison method is:

- Very slow.
- Very sensitive to noise.
- Not very accurate, since the accuracy is a function of the integration capacitor precision.

The following discussion will show that these assumptions are not necessarily true today.

The simple ramp-comparison a/d converter (Fig. 1a), first converts the analog input signal $V_x$ into a pulse-width signal $t_r$, and then converts $t_r$ into a parallel binary number $X_r$. The conversion from voltage to pulse width is accomplished by comparing $V_x$ with a linear ramp
function, or a sawtooth voltage, \( V_s = tV_R \). When \( V_x \) is smaller than \( V_s \), the comparator output is ZERO, and when \( V_x \) is larger, the output is a logical ONE (Fig. 1b).

Since the sawtooth function is periodic, \( t_s \) is also a repetitive waveform having an ON-time of \( T \) — \( t_s \) and a repetition period \( T \). The linear relationship of \( t_s \) and \( v_{x} \) can be easily verified. At the point when the comparator switches from ZERO to ONE, the following equation can be written.

\[
V_x = t_s V_R
\]

or

\[
t_s = \frac{V_x}{V_R},
\]

where \( V_R \) is a reference voltage.

The conversion from the pulse width signal, \( t_s \), to a parallel binary number, \( X_p \), is usually performed by counting a clock frequency, \( f_c \), during \( t_s \).

As shown in Fig. 1a, the ramp-comparison a/d converter can be divided into three parts: the ramp generator, the comparison circuit and the digital circuit. The ramp generator consists of one dc amplifier, one analog switch, one resistor and one capacitor. These components are interconnected as a resettable integrator in which the reference voltage, \( V_R \), is constantly integrated. The output voltage of the amplifier, \( V_s \), hence increases linearly with time so long as switch \( S_1 \) is open.

When \( S_1 \) is closed, the integration capacitor is discharged, and the amplifier output, \( V_s \), is held at zero for as long as the switch is closed. In the circuit shown, \( S_1 \) is controlled by the most-significant stage of the 12-bit counter, which closes the switch during time period \( T_2 \).

The amplitude of sawtooth voltage \( V_s \) is directly proportional to \( V_R \) and to time, and is inversely proportional to \( R \) and \( C \). Therefore, the magnitudes of \( R \) and \( C \) are extremely important and precision components are needed.

The reset operation of the integrator requires a finite amount of time; this depends on the slewing capabilities of the amplifier, the value of the integrating capacitor, and the ON-resistance of the switch. It would be desirable if the reset operation could be performed in less than one clock period. But because this would impose very stringent speed requirements on the linear circuits, the full period \( T_2 \) is provided. This allows more than sufficient time to properly reset the integrator.

The converter of Fig. 1a should be able to operate with a 10-MHz clock frequency, which means a repetition period of approximately 400 \( \mu s \). In this case, the values of \( R \) and \( C \) must be chosen so that

\[
V_s^{\text{max}} = \frac{V_R T_2}{2RC}.
\]

Setting \( V_s^{\text{max}} = 5 \text{ V} \), \( V_R = 5 \text{ V} \) and \( R = 20 \text{ k} \Omega \), the value of the integrating capacitor becomes \( C = (T_2/2)/R = 10,000 \text{ pF} \).

With these values, the dc amplifier can be a monolithic device, like the \( \mu A709 \), and switch \( S_1 \) can be a high-impedance J-FET or MOSFET series switch. With the total reset period being 200 \( \mu s \), the discharge time constant of the circuit can be as long as 10 \( \mu s \), and the ON-resistance of the switch does not need to be any lower than 1000 ohms.

The comparator circuit of the simple ramp-comparison converter of Fig. 1 is comprised of the actual comparator, the input filter and a clocked digital differentiator. The actual comparator should have a sensitivity of better than \( \pm 1 \text{ mV} \) and a total offset voltage of less than \( \pm 1 \text{ mV} \). It should also respond in less than one clock period, or 100 ns for a 10-MHz clock fre-
quency. Various commercially available monolithic comparators can fulfill these requirements. The purpose of the input filter is to reduce the effect of high-frequency noise on the input signal and on the sawtooth.

The clocked digital differentiator of Fig. 1a generates a narrow pulse when the input signal \( t_x \) and clock pulse \( f_c \) change from LOW to HIGH. The width of the narrow output pulse, \( t'_x \), is determined by the propagation delay of the three NAND gates, \( N_1 \) to \( N_3 \), shown in Fig. 2. The latch, consisting of \( N_6 \) and \( N_7 \), is reset when the input \( t_x \) returns to a LOW level. Power gate \( N_4 \) provides the capability of driving the converter-output switches.

The digital circuits of the simple ramp-comparison converter are comprised of a 12-bit counter together with counter output gating. A synchronous counter is needed for high-speed operation. The counter output-gating circuits connect the parallel digital number \( X_p \) to the output terminals at the instant that \( V_x = V_x \). The narrow output pulse \( t'_x \) of the digital differentiator closes the switches for only a short time at the beginning of each clock period.

The accuracy of the simple ramp-comparison a/d converter is a function of how precise a sawtooth can be generated and the accuracy with which the comparison can be performed. With a clock frequency of 10 MHz, a maximum output voltage of 5 V, a comparison accuracy of \( \pm 1 \) mV and precisely trimmed \( RC \) values, the ramp-comparison converter can perform with an accuracy of \( \pm 0.05\% \) of full scale. This remains true, however, only for a constant operating temperature, since \( RC \) cannot be maintained at the desired value over the temperature range. With the 10-MHz clock frequency, the device can perform 2500 conversions per second.

Another drawback of this converter is that there is no simple way to transform it into a bipolar device, mainly because an integrator cannot easily be reset to a negative reference voltage.

2. Precision ramp-comparison a/d converter

Many limitations of the simple ramp-comparison a/d converter can be overcome by a more precise method of generating the sawtooth function. One such method, to be described here, generates the sawtooth wave by means of a parallel d/a converter operating in combination with a master counter. There is no need for precision capacitors, and the resulting circuit is therefore capable of high accuracy. However, the cost, size and weight of this converter are considerably higher than that of a simple ramp-comparison converter.

The additional complexity of the precision ramp-comparison converter involves only the sawtooth generator. And because the same sawtooth waveform can be connected to many comparators, this technique is highly suitable for multichannel a/d conversion applications.

A precision ramp-comparison converter for multichannel use is shown in Fig. 3.

The multichannel ramp-comparison converter consists of only one sawtooth generator, which is common to all channels; one comparator, and one digital-differentiation circuit for each input channel. The 12-bit digital storage circuits provide intermediate storage for the output signals.

Each of the “n” analog input voltages, \( V_{x1} \) to \( V_{xn} \), is connected to one input of a comparator, while the sawtooth voltage, \( V_s \), is connected to the other. As \( V_s \) becomes equal to, and then larger than \( V_x \), the output of that particular comparator switches from LOW to HIGH. At this instant, the digital-differentiation circuit produces a narrow pulse which is used to close a row of transfer switches and to connect the output of the master counter to the 12-bit digital storage circuits.

The master counter operates continuously, and provides as outputs binary digital signals that represent a linearly increasing number, from 000 . . . 00 to 111 . . . 11. Here 000 . . . 00 represents a maximum negative value, 111 . . . 11 a maximum positive value and 100 . . . 00 represents zero. A continuously operating counter can be regarded as a digital sawtooth generator, since it resets itself to 000 . . . 00 after it has reached 111 . . . 11.

Conversion from the digital number in the master counter to an analog sawtooth voltage is performed with a conventional d/a converter. With appropriate biasing, the output of the d/a converter swings between the negative reference voltage, \(-V_r\), and the positive reference, \(+V_r\).

In addition to generating the sawtooth voltage, the outputs of the master counter are also gated into the digital storage circuits. Since the number in the counter increases linearly with time, the number transferred out at any given time is proportional to the elapsed time, measured from the start of the counting cycle. By gating the outputs of the master counter into the storage circuits at the end of the \( t_x \) pulse—whose width is proportional to \( V_x \)—a number proportional to \( V_x \) is actually transferred.

Any of the parallel d/a converters described in reference 2 can be used in this application. For best accuracy and speed, however, the resistor-ladder or the inverted ladder d/a converter should be given preference. The amplifier at the output of the d/a converter must have sufficient current capability to drive all n-comparators.

The comparison and differentiation circuits of this converter are similar to those described for the simple ramp-comparison converter.
Over-all accuracy of this converter can be better than ±0.05%. And as the number of parallel input channels is increased, it can become just as fast as many multiplexed successive-approximation converters.

3. Up/down integration a/d converter

The up/down integration converter uses the well-known up/down-integration technique, which is now employed in many digital voltmeters. This technique represents the most accurate method of converting from analog to digital. The technique completely eliminates the dependence of the pulse-width signal, \( t_x \), on the magnitude of the integration \( RC \) time constant. The value of the integration capacitor, therefore, can change over a wide range without effecting the value of \( t_x \).

The up/down-integration a/d converter is also less susceptible to noise than any of the ramp-comparison converters, because the input signal, \( V_x \), is integrated for a relatively long time. Another advantage is that \( t_x \) is independent of the initial voltage on the integration capacitor, which means that any voltage or current offset in the comparator will not introduce errors.

Another advantage of this converter, in fact, is that any offset can be easily corrected with an extremely simple offset-correction network.

The heart of the up/down integration converter is a pulse-width modulator, a simplified version of which is shown in Fig. 4. In the modulator, an unknown input voltage, \( V_x \), is integrated for a precise and constant period, \( T \). During this period the output \( V_o \) of the integrator increases linearly with time. If \( V_x \) is constant during \( T \), the output at the end of \( T \) is

\[ V_o = V_o + V_x (T / RC) \]

where \( V_o \) is the initial voltage on the integrator.

During the second period, \( T \), a reference voltage, \( V_R \), having opposite polarity to \( V_x \) is integrated until the output of the integrator becomes again \( V_o \). The time required for the second operation is the desired information.

It can be shown that the result of this second integration is

\[ V_o = V_o + \left( T / RC \right) \int_0^t V_x dt \]

or

\[ t_x = T \cdot (V_x / V_R) \]

Thus, not only is \( t_x \) linearly related to \( V_x \), but it is also completely independent of both the integration time constant \( RC \), and the initial integrator voltage.

A four-channel up/down-integration a/d converter is shown in Fig. 5. Again, although a multichannel arrangement is shown, the basic operation is the same for single-channel use. The analog section converts each of the four input signals, \( V_{x1} \) to \( V_{x4} \), into four pulse-width signals, \( t_{x1} \) to \( t_{x4} \). These conversions are done sequentially in time. The digital section then transforms the four pulse-width signals into four serial-binary signals, \( X_{x1} \) to \( X_{x4} \).

The master and sequence counters generate the timing and control signals; these determine which input signal is to be converted and the phase in which the converter is operating. The

2. Digital differentiation circuit produces narrow output pulse, \( t_x' \), when both the clock pulse and pulse-width signal, \( t_x \), go HIGH.

3. Precision ramp-comparison a/d converter uses a digital technique for generating the precision linear ramp. This is accomplished with a d/a converter and a 12-bit master counter.
operation of the up/down integrator and master counter are thus synchronized, so that the output of the master counter at any specific instant is related to pulse-width signal, \( t_x \), and analog input voltage, \( V_x \).

In addition to the four time periods, \( T_1 \) to \( T_4 \), required to convert \( V_x \) to \( V_{x,4} \), there is one other period, \( T_5 \), during which the input to the converter is zero. During this period, the pulse-width output signal, \( t_x \), is compared with a reference pulse-width signal, \( T_{\text{REF}} \). The difference between \( T_{\text{REF}} \) and \( t_x \) is used to generate an error voltage, \( V_e \), which is stored in a capacitor and fed back to the input of the integrator during \( T_1 \) to \( T_2 \), to correct for the offset error.

The timing and waveform diagram for the 4-channel up/down-integration converter is shown in Fig. 6. As shown, each conversion period, \( T_1 \), is divided again into halves. During the first half, \( T_{1,1} \), the input voltage \( V_{x,1} \) is integrated; during the second half, \( T_{1,2} \), the reference voltage, \( V_{n} \), is integrated. The diagram also shows when the differentiated pulses, \( t_x' \), transfer the contents of the master counter into the appropriate 12-bit storage register.

The analog section of the up/down-integration converter is an extension of the simple up/down pulse-width modulator of Fig. 4.

The input resistors (Fig. 5) transform the various input and reference voltages into currents which are selectively connected to the input

---

4. Pulse-width modulator (a) performs an up/down integration by first integrating the input signal \( V_x \), and then a reference voltage, \( V_x \), which has a polarity opposite that of \( V_x \). Output waveforms for the pulse-width modular circuit are shown in (b).

5. Up/down-integration a/d converter can provide multichannel a/d conversions using only a single integrator.
of the integrator by the analog current switches. These resistors also perform the function of scaling, so that almost any reasonable value of input voltage can be accepted by this a/d converter. Only the magnitude of the current is important. If, for example, the value of the input current must be 100 µA, then \( R_i \) must be 100 kΩ if \( V_x = 10 \text{ V} \), or \( R_i \) must be 1 MΩ if \( V_x = 100 \text{ V} \).

The overall accuracy of the converter is a function of the precision of these scaling resistors. Absolute accuracy, however, is not required; only the ratio between the various resistors need be precise.

Either J-FET or MOSFET current switches are suitable for this application. Most of the switches are controlled directly by the outputs of the 10-stage sequence counter. It can be shown that the performance of this converter is not a function of the ON-resistance of these switches, but only of how well their ON-resistances can be matched. With identical scaling resistors, \( R_o \), the maximum difference in \( R_{ON} \) between any two of the switches should be less than 0.01% of \( R_o \).

The only important requirements of the integration amplifier are high gain (larger than 10,000) and a capability to drive the integration capacitor, which commonly has values between 5000 and 20,000 pF.

The integration capacitor must have a low voltage-coefficient and a high leakage-resistance; but otherwise it needs to be neither very accurate, nor have a very low temperature-coefficient.

The comparator circuit of Fig. 5 is built around the \( \mu A710 \) monolithic comparator, like that previously described for the simple ramp-comparison converter.

The digital section of the up/down-integration a/d converter (Fig. 5) consists of the master counter, the sequence counter, the four output registers, the digital differentiation circuit, and the output multiplexer.

For high-speed operation it is best that the 12-bit master counter be synchronous. It should also be capable of operating with a clock frequency of about 4 MHz, so that the half period, \( T_{hl} \), can be made approximately 1 ms.

The sequence counter must have 2 \((n + 1)\) stages, where \( n \) is the number of input channels. A 4-channel converter therefore requires a 10-stage ring counter. Switch \( S_n \), which connects the reference voltage \( +V_n \) to the integrator, must always be closed during the first-half of each period, \( T_{hl} \); switch \( S_r \), which connects \( -V_n \) to the integrator, must be closed only when the pulse-width output signal \( t_x \), is HIGH. The control signal for \( S_r \), namely \( T_{hl} \), can be generated simply by OR-ing \( T_{01}, T_{11}, T_{21}, T_{31} \) and \( T_{41} \); the control signal for \( S_n \) is simply \( t_x \).

The intermediate storage circuits are 12-bit parallel-in, serial-out registers. The control signal for transferring the contents of the master counter into the storage circuits is the output of the

6. Each conversion of the up/down-integration converter is divided into two halves.
7. Precision up/down-integration a/d converter uses voltage switches at its input. This allows a single input-resistor to be used for all channels, instead of a separate resistor for each channel.

8. Waveforms show operation of precision up/down integration converter of Fig. 7.

digital differentiation circuit, $t'$'. This pulse occurs at the instant when $t_x$ and $f_c$ change from LOW to HIGH. Because the operation of the integrator is synchronized with the master counter, the content of the master counter at that instant is proportional to both $t_x$ and input voltage $V_x$.

The up/down-integration converter of Fig. 5 can accept bipolar input signals. This is made possible by biasing $\pm V_1$ with $V_1/2$. More specifically, switch $S_1$ connects $-V_1$ through a 2R resistor to the input of the amplifier during the first-half of all periods of $T_i$.

The static accuracy of the up/down-integration converter can be analyzed most conveniently by examining its three basic types of errors; namely, offset, linearity and gain errors.

There are two major sources in the converter that can cause a constant offset error at the output. These are the voltage and current offsets of the integration amplifier.

Other sources of offset error are the delays introduced by the logic circuits, the comparator and the low-pass filter in front of the comparator. As mentioned previously, an offset in the comparator will not cause an offset error at the converter output.

Linearity errors are produced by the up/down integrator. These are caused by the finite gain and finite bandwidth of the amplifier.

Finally there are the gain errors which are caused by changes in the reference voltages, variations in the input resistor ratios, and differences in the ON-resistance of the analog switches. To achieve high accuracy from the converter, such as 0.05%, it is essential that these three parameters be well controlled.

4. Precision converter without precision components

In the foregoing analysis of the up/down-integration a/d converter, it was shown that the pulse-width signal, $t_x$, is independent of the value of the integration capacitor $C$. This concept is further extended by the converter of Fig. 7, which does not require any precision components; that is, no precision resistors or precision capacitors.

There are two basic differences between the
up/down integration a/d converter of Fig. 5 and that of Fig. 7. The first uses current switches and two basic time periods for each conversion. The second employs voltage switches and four basic time periods. In all other respects, the principles of operation and the implementation are very similar.

The use of analog "voltage" switches in the converter of Fig. 7 eliminates the need for one resistor per switch. Instead, the five series switches, \( S_1 \) to \( S_s \), are interconnected and operated as a 5-channel multiplexer switch, which means that only one of the switches is closed at any one time. With such a multiplexer switch, only one input resistor is required. Since the pulse-width signal \( t_x \) is independent of the \( RC \) time constant, there is no need for this resistor to be precise.

The use of a multiplexed voltage switch, however, also has disadvantages. First, with only one resistor, the convenient method of scaling no longer exists. Second, since only one input voltage can be connected to the integrator at any one time, the simultaneous summation of two input signals cannot be performed.

Although the circuit of Fig. 7 cannot perform simultaneous summation, it can perform sequential summation, thus making bipolar operation possible.

From the timing and waveform diagram of Fig. 8, it can be seen that the operation of this single-channel converter is divided into eight equal time-intervals. Of these, \( T_{o1} \) to \( T_{o6} \) are used exclusively for offset correction. During \( T_{11} \) to \( T_{14} \), input signal \( \pm V_x \) is converted to digital form.

More specifically, the negative reference voltage \( -V_n \) (Fig. 7) is integrated during \( T_{o1} \) so that the output \( V_o \) of the integrator increases linearly to positive half full-scale. During \( T_{o2} \) to \( T_{o4} \), switch \( S_t \) is closed, and the signal ground is connected to the integrator. Thus any voltage difference between the analog ground of the converter and the ground of the signal source is also integrated. Consequently, the offset correction network compensates for slowly-varying differences in the ground potentials.

At the beginning of \( T_{o5} \), switch \( S_t \) closes, and the positive reference voltage \( +V_n \) is connected to the integrator until \( V_o \) again becomes zero. The time required to reduce \( V_o \) back to zero, \( t_{x0} \), is used only as input to the offset correction network, where it is compared with the time period \( T_{o5} \). The difference between these two pulse-width signals is used to generate the offset correction voltage \( V_{sc} \), which is fed back to the input of the integration amplifier to compensate for any offset and to force \( t_{x0} \) to become equal to \( t_{o5} \).

The actual signal conversion starts with \( T_{11} \), when \( S_t \) is closed again to bias the integrator to positive half full-scale. During \( T_{12} \), switch \( S_t \) is closed and the input signal \( \pm V_x \) is integrated. Depending on whether \( V_x \) is negative or positive, the integrator voltage will rise or fall. At the beginning of \( T_{13} \), the positive reference voltage \( +V_n \) is connected to the integrator until \( V_o \) again becomes zero. Both \( T_{13} \) and \( T_{14} \) are necessary for the down integration. This is because two periods are used for the up integration and because the slope for the down integration is the same as the maximum slope for the up integration.

To reduce the effects of leakage currents in the switches, to avoid picking up noise in the integration resistor, \( R \), and to provide a constant source impedance for the integrator, switch \( S_t \) is provided to connect \( R \) to analog ground, whenever \( S_t \) or \( S_r \) are open.

With the offset correction network, the offset errors of this converter are practically zero. In addition, the linearity errors are very small. Because there is only one resistor in this converter, the major source of gain-error—the resistors—has also been eliminated. As a result, given enough time, it is presently the most accurate type of a/d converter.

5. Voltage-to-pulse-rate a/d converters

In the voltage-to-pulse-rate method of a/d conversion, an analog voltage is first converted into a pulse-rate signal, or a frequency, and then into a parallel or serial-binary number. Although the technique is quite common in digital voltmeters, it is seldom used in actual a/d converters. The reason for this is that the conversion speed is very low, even with state-of-the-art components.

Voltage-to-pulse-rate conversion can be accomplished either with the basic ramp-comparison technique or with the up/down integration technique. Only the up/down integration technique will be described here.

In the voltage-to-pulse-rate converter (Fig. 9), the input voltage, \( V_x \), is permanently connected to the integrator, while the reference voltage, \( +V_n \), is connected to the integrator only when the pulse-rate signal \( R_x \) is a logical ONE. The inputs to the comparator are the output, \( V_o \), of the integrator and the constant voltage, \( +V_n / K \).

In the waveform diagram of Fig. 10, it is assumed that the integrator starts at zero volts, that \( V_x = 3/4 V_{max} \), that \( V_n / K = 1 \text{V} \) and that the \( RC \) time constant of the integrator is selected so that

\[
\frac{1}{RC} \int_{t_{11}}^{t_{13}} V_{x\text{max}} \, dt = +2V_n / K = 2 \text{V}
\]

where \( V_n = 10 \text{V} \), \( K = 10 \), and the time from 0 to \( t_{11} \) is half a clock period, \( t/2 \), or \( 1/2 f_c \).

The output of the integrator, \( V_o \), thus increases...
9. **Up/down integration technique** is used in this pulse-rate a/d converter.

During the first half of clock period $t_{11}$, with a slope of $3/4$. When $V_o$ becomes larger than $1 \, \text{V}$, the output of the comparator becomes ONE, but $V_o$ continues to increase until the end of $t_{11}$, where it becomes $+1.5 \, \text{V}$.

At the beginning of $t_{12}$, the logical ONE is shifted into the single-stage shift register, consisting of flip-flop FF-1. The output of FF-1, $f_x$, is gated with clock pulse $f_c$. Since $f_x$ is a ONE during $t_{12}$, switch $S_1$ is closed, connecting $+V_R$ to the integrator. Note that the input resistor for $+V_R$ is only $R$ while the input resistor for $V_x$ is $2R$. The total current flowing into the summing point of the integration amplifier is hence

$$I_T = -V_x/2R + V_R/R$$

and if

$$-V_x = -V_{X_{\text{max}}} = -10 \, \text{V}, \text{ and if } +V_R = +10 \, \text{V}$$

$$I_T = -10 \, \text{V}/2R + 10 \, \text{V}/R = +V/2R$$

Thus, the current caused by $V_R$ is twice as large as the current caused by $V_{X_{\text{max}}}$. The total integration current in $t_{12}$ is positive, whereas the current during $t_{11}$ was negative. The output of the integrator therefore decreases with a slope proportional to $2/K (V_x - 2 \, V_R)$, which is, for the numbers above, $1.5 \, \text{V} - 4.0 \, \text{V} = -2.5 \, \text{V}$ per half clock period. At the end of $t_{12}$, the integrator output is $1.5 \, \text{V} - 2.5 \, \text{V} = -1 \, \text{V}$.

During $t_{21}$, $S_1$ is open, only $V_x$ is connected to the integrator, and $V_o$ increases with a rate of $1.5 \, \text{V}/(t/2)$. At the end of $t_{22}$, the integrator output voltage is $V_o = -1 \, \text{V} + 1.5 \, \text{V} = +0.5 \, \text{V}$. The output of the comparator remains a ZERO, which is also shifted into FF-1 at the beginning of $t_{22}$. With $R_x$ being a ZERO, during $t_{22}$, $S_1$ stays open and $V_o$ keeps increasing at the same rate, and is $+2.0 \, \text{V}$ at the end of $t_{22}$ and $+3.5 \, \text{V}$ at the end of $t_{31}$.

As soon as $V_o$ became larger than $1.0 \, \text{V}$ in $t_{22}$, the output of the comparator became a ONE; but there is no negative transition on the clock pulse until the beginning of $t_{32}$. At that time the ONE is shifted into FF-1 to make $R_x$ a ONE also. Switch $S_1$ closes, and $V_o$ decreases during $t_{32}$ from $+3.5 \, \text{V}$ to $+1.0 \, \text{V}$. During $t_{31}$, $S_1$ is again open and $V_o$ increases to $+2.5 \, \text{V}$. During $t_{32}$, $R_x$ is again ONE, $S_1$ is closed and $V_o$ decreases from $+2.5 \, \text{V}$ back to zero, which is the value $V_o$ started from in $t_{31}$.

With an input voltage, $V_x$, of $3/4 \, V_{X_{\text{max}}}$, a total of three out of four possible pulses were generated, with no voltage left in the integrator. This is, of course, the desired output from the voltage to pulse-rate converter.

The conversion from pulse-rate to a serial-binary number is accomplished by summing all the $R_x$ pulses during a constant time period $T = 2^{-12} \cdot t_c$, where $t_c = 1/f_c$.

Just as for pulse-width converters, the voltage-to-pulse-rate conversion is independent of the RC time constant of the integrator and is only a function of $V_x$, $V_R$, the clock period $t_c$, and the total conversion period $T$. The time required for one 12-bit conversion is determined by how fast the integration amplifier can integrate $2 \, \text{V}$ up and $2 \, \text{V}$ down. ■

10. **Wave forms describe the operation** of the pulse-rate a/d converter using up/down integration.
High-speed, high-accuracy a/d converters use parallel operating techniques.

There is an ever increasing demand today to reduce a/d conversion time without sacrificing conversion accuracy. To meet these demands, a variety of different high-speed, high-accuracy a/d conversion techniques have been developed.

These conversion techniques are characterized by the fact that they do not obtain their high speed by using higher-speed circuits or components, but by using parallel, rather than serial, circuit configurations. Although this requires additional hardware, it does not necessarily mean that converters employing such techniques are more expensive than other types. With the price of components steadily decreasing, the cost of actual hardware is becoming a smaller percentage of total converter price.

1. Multi-threshold a/d converter

The multi-threshold converter is by far the fastest and most straightforward of all a/d converters. It operates almost instantaneously and is limited only by the delays of one comparator and a few logic gates. The total conversion time is less than 100 ns with conventional µA710 comparators and with ordinary TTL logic gates.

The multi-threshold converter requires one comparator for each comparison level, except for zero. In an n-bit converter, there are therefore 2^n —1 comparators. Obviously, this seriously limits the number of bits to be converted, even when using integrated circuits. The approach is nevertheless of interest and can be used, as will be shown later, as a basic building block to partially-cascaded, high-speed converters.

A unipolar 3-bit multi-threshold a/d converter is shown in Fig. 11 to consist of seven comparators and two OR gates. The analog signal voltage, V_x, is connected to one input of each comparator, and one of seven reference voltages, 1/8 V_R, 2/8 V_R, 3/8 V_R, etc., is connected to the other input. Input voltage V_x is thus compared simultaneously with seven possible threshold levels. If, for example, V_x = 0.3 V_R, then the outputs of the first two comparators, CP1 and CP2, are logical ONES, which indicates that V_x is larger than 1/8 V_R and 2/8 V_R. The total digital output from the seven comparators is 0000011. Similarly, if V_x = 0.55 V_R, the output of the seven comparators is 0001111, indicating a value larger than 4/8 V_R.

The seven reference voltages are generated with a resistor voltage-divider, consisting of
11. Multi-threshold a/d converter requires $2^n - 1$ comparators to generate an n-bit digital output signal.

12. Cascade, analog-to-pure-binary a/d converter employs a cascade arrangement of identical, single-bit a/d conversion stages.

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eight equal resistors. The values of these resistors must be sufficiently low so that any current flowing into or out of the comparators will not appreciably change the reference voltage levels.

The seven comparators can be relatively simple devices, inasmuch as the comparison accuracy need not be very high. For a single 3-bit converter, this accuracy has to be only slightly better than the converter resolution.

The output of the 3-bit multi-threshold a/d converter is a binary signal between zero and seven, with the specific value determined by the comparator outputs. This can be seen from Table 1.

2. Cascade, analog-to-pure-binary a/d converter

The cascade, analog-to-pure-binary conversion technique is also referred to as sequential or propagation a/d conversion. Early implementations of this technique, using vacuum tubes, were not very accurate and proved no faster than converters that used less hardware. But with today's components, considerably higher accuracies are possible—although conversion speed is still a problem.

As shown in Fig. 12, a 12-bit cascaded analog-to-binary converter consists basically of 12 single-bit a/d conversion stages, if we neglect, for the moment, the sample-hold and intermediate storage circuits. The first stage of the converter receives the analog voltage signal, $V_x$, as an input. For all other stages, the input voltage is the analog output from the previous stage: in short, the $n$ conversion stages are cascaded. The reference voltage, $V_{R}/2$, is connected to each single-bit converter. The digital output from each converter stage represents one bit of the parallel-binary output signal, with the converter having $V_x$ as its input representing the most-significant bit.

One major advantage of this converter is that all $n$-conversion stages are identical, both in circuitry and in operation. A generalized diagram of one of these stages is shown in Fig. 13. It consists of a comparator, an analog switch, a subtractor and an amplifier having a gain of two.

The comparator determines whether the input voltage, $V_i$, is larger or smaller than the reference voltage, $V_{R}/2$. When $V_i$ is larger, the output of the comparator, $a_i$, is a ONE, switch $S$ is closed and $V_{R}/2$ is subtracted from $V_i$. When $V_i$ is smaller than $V_{R}/2$, $a_i$ is ZERO, switch $S$ is left open and nothing is subtracted from $V_i$. The amplifier multiplies the output of the subtractor by two. The amplifier output is therefore:

$$V_{i+1} = 2[V_i - (a_i V_{R}/2)].$$

For illustration, consider the example where $V_x = +8.4$ V and $V_R = +10$ V. For the above equation, the outputs $a_i$ (where $X_i = a_i$) and $V_{i+1}$, from the cascade series of single-bit converters are:

- For converter 1: $a_1$ = ONE and $V_2 = +6.8$ V
- For converter 2: $a_2$ = ONE and $V_3 = +3.6$ V
- For converter 3: $a_3$ = ZERO and $V_4 = +7.2$ V
- For converter 4: $a_4$ = ONE and $V_5 = +4.4$ V
- For converter 5: $a_5$ = ZERO and $V_6 = +8.8$ V

The parallel-binary output of the first five converter stages is thus 11010, or 26/32, which is the closest approximation to 8.4 V/10 V = 0.84 in a 5-bit binary word.

One possible implementation of a unipolar single-bit a/d converter is outlined in Fig. 14. A monolithic comparator, like the Fairchild µA710, can determine to within a few millivolts whether input voltage $V_i$ is larger or smaller than the reference voltage $+V_{R}/2 = +5$ V. A low-pass filter, consisting of two 2-kΩ resistors and a 200-pF capacitor reduces the effects of noise on the input and reference voltage. A monolithic amplifier, like the µA709, is connected as a voltage follower with a gain of two. The subtraction $[V_i - (V_{R}/2)]$ is carried out by returning the...
13. **Single-bit converter stage** for a/d converter of Fig. 12 compares the voltage \( V_i \), from the previous stage with the reference voltage to determine whether digital output bit \( X_i \) is ONE or ZERO.

14. **Operations of subtraction and multiplication by two** are performed by the amplifier in this unipolar implementation of the single-bit conversion stage for the converter of Fig. 12.

### Table 1. Multi-threshold converter logic

<table>
<thead>
<tr>
<th>Threshold levels</th>
<th>Comparator outputs</th>
<th>Converter output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CP1</td>
<td>CP2</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
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<tr>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The operational amplifier thus performs both the subtraction and the multiplication by two.

A series-shunt switch is used to connect \( +V_R \) or ground to the voltage divider of the single-bit converter, depending on whether the output, \( a_i \), of the comparator is ONE or ZERO, respectively. There are some rather strict requirements on the ON-resistance of this switch, as its resistance will add directly to that of \( R_x \). If the converter is to be accurate to 1 part in 4096 (12 bits), then the gain of the voltage follower must be maintained to about 1 part in 20,000. The voltage divider must have the same accuracy, so the ON resistance of the switches, or at least the change in \( R_{OX} \), must be less than 1/20,000 of \( (R_1 + R_2) \), which is less than \( \pm 2 \) ohms.

The time required for this changeover is determined by how fast the change can propagate through the 12 cascaded converter stages. This
15. **Bipolar signals** can be accepted by this version of the single-bit conversion stage for the converter of Fig. 12.

16. Cascade, analog-to-Gray-code a/d converter converts the analog input voltage into a Gray-code signal which is then converted into a pure binary signal.

17. Operation of the cascade, analog-to-Gray-code converter is described by the digital and analog transfer characteristics of the first four stages.
is mainly a function of the slewing rate and the settling time of the converter amplifiers, since the switches and comparators are about one order of magnitude faster than the amplifier.

The sample-hold circuit applies the input signal to the converter at the beginning of the clock period \( t_1 \). Thereafter, it holds \( V_s \) at a constant value. If the first-half of the clock period is equal to the time required to propagate a change through all 12 stages, then the digital output signal, \( X_n \), will be constant during the second-half of \( t_1 \).

The accuracy of a cascade a/d converter is mainly determined by the accuracy of the most-significant stages. This is because the error caused by the most-significant stage is included unattenuated in the total error of the system, whereas the error in the second-most-significant bit is attenuated by a factor of two; the error in the third-most-significant bit by a factor of four, and so on.

With presently available monolithic comparators, monolithic amplifiers, bipolar junction-transistor switches, and precision resistors having a \( \pm 0.01\% \) ratio tolerance—assuming offset correction is used—it is possible to achieve a 12-bit accuracy (1 part in 4096) over temperature for a single-bit converter.

The over-all accuracy of the cascade a/d converter is a function of the sum of the errors of the 12 individual stages and of the sample-hold circuit. As mentioned previously, the magnitude of the total error from the 12 converter stages is between 2 and 12 times the magnitude of the error of the most significant stage, typically, somewhere between 0.05 and 0.1\%.

The speed of conversion of this converter is almost exclusively a function of the type of amplifier used. Since the amplifier must be capable of slewing between zero and full scale, even for small changes in the input signal, the propagation delay is mainly a function of how far each of the 12 amplifiers must slew. Since this is a random function of the input voltage, \( V_s \), it can be assumed that the total excursion of all amplifiers is an average of \( 12 \times 1/2\)-full scale, or \( 6 \times \) full scale. With a monolithic amplifier that has a slew rate of 200 mV/\( \mu \)s and using a full scale of 10 V, it would require 300 \( \mu \)s for the 12 amplifiers to reach steady state. However, this does not include the comparators and switches, which will add another few microseconds delay.

It is obvious that faster amplifiers are needed to make this converter high-speed. There are now several monolithic amplifiers available, like the Fairchild \( \mu A715 \), which have slew rates of 10 and 25 V/\( \mu \)s. With these slew rates, the total conversion time is less than 10 \( \mu \)s.

The term “slew rate” as used here refers not only to the time required by the amplifier to slew from one value to another, but also the time required by the amplifier to settle to the final value to within \( \pm 0.05\% \).

The cascade a/d converter of Figs. 12 through 14 can accept only unipolar input signals. Several techniques, though, are available for making this converter operate with bipolar input signals.

The first method is to bias the input signal by one-half full scale in the sample-hold circuit, or some other preceding circuitry.

The second method requires no additional hardware and introduces no additional errors. All that is needed are two changes in circuit interconnections. As shown in Fig. 15, these are:
- The reference voltage connected to the input of the comparator must be made zero.
- The potentials connected to the series-shunt switch must be \( +V_R \) and \( -V_R \).

With these changes, the conversion accuracy and speed of the bipolar converter are identical to those of the unipolar converter.

3. Cascade, analog-to-Gray-code a/d converter

In the cascade, analog-to-pure-binary a/d converter of Fig. 12, the sample-hold circuit, the transfer gates and the intermediate storage register are needed to overcome the significant errors that would otherwise occur when the output signal changes, for example, from 011...11 to 100...00, or vice versa. These transient errors and the circuits required to suppress them, can be eliminated by converting first to Gray code and then to pure binary. The reason for this is that only one bit in a Gray code changes at any one time.

In addition to eliminating the binary transition problems and reducing hardware, the cascade, analog-to-Gray-code converter also offers higher accuracy and higher speed. The only disadvantage is that the Gray code output must eventually be converted into a pure-binary signal, because most digital control and computation circuits cannot work with a Gray code-signal. However, this can be accomplished with relatively little hardware.

Figure 16 shows the generalized form of a 12-bit cascaded, analog-to-Gray-code converter. The stage is comprised of only the comparator, \( CP_i \), while all other 11 stages contain an amplifier circuit and a comparator.

All 12 stages are cascaded, which means that the output of stage \( i \) is the input to stage \( i+1 \). The transfer function for the 11 identical stages is:

\[ V_{i+1} = -2|V_i| + V_R. \]
The transfer function of the first stage is simply

\[ V_1 = V_x. \]

The 12 comparators are identical, and compare the voltage \( V_x \) with ground. The output of the comparator is therefore

\[ X_1 = 1 \text{ if } V_1 > 0 \]

\[ X_1 = 0 \text{ if } V_1 < 0. \]

The analog and digital output signals of the first-four stages of the converter of Fig. 16 are plotted on Fig. 17 as functions of the analog input signal \( V_x \). More specifically, Fig. 17a shows that the digital output signal \( X_1 \) is ONE when the analog signal \( V_1 = V_x \) is positive, and \( X_1 \) is ZERO when \( V_1 \) is negative.

Figure 17b shows the transfer characteristics of the second stage as a function of \( V_x \). Since \( V_1 = V_x \), the analog transfer function could also be written as

\[ V_2 = -2|V_x| + V_R, \]

which indicates that \( V_2 = V_R \) when \( V_x = 0 \), that \( V_2 = 0 \) when \( V_x = V_R/2 \), and that \( V_2 = -V_R \) when \( V_x = V_R \). The digital transfer function expresses that \( X_2 \) is ONE when \( V_2 \) is positive, and \( X_2 \) is ZERO when \( V_2 \) is negative.

Figure 17c represents the transfer function for the third stage, which is

\[ V_3 = -2|V_2| + V_R. \]

Replacing \( V_2 \) with its equivalent gives

\[ V_3 = -2|-2V_x + V_R| + V_R. \]

Therefore, \( V_3 = -V_R \) when \( V_x = 0 \), +8 V, or -8 V. Similarly, \( V_3 = 0 \) when \( V_x = -6 \) V, -2 V, or +6 V, and \( V_3 = +V_R \) when \( V_x = +4 \) V or -4 V. Again the digital output \( X_3 \) is ONE when \( V_3 \) is positive, and ZERO when \( V_3 \) is negative.

Finally, Fig. 17d depicts the analog and digital transfer functions of the fourth stage, which are

\[ V_4 = -2|V_3| + V_R = -2|-2V_x + V_R| + V_R. \]

And, as in the other stages, \( X_4 \) is ONE when \( V_4 \) is positive, and ZERO when \( V_4 \) is negative.

The transfer characteristics of the four converter stages in Fig. 17 show that the slopes of the analog curves increase by a factor of two for each successive stage. This means that for a change of 1 V in \( V_x \), the outputs of the four stages, \( V_1, V_2, V_3 \), and \( V_4 \), will change 1, 2, 4 and 8 V, respectively. However, these voltages never exceed the reference voltage levels \( +V_R \) and \( -V_R \). Therefore, the frequency of reflection (not of time) also increases by a factor of two with each additional stage.

By dividing the analog input signal \( V_x \) into 16 equally spaced 1-V intervals and by specifying the status of each of the four output signals, \( X_1 \) through \( X_4 \), for each of the voltages, the binary numbers shown in Table 2 result. These binary numbers represent the 16 intervals in the conventional Gray code. As an example, for a voltage, \( V_x \), of -4 V, \( X_1 = 0 \), \( X_2 = 1 \), \( X_3 = 1 \) and \( X_4 = 0 \). The converter, therefore, does indeed convert an analog voltage to a digital Gray-code signal.

Each stage of the analog-to-Gray-code converter, except the first, consists of an absolute value circuit, an amplifier with a gain of minus two, a summing circuit and a comparator. Although there are several possible implementations of this circuit, only one will be described.

As shown in Fig. 18, the single-bit converter consists of two amplifiers, three diodes, one transistor and six precision resistors.

The first amplifier operates as a precision rectifier and also as a comparator. It is well known that an operational amplifier having a diode in series with the feedback resistor has a transfer characteristic like that of an ideal diode (Fig. 18a). In other words, the output voltage, \( V_o \), is zero if the input voltage, \( V_i \), is negative, and \( V_o = V_i \) if \( V_i \) is positive. The only difference between this circuit and the ideal diode is that when \( V_i \) is positive, the output voltage of the amplifier, \( V_o \), equals \( V_i \), because of the inversion in the amplifier.\(^{16,17}\)

The first amplifier performs also as a comparator because when \( V_i \) is positive, the output of the amplifier, \( V_o' \), is negative. And when \( V_i \) is negative, even if by only a millivolt, \( V_o' \) is approximately 1.4 V (2 diode-drops) positive. A transistor, \( Q_1 \), whose base is connected to \( V_o' \) is turned ON when \( V_o' \) is +1.4 V, and is turned OFF when \( V_o' \) is negative. The output of \( Q_1 \) swings between zero and +5 V and is, therefore, compatible with TTL and DTL circuits.

The second amplifier sums \( V_1 \) with \( V_o \) and \( +V_R \). If \( V_i \) is positive, \( V_o \) is negative; the sum of the two is therefore

\[ V_i + 2V_o = V_1 - 2V_o = -V_i. \]

If \( V_i \) is negative, \( V_o \) is zero and the effective input to the second amplifier is only \(-V_i\). The feedback resistor around the second amplifier is chosen as 40 k\( \Omega \), to amplify \( V_i \) by the required factor of two. The input resistor for the reference voltage \( V_R \) is also 40 k\( \Omega \). The two amplifiers with the associated circuitry thus perform the absolute value function, the multiplication of two for \( V_i \), the addition of \( V_R \) and the comparison function as well.

The static accuracy of the single-bit converter of Fig. 18 is mainly a function of the offsets of the amplifiers and the precision of the resistors. The operation of the precision rectifier is largely independent of the diode characteristics. Assuming that the amplifier offsets can be maintained at less than \( \pm 0.01\% \) of full scale, or \( \pm 1 \) mV, and that the resistors can maintain a ratio tolerance of \( \pm 0.01\% \) through temperature and life.
then the accuracy of a single-bit conversion stage will be better than 1 part in 4000. The total accuracy of a 12-bit converter will thus be about ±0.05% over temperature, if the lower-significant stages are also fairly accurate. Schafer\textsuperscript{15} claims a 12-bit (±0.025%) accuracy for his converter; but this is probably at 25°C.

The dynamic accuracy of any such one-bit converter is a very complex function of many factors. Slewing rate and settling time of the amplifiers are the most important ones, but delays through the resistors are also important. The 12-bit converter built by Schafer\textsuperscript{15} exhibited a transport delay of 1.2 ± 0.2 µs, and a settling time for a step-function input of less than 2 µs. This means that a converter of this type could convert

### Table 2. The Gray code

<table>
<thead>
<tr>
<th>$V_x$</th>
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<th>$X_2$</th>
<th>$X_3$</th>
<th>$X_4$</th>
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</tbody>
</table>

multiplexed inputs at a rate of approximately 500,000 per second.

### 4. Variable-reference cascade a/d converter

In all of the cascade a/d conversion techniques described so far, the speed of response is mainly a function of the propagation delays in the amplifiers. Thus high-speed operation can be obtained only when high-speed amplifiers are used.

The variable-reference cascade a/d converter overcomes this dependence on high-speed amplifiers. It does not require any amplifiers, because each conversion stage compares the input signal $V_x$ directly with a specific fraction, $V_{Ri}$, of the

18. Single-bit conversion stage for a/d converter stage of Fig. 16 requires two amplifiers (b). The first amplifier operates as both a precision rectifier and a comparator, and has a transfer characteristic similar to that of an ideal diode (a).

19. Variable-reference cascade a/d converter does not require any amplifiers. This is because each stage compares the analog input voltage with a specific fraction of the reference voltage.
reference voltage to determine the status of the digital output signal \( X \).

A variable-reference cascade a/d converter stage consists only of a comparator and a resistor network that generates the variable reference voltage (Fig. 19). The first converter stage compares \( V_x \) with ground and thus does not even need a resistor network. The networks for the three other stages of Fig. 19 are all different. While the output of the first resistor network, namely \( V_{r1} \), is only a function of \( X_1 \), \( V_{r2} \) is a function of \( X_1 \) and \( X_2 \), and \( V_{r3} \) is a function of \( X_1 \), \( X_2 \), and \( X_3 \).

In general, the output voltages, \( V_{r_k} \), of the resistor networks can be expressed as

\[
V_{r_k} = X_1V_{r1}/2 + X_2V_{r2}/4 + X_3V_{r3}/8 + \ldots,
\]

where \( X_1 \), \( X_2 \), and \( X_3 \) are the digital outputs, and are either ONE or ZERO.

All values of reference voltage required for a four-bit variable-reference cascade encoder are shown in Table 3.

The 4-bit variable-reference cascade a/d converter of Fig. 19 is comprised of four comparators, \( CP1 \) to \( CP4 \), three series-shunt switches, \( S1 \) to \( S3 \), and three resistor networks. The switches, in combination with the resistor networks, generate the variable reference voltages, \( V_{r_2} \) to \( V_{r_4} \), while \( V_{r_1} \) is zero. From Table 3 it can be seen that \( V_{r_2} \) must be \(+1/2 V_R\) if \( X_1 = 1 \), or \(-1/2 V_R\) if \( X_1 = 0 \); that \( V_{r_3} \) must be either \(+3/4 V_R\), \(-1/4 V_R\) or \(-3/4 V_R\), depending on the status of \( X_1 \) and \( X_2 \); and that \( V_{r_4} \) must have 8 different values, depending on \( X_1 \), \( X_2 \), and \( X_3 \).

Strictly speaking, the three resistor networks do not generate \( V_{r_2} \) to \( V_{r_4} \) but instead the voltages \( 1/2(V_x - V_{r_2}) \), \( 2/5(V_x - V_{r_3}) \) and \( 4/11(V_x - V_{r_4}) \). This allows one side of the comparator to be connected always to ground; it also makes smaller both the absolute and differential input voltages to the comparator. The latter is quite important when monolithic comparators are used.

To illustrate the operation of this converter consider the case where \( V_x = +8.4 \text{ V} \), \( V_R/2 = +5 \text{ V} \), and \( -V_R/2 = -5 \text{ V} \). The first comparator, \( CP1 \), determines if \( V_x \) is larger or smaller than zero. Since \( V_x \) is positive, \( X_1 \) becomes a ONE.

As a result, switch \( S1 \) must be in position \( A \), connecting \(-5 \text{ V} \) to its output. The input to the second comparator, \( CP2 \), is hence \( 1/2(V_x + V_{r_2}) = 1/2( +8.4 \text{ V} - 5 \text{ V}) = +1.7 \text{ V} \). Since \( 1/2(V_x - V_{r_2}) \) is positive, \( X_2 \) also becomes a ONE.

Accordingly, \( S2 \) must be in position \( A \), also connecting \(-5 \text{ V} \) to its output. So the input to \( CP3 \) becomes \( 2/5(V_x - V_{r_3}) = 2/5(+8.4 \text{ V} - 5 \text{ V} - 2.5 \text{ V}) = +0.36 \text{ V} \). The resultant voltage is still positive, and \( X_3 \) becomes ONE. Switch \( S3 \) must therefore be in position \( A \), connecting \(-5 \text{ V} \) to the \( 4R \) resistor, and making \( 4/11 \)

\[
(V_x - V_R) = 4/11 (+8.4 \text{ V} - 5 \text{ V} - 2.5 \text{ V}) = -0.1 \text{ V}.\]

Therefore \( X_4 \) becomes ZERO.

The resultant digital output signal is 1110, which represents \(-6/8\). This is the closest approximation possible for a 4-bit encoder with an input of \(+8.4 \text{ V} \) and a reference voltage of \( 10 \text{ V} \).

Any high-speed comparator can be used in this application if its input resistance is high or if its input current is low. The switches used must have either small voltage offsets or small ON-resistances. This is especially true of the switch in the most-significant stage, because it must not only drive lower-value resistors, but more of them as well. This problem could be overcome, somewhat, by using one switch for each resistor, but this would increase circuit complexity. The more practical solution is to make \( R \) large enough so that the switch can still drive three resistors in parallel.

In these resistor networks, only the ratio of the resistors must be accurate. Several types of precision resistors can provide a ratio accuracy of \( +0.025\% \) over temperature and through life.

The accuracy of the variable-reference cascade a/d converter is determined by the precision of the resistors, the voltage offsets or the ON-resistance of the analog voltage switches, and by the offset and gain of the comparator. With suitable components, the four-bit converter of Fig. 19 is capable of performing to an accuracy of approximately \( \pm1 \text{ part in 2000} \).

Basically, this technique can be extended to 10 or 12 single-bit stages. However, a 12-bit converter would require as many as 77 precision resistors, and the switch in the second most-

| \( V_{r_1} \)   | 0 |
| \( V_{r_2} \) | \(+1/2 V_R\) if \( X_1 = 1 \) |
|               | \(-1/2 V_R\) if \( X_1 = 0 \) |
| \( V_{r_3} \) | \(-1/4 V_R\) if \( X_1 = 1, X_2 = 0 \) |
|               | \(+1/4 V_R\) if \( X_1 = 1, X_2 = 0 \) |
| \( V_{r_4} \) | \(-3/4 V_R\) if \( X_1 = 0, X_2 = 1 \) |
|               | \(+3/4 V_R\) if \( X_1 = 0, X_2 = 1 \) |

Table 3. Reference voltages

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significant stage would have to drive as many as 11 resistors of magnitude $R$, or a load of 5 kΩ. The over-all accuracy of a 12-bit converter, assuming a reasonable value of comparator offset voltage, would be approximately 1 part in 1000.

The speed of conversion of this converter is determined only by the propagation delays in the comparator and the analog voltage switches, which can be made 50 and 200 ns, respectively. The total time for a 4-bit conversion is therefore on the order of 1 µs, or about 3 µs for a 12-bit conversion.

5. Partially-cascaded a/d converter

In successive-approximation and serial a/d converters, $n$ basic encoding operations are performed sequentially in time with the same circuitry. In contrast, multi-threshold a/d converters use one comparator for each of the $2^n - 1$ quantizing levels, whereas cascade a/d converters employ one single-bit encoder for each of the $n$ bits of the parallel-binary output signal $X_p$.

A reasonable compromise between these extremes in speed and hardware are the partially-cascaded a/d converters; these are sometimes also referred to as serial/parallel converters.\(^{18,19}\) The generalized form of a 12-bit “4×3” partially-cascaded a/d converter is shown in Fig. 20. The “4×3” implies that there are four stages of three-bit converters. Other possibilities for building a 12-bit encoder would be (3×4) or (6×2).

Theoretically, any a/d conversion technique lends itself to a partially-cascaded system. However, some of these implementations would not offer any advantage over the present methods.

For example, there would be little advantage in partially cascading three 4-bit successive approximation a/d converters or three 4-bit circulation converters, since this would neither improve the conversion accuracy nor the conversion speed, but would only increase the parts count.

Conversely, partial cascading of three 4-bit, variable-reference converters offers a lower parts count with better accuracy and at slightly reduced conversion speed than a 12-bit variable-reference a/d converter. But much more drastic is the parts-counts-reduction for a partially-cascaded $4\times3$ multi-threshold encoder. This would require only 21 comparators as compared with 4096 comparators for a straightforward 12-bit multi-threshold encoder. This tremendous reduction in hardware is obtained without sacrificing accuracy, just conversion speed.

An $m$-by-$n$ bit partially-cascaded a/d converter can be built by cascading $m$ identical $n$-bit a/d and d/a converter combinations with $(m-1)$ operational amplifiers. As an example, in Fig. 20, four 3-bit converters are cascaded with three operational amplifiers. The input signal $V_x$ is connected to the first 3-bit encoder $A/D-1$, which converts $V_x$ into the three most-significant parallel binary bits, $2^{-1}$, $2^{-2}$ and $2^{-3}$. This three-bit digital output signal is then converted back into an accurate analog voltage, $V_{F_1}$, by the 3-bit decoder $D/A-1$, and $V_{F_1}$ is subtracted from $V_x$. The difference $V_x - V_{F_1}$ is then multiplied by a factor of 8 in operational amplifier $A1$, so that the output voltage of $A1$ becomes

$$V_z = 8 (V_x - V_{F_1}).$$

This voltage, $V_z$, is encoded by $A/D-2$ into the three next-most significant digits, $2^{-4}$, $2^{-5}$ and $2^{-6}$, which are converted back into $V_{F_2}$ by

---

20. Concept of partially-cascaded a/d converters is shown by this generalized form of a 12-bit converter.
The second, third, and fourth stages can have errors calculated in a like manner by $A/D - 3$, while $D/A - 3$ produces $V_{r_3}$. The output of amplifier $A3$ is

$$V_i = 8(V_a - V_{r_3}),$$

which is converted by $A/D - 4$ into the three least-significant bits $2^{-10}, 2^{-11}, 2^{-12}$. There is obviously no need for $D/A - 4$, as $V_i - V_{r_4}$ is of no interest.

Although the performance of a partially-cascaded a/d converter is very much dependent on the specific techniques used for the a/d and d/a conversions, there are still many features that are common to all.

- The over-all accuracy is mainly a function of the precision obtained in the first stage. The second, third, and fourth stages can have errors that are 8, 64, and 512 times as large as the allowable error for the first stage.

- Plotting the outputs of any of the three stages, $V_{r_3}$, as a function of their inputs, $V_i$, results in a sawtooth relationship, as shown in Fig. 21. When both the 3-bit a/d and the 3-bit d/a converters of one stage are precise (when the gain through them is exactly unity), the sawtooth voltage, $V_{r_3}$, never exceeds the limits of $+V_a$ and zero (Fig 21a). Here, $+V_a = V_x_{max}$, which for convenience is assumed to be $+8$ V. When the gain through the converters is smaller than unity, $V_{r_3}$ can become smaller than $V_i$ and the sawtooth voltage will exceed the $+8$-V limit for certain values of $V_i$ (Fig. 21b). When the gain is larger than unity, $V_{r_3}$ can become larger than $V_i$, and the sawtooth voltage becomes negative for certain values of $V_i$ (Fig. 21c).

- Only the 3-bit d/a converters need to be precise.

- Any errors in the 3-bit d/a converters can be detected by determining whether the sawtooth waveform is larger than $+8$ V or whether it is negative.

- If any of the amplifier output-voltages exceed the above limits, corrective measures can be initiated. This, however, requires additional comparison circuits and means for storing and changing the digital outputs of the 3-bit encoders.

- The question thus arises whether it would not be more economical to make the 3-bit a/d converters accurate in the first place and, by so doing, eliminate the need for the error-correction circuits.

References:


21. Errors occur in a cascaded a/d converter when the gain through one of the 3-bit stages is other than unity.
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<th>Pulsed</th>
<th>VceX</th>
<th>VceO(sus)</th>
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<th>Vce(sat)@10A</th>
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INFORMATION RETRIEVAL NUMBER 38
Design better sequential circuits
by combining flow tables with Karnaugh maps
to minimize the number of logic elements needed.

In designing sequential circuits, such as counters, you can rely on timing diagrams—and then hope that your design doesn’t use too many extra logic elements. Or you can adopt a systematic approach that uses flow tables and Karnaugh maps—and wind up with a guaranteed minimum-element logic design.

It’s a little more work to use the systematic method, but it will increase the reliability of the circuits and will probably save you money in the end. Consider, for example, the design for a decade counter.

A counter consists basically of a series of memory elements connected by a combinational network. The memory elements are normally flip-flops, and the combinational network is usually an array of gates that feed the outputs back into the inputs of the flip-flops to form a sequential circuit. As the counter receives pulses, the series of flip-flops changes its state, according to a predetermined pattern. The state at a particular time reflects the number of pulses received, until a maximum number of counts is reached; at this time the counter begins another cycle and the pattern of states is repeated.

For a decade counter, there are 10 states.

First write your specs

In designing a counter, you must consider the following design points:

- Counting speed.
- Logic characteristics of flip-flops.
- Synchronous or asynchronous operation.
- Maximum count or modulo required.
- Counting code.

The required counting speed will determine the family of integrated circuits to be used. Typical counting rates are shown in Table 1. The logic characteristics of the flip-flop will be determined mainly by the device types available in the chosen family.

Synchronous operation, in which all the flip-flops are switched simultaneously by the active transition of a common clock pulse, can be used to increase the counting speed. In the asynchronous mode, the output of one flip-flop is used to trigger the next. Asynchronous operation provides simpler counters, but the delay caused as the count ripples through several flip-flops in series requires a slower counting rate.

In a modulo $M$ counter, $M$ pulses will be received before the count cycle is repeated. This requires that the counter have $M$ distinct states in normal operation. These $M$ states can be chosen from the $2^N$ states obtained by connecting $N$ flip-flops in a sequential circuit. The states chosen, and the order in which they are made to occur, will depend on the design objectives. Once these are chosen, we can draw a flow table showing the state of all of the flip-flops as each of the input pulses indexes the counter. We can then examine the changes that each flip-flop must undergo as the counter indexes from its state at bit time $t$ to the state at $t+1$. A Karnaugh map can then be made for each of the $N$ flip-flops.

Each map will have a square for each of the $2^N$ possible states. The changes that a particular flip-flop must make (determined from the flow table) can be entered onto its Karnaugh map. This procedure will leave us with $N$ maps (one for each flip-flop) that show the logic changes required for each state of the counter.

We can then use the maps to determine the simplest inputs to the flip-flops that will do the job.

Hence the task of designing a counter that counts to a particular code is reduced to the determination of a combinational network. This network will provide the correct inputs to the flip-flops to ensure that each makes a correct change as the counter changes state.

Note that by constructing maps for both the forward and reverse direction of the state flow table, the input conditions for an up-down counter can be obtained.

The $2^N-M$ redundant states on the map can be marked "optional" to provide further simplification. However, noise may trigger the counter into one of these spare states. If this occurs, it will
be desirable to have the counter index back into the normal cycle and thus avoid a "locked up" condition. Therefore, when the counter has been constructed with use of the minimized connections obtained from the Karnaugh map, it should be forced into each of the spare states and checked to see that it will index back into the normal counting cycle. Modifications may be required to ensure that no "locked up" condition occurs.

**Designing a synchronous decade counter**

By definition, a decade counter must have 10 unique states. This requires four flip-flops, since three can produce only \(2^3 = 8\) states. A flow table can be constructed showing the states of each of the four flip-flops—A, B, C and D—for 10 consecutive time periods. This has been done in Table 2. In the table, the state of each flip-flop is shown for two consecutive time periods, \(t\) and \(t+1\). As we proceed down the two columns labeled "A," we can see the change required of flip-flop \(A\) each time the counter is indexed. These changes are noted on the Karnaugh map for flip-flop \(A\), along with a notation showing the state of the counter. The Karnaugh maps for the four flip-flops are shown in Fig. 1. The symbols used in the maps are defined in the nomenclature box.

To understand the use of these maps and tables, let's examine, in detail, the changes occurring between states 3 and 4. At the termination of state 3, flip-flops \(A\) and \(B\) are RESET so a \(\phi\) is inserted in the squares \(ABCD\) of Fig. 1a and 1b. At the same time flip-flop \(C\) is SET and a 1 is placed in the \(ABCD\) square of Fig. 1c. Flip-flop \(D\) remains RESET and therefore a 0 is placed in the \(ABCD\) square of Fig. 1d. There are six squares corresponding to the six unused states of the 16 states that are possible with four flip-flops. These can be marked "optional" and used to simplify the Boolean terms derived for the SET and

---

**Table 1. Typical counting rates**

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<th>Family</th>
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<td>Diode transistor logic (DTL)</td>
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<td>Transistor transistor logic (TTL)</td>
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<td>Complementary transistor logic (CTL)</td>
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<tr>
<td>Emitter coupled logic (ECL)</td>
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**Table 2. Decade counter flow table**

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<th>State</th>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
RESET conditions.

The rules for writing equations from the maps are different for the three basic types of flip-flops and are given in the box on page 84.

From Fig. 1a, we get the equations:
\[ S_A = A \text{ and } R_A = A. \]

From Fig. 1b, we get:
\[ S_B = AB \overline{D} \text{ and } R_B = AB, \]
or, alternatively: \( R_B = \overline{ABD}. \)

From Fig. 1c, we have:
\[ S_C = ABC \text{ and } R_C = ABC, \]
or alternatively: \( S_C = \overline{ABC} \overline{D} \text{ and } R_C = \overline{ABC} \overline{D}. \)

And, finally, from Fig. 1d, we get:
\[ S_D = ABC \text{ and } R_D = AC, \]
or, alternatively: \( S_D = ABCD \text{ and } R_D = AD. \)

The alternatives are preferred in constructing the decade counter, since they can be formed from existing signals, as illustrated in the final design of Fig. 2, where a counter was designed with R-S flip-flops.

As the colored areas on the Karnaugh maps show, the equations are written by describing, in Boolean algebra, the inputs necessary to produce the desired changes in the outputs. The map-reading rules for R-S flip-flops tell us how to do this.

2. The simplicity of this synchronous decade counter has been enhanced by taking maximum advantage of existing signals in constructing the combinational network. Only R-S flip-flops have been used.

### Karnaugh map nomenclature

The following notation is used to indicate each of the five possible conditions.

1. The flip flop changes from the RESET to the SET state.
2. The flip flop is initially in the SET state and remains in the SET state.
3. The flip flop changes from the SET state to the RESET state.
4. The flip flop is initially in the RESET state and remains in the RESET state.
5. Input conditions do not occur or a DON'T CARE state occurs.

More concisely:

<table>
<thead>
<tr>
<th>Change</th>
<th>t</th>
<th>t + 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>/</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( \phi )</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The SET state of flip-flop \( A \) is defined by the output \( A \) being 1 and \( \overline{A} = 0 \). The RESET state occurs when \( A = 0 \) and \( \overline{A} = 1 \).

### Table 3. Waveform generator table

<table>
<thead>
<tr>
<th>STATE</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

CLOCK

\( 0 \quad 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \)

### Circuit Diagram

[Diagram of a synchronous decade counter with flip-flops and logic gates]

3. A problem arises in the generation of these three waveforms, because the states in the sequence are not all unique. The solution is a fourth waveform designed to resolve the ambiguity.
For example, if we consider flip-flop B, we note that the SET term, $S_B$, must include all of the ones and omit all of the zeros and $\phi$s. Any of the six redundant squares and those marked with a $\phi$ can be used to obtain a minimum SET term. Since the ones occur in the boxes $A B C D$ and $A B C D$, we can write $S_B = ABD$. Similarly $R_B = AB$. Here we note that if we make the equation more complex, by writing $R_B = ABD$, we do not change its validity because the two states we eliminated were optional, but we have changed the logic to a form including $AD$, which we are going to need anyhow to satisfy $S_B = ABD$. Thus we have reduced the complexity of the final circuit.

Synchronous waveforms can be generated

The techniques we have been considering can be used for other sequential circuit applications, such as the generation of a set of synchronous waveforms. In the latter application, each waveform is taken from the output of an individual flip-flop, and the set of sequential states that the set of flip-flops go through can be used as the basis for a flow table, as before.

4. Four Karnaugh maps are needed to generate the three waveforms of Fig. 3, because of the need for ambiguity resolution. The fourth map (d) provides it by introducing a fourth waveform.

5. The three waveforms of Fig. 3 are generated by flip-flops A, B and C of this synchronous waveform generator. Flip-flop D is employed to ensure that all of the generator states are unique.
Map reading rules

For the R-S flip-flop

S TERM 1 Each square must be accounted for in S Term
/ Optional
φ Must not be used
0 Must not be used
- Optional

R TERM 1 Must not be used
/ Must not be used
φ Each square must be accounted for in R Term
0 Optional
- Optional

For the T flip-flop

T TERM 1 Each square must be accounted for in T term
/ Must not be used
φ Each square must be accounted for in T term
0 Must not be used
- Optional

For the J-K flip-flop

J TERM 1 Each square must be accounted for in J term
/ Optional
φ Optional
0 Must not be used
- Optional

K TERM 1 Optional
/ Must not be used
φ Each square must be accounted for in K term
Each square must be accounted for in K term

The differences between the various types of flip-flops are shown in the truth tables below. In each case the output is shown as a function of the input signals. But, since the flip-flop has memory properties, the output may also be a function of its history. Thus, the notation "NC" means no change from its previous condition and "C" means complement or change the output. In the case of the R-S flip-flop, the notation "?" is used to indicate an indeterminate condition.

As an example, suppose we want to generate the three waveforms of Fig. 3. An interesting subtlety arises here, because the flip-flop states are symmetrical about clock period 3. This means that the state of the generator cannot be uniquely determined by examining the states of the three flip-flops. To eliminate this ambiguity, a fourth flip-flop is employed. It is left in the RESET state for periods 0 through 2 and in the SET state for periods 3 through 5. This artificially makes each state different from all of the others.

The logic diagrams for the three kinds of flip-flops show how the R-S flip-flop is converted to the J-K type by adding two feedback signals.

lead to the following equations:

\[ S_A = A, \quad R_A = BD \]
\[ S_B = AD, \quad R_B = CD \]
\[ S_C = BD, \quad R_C = D \]
\[ S_D = B, \quad R_D = B \]

An implementation of these equations using R-S flip-flops is shown in Fig. 5.

Asynchronous counters are no problem

There is no need for these design methods to be limited to synchronous counters; asynchronous, or ripple, counters can also be treated. These counters do not have a clock input common to all of the flip-flops. Only the first one is activated by an external clock.

To illustrate the peculiarities of an asynchrone-
nous design, let's do an asynchronous decade counter. Table 2, for the synchronous counter, still applies. However, Fig. 6, the Karnaugh maps, differs from Fig. 1 because all of the flip-flops do not receive a clock pulse every time flip-flop A does.

For the type of flip-flop we will use in our design, the active edge of the clock signal is that which occurs when the clock input is falling from a 1 level to a 0 level.

Working from Table 2, we can choose the A output to activate the clock input of flip-flop B and the B output to activate the clock input of flip-flop C. However, we must use the A output for the clock input of flip-flop D, as this is the only output with an active edge at state 9, when flip-flop D must be reset.

After choosing the clock inputs, we must complete the Karnaugh maps. It will be observed that each square for a particular map must be defined whenever an active transition of the clock input occurs for the flip-flop corresponding to that map. For flip-flop A, each of the squares for the 10 separate states has a 1 or $\phi$, because an active clock transition occurs at its clock input for each of the 10 states.

For flip-flop B, active input clock transitions occur for states 1, 3, 5, 7 and 9. For states 0, 2, 4, 6 and 8, we can place an optional mark in the corresponding squares of the B Karnaugh map. This indicates that we should choose a clock input with the minimum number of active transitions to maximize the number of optional squares. After the maps have been completed, the minimum SET and RESET terms can be used to construct the ripple counter shown in Fig. 7.

6. These maps differ from those of Fig. 1, even though they are based on the same flow table. The reason is that the asynchronous counter does not have all of its flip-flops clocked with every input pulse.

7. The asynchronous counter is simpler than its synchronous counterpart (Fig. 2) but not as fast. The speed is limited by the need to wait for each pulse to ripple through the entire counter before the next one is applied.
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INFORMATION RETRIEVAL NUMBER 39

INFORMATION RETRIEVAL NUMBER 40
Stop the revolt in the labs! Engineers demand more than pay to be content. Learn how to ‘involve’ them in their work.

Unlike the college campus, on which students are resorting to picketing, faculty lockouts and riots to gain participation in decisions affecting their careers, there is no visible revolt in the nation’s laboratories.

Yet numerous opinion studies among engineers and scientists in industry reveal that, like the students, many feel that their wishes on the job have been receiving short shrift. Like today’s students, they’re seriously dissatisfied with the situation. Only their dissatisfaction shows up, not in wrecked classrooms, but in such symptoms as turnover and just-enough-to-get-by performance.

Surveys show that basic managerial practices may be to blame for much of the problem. They can be corrected, in some cases relatively painlessly, but in others, only by reversal of ingrained policy.

Why pick out engineers and scientists? Do they need more say-so in their work than other groups? The answer is yes, as indicated by a number of studies conducted by Opinion Research Corp., Princeton, N.J.

In the excerpted ratings of the importance of various job factors to the employees of three companies (Table 1), compare the way electrical, mechanical and chemical engineers feel with the way clerical and hourly rated employees do. Such factors as pay and job security were deliberately omitted to gain insight into the satisfactions that employees seek once these basic needs are met.

More so than clerical or hourly employees, engineers seek personal involvement in their work. On the other hand, they are less sensitive than other employees to fringe factors of the job such as a clean house, a one-big-happy-family atmosphere and the like.

Note the shift of engineers’ interest away from areas that supervisors and company personnel structures traditionally stress as the survey continues in Table 2.

In yet another study that covered only research scientists and engineers, respondents rated work enjoyment and the authority to make decisions second and third behind pay as of major importance on the job.

Fit management to the men

Results like these, which have been confirmed in numerous studies, carry a clear message to the engineering manager: A “we know best what you need” style of supervision simply falls short of the mark with engineers. Leaning on it invites, in sequence, apathy, noninvolvement and minimal productivity.

Conversely, a strong clue to gaining maximum productivity from engineers lies in their openly expressed desire for job involvement. Giving serious consideration to engineers’ views, letting them assist in making decisions involving their work and seeing to it that they’re given meaningful responsibilities and the chance to make the most of their talents could open the door to new heights of achievement.

What continues to surprise, however, is the continued apathy of many companies toward meeting these expectations of their professional employees. In 1959, Opinion Research Corp. published a study, “The Scientific Mind and the Management Mind.” This report documented the widespread discontent among scientists and engineers with how they were being treated in

<table>
<thead>
<tr>
<th>“It’s of top importance to me—”</th>
<th>Engineers</th>
<th>Clerical employes</th>
<th>Factory employes</th>
</tr>
</thead>
<tbody>
<tr>
<td>That I make the most of my talents.</td>
<td>73%</td>
<td>57%</td>
<td>50%</td>
</tr>
<tr>
<td>That I feel my views are taken seriously by those above me.</td>
<td>63</td>
<td>51</td>
<td>44</td>
</tr>
<tr>
<td>That I have important responsibilities.</td>
<td>41</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>That I be allowed to make important decisions affecting my work.</td>
<td>34</td>
<td>18</td>
<td>15</td>
</tr>
</tbody>
</table>

Alfred Vogel, Director of Employee Relations and Management Research, Opinion Research Corp., Princeton, N.J.
"An environment that invites innovation and taps a wider range of their abilities will release the energies of professional people."
industry. In it substantial majorities of engineers and scientists in six companies noted that they were forced to overspecialize, that they weren't given enough freedom on the job, that too often they were immersed in detail, that their abilities were being too closely channeled to what had already been proved—in short, that they were poorly utilized.

Today, as new studies are undertaken, the same problems are turning up in many companies, some of which are constantly recruiting new talent in the market. Quite often little or no attempt has been made to give the talent on hand an opportunity to reach full potential, according to scientists and engineers.

Education breeds disbelief

The evidence is mounting through opinion surveys that younger, better-educated employees tend, in fact, to be more dissatisfied with their experiences in industry than older, less educated employees. There is, of course, a high correlation between age and education. Younger people, by and large, have had more schooling, and three factors cause them to question managerial attitudes that they encounter in industry.

(1) A product of today's education is an attitude of questioning "the establishment." The more recently schooled employees tend to ask of high-sounding management policies, "Is it so, or is the management only giving lip service to it?"

(2) There is a rising trend in society, especially among young people, toward favoring democratic values. And young people have learned to equate participation in decisions that affect their lives with democratic values.

(3) Young people today have higher expectations regarding work than previous generations. A job is regarded as more than just a way of earning a living; it's a means of achieving psychological satisfaction.

The results of a study of all employee groups in a large company (Table 3) illustrates the relationship between education and employee attitudes. The better-educated group includes engineers and other who attended or graduated from college. Note that better-educated employees consistently give their company lower ratings.

A second example from a study among employees in another company (Table 4) touches on other areas and further points out how the "acceptance gap" widens with education.

Both studies show that better-educated employees are more critical. Indications are that this trend will grow and that widespread frustration and discontent among them will increase.

Lack of outspoken resentment should not be taken as an indication that a manager's decisions meet with his engineers' approval and support, as the companies sponsoring the preceding surveys learned. And the manager seeking to avoid the effect of frustration and discontent on the job will do well to consider delegating to his engineers certain important decisions affecting their work. It may make the difference between a group which merely "puts in time" and one that more fully cooperates in reaching goals.

At the opposite pole from the engineer who
Table 5. A monument to status-quo management

<table>
<thead>
<tr>
<th>Statement</th>
<th>Agree</th>
<th>Hard to decide</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many managers here practice a don’t-rock-the-boat philosophy,</td>
<td>95%</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>rather than attacking problems aggressively</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One can get by in this company merely by keeping one’s nose clean</td>
<td>97%</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Good ideas for improving performance often don’t get to the people who</td>
<td>86%</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>have the power to make decisions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>There is too much emphasis on established procedures, not enough on</td>
<td>81%</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>providing new ways</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Many people here are against change—they prefer to keep things the way</td>
<td>73%</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>they were in the past</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The above judgements were expressed in an opinion survey made among</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>engineers (largely EEs) and management personnel of one company.</td>
<td></td>
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</tr>
</tbody>
</table>

“puts in time” is the one who comes up with creative performance. A prized commodity, creative performance calls for a high degree of voluntary self-commitment to the job by the engineer, which one would think an employer would go to great lengths to generate through his chains of command.

But studies show that in more than one company preventing innovation has become an institutional feature; it’s part of the company’s reward structure through which engineers and managers alike take their cues as to what is legitimate and what is prescribed behavior. Results of an opinion survey in one such company are shown in Table 5.

While major upheavals may be called for to reverse the anti-creativity climate in such companies, two steps are basic:

1. Rewards for innovation must be incorporated into the compensation structure.
2. “Change-mindedness” must be institutionalized through strong management actions. The higher up the ladder they begin, the more effective.

Back-talk is not a waste product

The fond delusion exists among some top managements that professional employes consider themselves “one of us” and are more willing than other employes to exert themselves for company goal as a result—“Aren’t they allowed more freedom of motion, consultation and expression than the man on the machine or the clerk at the desk?”

But this feeling is frequently unfounded. Surveys show that engineers, often only to a slightly lesser extent than other employees, feel left out when it comes to shared confidences with management.

In many companies, management stands to cut away layers of resentment that block fuller job commitment on the part of engineers by diverting some of the attention now lavished on elaborate house organs and programs designed to communicate to or at employes into encouraging questions from employes and listening to their views.

One 10-plant company discovered this when these survey responses were returned from its employes:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Agree</th>
<th>Disagree</th>
<th>No Opinion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generally, management is more interested in telling us what they think we</td>
<td>78%</td>
<td>21%</td>
<td>1%</td>
</tr>
<tr>
<td>ought to know than what we want to know.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clerical employes</td>
<td>67</td>
<td>29</td>
<td>4</td>
</tr>
<tr>
<td>Production employes</td>
<td>68</td>
<td>31</td>
<td>1</td>
</tr>
<tr>
<td>Engineers-scientists</td>
<td>73%</td>
<td>25%</td>
<td>2%</td>
</tr>
</tbody>
</table>

There is not enough opportunity for employes to let management know how we feel on things that affect us and our work.

Constricted communication lines to management are a root cause of engineer dissatisfaction. And the second article in this series will show just how serious this problem is and what can be done about it. ■
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Home Address (Street) | City | State | ZIP Code |
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Age | U.S. Citizen | Security Clearance |
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<td></td>
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<td>No</td>
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Prime Experience

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<th>Dates to</th>
<th>Title</th>
<th>Specialty</th>
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</thead>
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Secondary Experience

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<th>Dates to</th>
<th>Title</th>
<th>Specialty</th>
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Desired Salary

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<th>Employment History – present and previous employers</th>
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<td>Company</td>
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Availability Date

Education – indicate major if degree is not self-explanatory

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Additional Training – non-degree, industry, military, etc.

Professional Societies

Published Articles

Career Inquiry Numbers:

900 901 902 903 904 905 906 907 908 909
910 911 912 913 914 915 916 917 918 919

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Book Reviews

Mathematical methods

Mathematical Methods for Physicists and Engineers, Royal Eugene Collins (Reinhold Book Corporation, New York), 385 pp., $14.95.

Focusing on the requirements of beginning graduate students in science and engineering, R.E. Collins has attempted to place in their hands the mathematical tools that they most sorely need. “Tools” is the term used by the author himself in describing his design of eliminating unnecessary rigor in order to impart a sound practical command in the shortest possible time. The areas covered include vector calculus, matrix algebra, linear vector operations, the calculus of variations, integral equations and methods of solving linear boundary problems. Because of the inadequacies of many university courses, much time is often spent, in physics and engineering courses, on the teaching of mathematics. With a view toward eliminating such deficiencies, this book offers a solid grounding in the mathematical methods that are the foundation of both science and engineering.

CIRCLE NO. 250

Scientific glass work


Together with the companion color film available from the publisher, Creative Glass Blowing can serve as the nucleus of a training program for you or members of your staff. It can also help personnel dealing with outside glass blowing firms to understand what is involved in creating a complex piece of apparatus.

Three chapters lay the groundwork by describing the tools, the equipment and the techniques. One full chapter is devoted to a discussion of scientific glassware including details on the fabrication of a helium-neon laser tube.

CIRCLE NO. 251
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FET and UJT provide timing over wide temperature range

The combination of an n-channel junction FET and a programmable unijunction transistor (the General Electric D13T2) can provide accurately timed pulses (1 second to many hours) over a wide temperature range.

In operation (see figure), capacitor $C_T$ charges to the threshold voltage of the unijunction circuit ($Q_2$), minus the $V_{GS}$ OFF voltage of the FET ($Q_1$). $C_T$ then discharges through the now forward-biased gate-to-source diode of $Q_1$. The voltage at which $C_T$ discharges to deliver an output pulse across resistor $R_3$ is:

$$V_{\text{firing}} = (R_1/R_1 + R_2) \times V_{CC} - V_{GS_{\text{off}}}$$

The gate-to-source diode of the FET has been examined for devices of several different manufacturers, and only the two shown have been found to contain characteristics suitable for this discharge.

If $R_1$ and $R_2$ are selected so that $V_{\text{firing}}$ is about 63 per cent of the supply voltage ($V_{CC}$), then the period of oscillation, $T$, for the circuit is one time constant.

$$T = R_T C_T$$

The circuit is a 30-second timer, and has been temperature cycled between $-30^\circ C$ and $+75^\circ C$ with the following results.

Use DDA techniques for arc sine/arc cosine generation

A past article in ELECTRONIC DESIGN has described the implementation of sine/cosine generation by means of digital-differential-analyzer (DDA) integrators. These integrators are based on MOS technology, and a complete integrator is composed of only two chips. Using a similar technique, arc sine/arc cosine generation can also be accomplished (see illustration).

The implementation of the digital arc sine/arc cosine generator as shown here, was performed with the General Instrument Corp.'s MEM5021 DDA adder element, MEM3016 dual shift register, and MEM5031 servo adder element. The DDA adder element and the shift register combine to form one DDA integrator, with the complete generator comprising three such integrators and one servo adder.

The operation of the DDA integrator is described in References 1 & 2 and is quite straightforward. The servo adder is a logic element that serially examines a shift register and determines whether the contents are greater than, equal to, or less than zero. For anything other than zero,
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the servo adder continuously puts out pulses. These pulses can be of either polarity, with specific polarity being dependent on the shift-register contents. The feedback signal, \((\sin y)\) is compared with input \(x\) and the result is applied to the input of the servo adder. The output of the servo adder, \(y\), will move incrementally in such a way as to make \(\Delta L\) go to zero. For instance, if \(\sin y > x\), a sequence of increments will occur at the output of the servo adder which will reduce \(y\), which will in turn reduce \(\sin y\). If \(\sin y < x\), then the reverse will happen. In this fashion a sine function is generated that is equal in amplitude to the input. Since the feedback block is a sine generator, it follows that the input to the sine generator is \(y\), or \(\arcsin x\), when \(\sin y = x\).

If \(\arccos x\) is required, then the feedback loop is connected to the cosine output of the sine-cosine generator.

**References:**


**Simple resistor network eliminates dc tachometer**

In servomechanisms, there is often a need for a feedback voltage that is proportional to the rate at which the servo is being driven. This signal voltage is sometimes required to stabilize a positional servo loop, or it is used as the total feedback, as in the case of a velocity loop.

If the servo is driven by a dc motor, a dc tachometer will often be used to provide the rate feedback. Consider a common application of a dc tachometer in a velocity loop, as shown in Fig. 1. The tachometer feedback signal is compared with the input signal, and the difference voltage is amplified. The amplifier error signal causes the dc motor to speed up or slow down until the error is minimized. The speed of the output is therefore made proportional to the input signal.

The same feedback voltage can be readily supplied with the simple resistor network shown in Fig. 2. An understanding of the circuit’s operation can be obtained by considering the following derivation:

The voltage across the armature of a shunt dc motor (with a fixed field excitation) can be expressed by the equation

\[ V_A = I_A R_A + V_B, \]

where

\[ V_A = \text{armature voltage (V)}, \]
\[ I_A = \text{armature current (A)}, \]
\[ R_A = \text{armature resistance (ohms)}, \]
\[ V_B = \text{back electromotive force (V)}. \]

The back emf is proportional to the speed of the motor, and therefore

\[ V_B = K \times S, \]

where

\[ K = \text{proportionality constant and } S = \text{motor speed (RPM)}. \]

Combining equations yields

\[ V_A = I_A R_A + (K \times S). \]

Analyzing this equation, we see that the armature voltage consists of two components, one proportional to the current passing through the

---

1. *Dc tachometer feedback* as commonly used in velocity servo loops.
2. *Simple resistor network* can provide the same feedback characteristic as a dc tachometer.
The MOS 701 and 901 Buffered Tape Units each provide three modes of operation... Write, Read or Search. The 701 handles data on 7-channel magnetic tape at 200 bpi, while the 901 provides 9-channel, 800 bpi facilities.

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armature and the second proportional to the speed of the motor. The voltage $V_a$ therefore cannot be used as a velocity feedback signal, but a voltage proportional to $V_n$ would be usable. This requirement is satisfied as follows:

The voltage across $R_2$ is

$$V_{R2} = \frac{R_2}{R_1 + R_2} (V_T),$$

where $V_T$ = total applied voltage (V).

The voltage across $R_3$ is

$$V_{R3} = (V_T - V_n) \frac{R_3}{R_1 + R_3},$$

and

$$V_{R3} = V_T \left( \frac{R_3}{R_1 + R_2} \right) - V_n \left( \frac{R_3}{R_1 + R_3} \right).$$

The feedback signal ($V_f$) can be seen to be

$$V_f = V_{R2} - V_{R3}.$$  

And, by substitution,

$$V_f = V_T \left[ \left( \frac{R_2}{R_1 + R_2} \right) - \left( \frac{R_3}{R_1 + R_3} \right) \right] + V_n \frac{R_3}{R_1 + R_3}.$$ 

It can be seen that if the ratio of $R_3:R_2$ is made equal to the ratio of $R_2:R_3$, then the above equation reduces to

$$V_f = V_n \frac{R_3}{R_1 + R_3}.$$ 

The feedback signal is therefore made proportional to the back emf of the motor and also proportional to its speed.

There is only one critical design decision in selecting values for a particular motor: the value of $R_a$. From the preceding equation, we see that the larger $R_a$ is, the greater the feedback voltage will be. However, $R_a$ cannot be made indiscriminately large, since the total armature current must pass through it. Generally, $R_a$ should be anywhere from 1/10 to 1/3 of $R_4$.

As an example, consider a typical dc shunt motor whose armature resistance is 10 ohms. At rated load it would draw 1 A, with 100 V applied to its armature, and it would run at 10,000 rpm. If $R_a$ is made 2.9 ohms, the total applied voltage would have to be increased to 102.9 V. The feedback voltage is derived and found to be

$$V_f = 90 \left( \frac{2.9}{10 + 2.9} \right) = 20 \text{ V}.$$ 

This is generally considered to be a good signal level, and the loss in $R_a$ is only 2.9 W.

The factors that determine the selection of $R_1$ and $R_3$ are the output impedance of the feedback voltage and the losses in these resistors. If the sum or $R_1$ and $R_3$ is made equal to 10,000 ohms, the output impedance of the network could never exceed the value of $R_a$, and in this particular case it would be 2.25 kΩ. The maximum loss would be 1 W ($100^2 / 10,000$).

The tachometer network is handled analytically, as one would handle an ordinary tachometer in a servo loop analysis. Further, the benefits derived from ordinary tachometer feedback are also derived from tachometer network feedback. For example, the dynamic gain of a positional servo loop would be reduced and stabilized, its open-loop characteristic linearized and, finally, its bandwidth extended. All of this can be had for the cost of a few resistors.

Martin Kanner, Staff Engineer, Grumman Aircraft Engineering Corp., Bethpage, N.Y.

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**Emitter-coupled multi boosts variable-frequency performance**

A simple addition to the basic emitter-coupled multivibrator circuit provides a versatile way to vary frequency without modifying the duty cycle. The circuit has good stability with respect to both temperature and supply-voltage variations, and it may be used in the nonsaturated current mode for wide-range, high-frequency operation.

A basic emitter coupled multivibrator is shown in Fig. 1. If the circuit is operated so that each transistor is saturated during its ON period, the boundary conditions do not depend on the transistor parameters to a first approximation. The operating frequency can therefore be expressed in terms of $R_1$, $R_2$, $i_1$, $i_2$ and the supply voltages.

---

**Figure 1.** Adjustment of resistor $R_3$ provides adjustment of frequency without affecting the duty cycle.
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TA7403 is a new configuration... designed especially to simplify oscillator circuitry. Featuring 0.5 watt output at 2 GHz (at 21 V operation), this all-new RCA epitaxial silicon n-p-n transistor will be especially attractive to designers looking for a device that acts as a superior self-excited oscillator at L-band and higher microwave frequencies.

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For more information on RCA-TA7403, see your RCA Representative. Ask him, too, about RCA-2N5470 for your UHF and microwave amplifier applications. For technical data, write: RCA Electronic Components, Commercial Engineering, Section P-G-12-1, Harrison, N.J. 07029.
However, if the circuit is required to operate in the nonsaturated mode, the T2-ON boundary condition is heavily $\beta$ dependent. As a result, the frequency of oscillation in the nonsaturated mode is not predictable and is also temperature dependent, due to variations of $\beta$.

The inclusion of resistor $R_3$ from the collector of T1 to ground immediately rectifies the inadequacy (see reference). Now, when T1 is OFF and T2 is ON, the emitter of T2 rises to a voltage determined only by the ratio of $R_3$ and $R_v$, provided the base current of T2 is small. Further, the addition of $R_v$ does not appreciably affect the T1-ON condition, since it presents merely an additional shunt across a small voltage. The modification to the basic circuit causes both boundary conditions to be well defined and predictable, and eliminates the severe temperature dependency of frequency.

It may be observed now that variation of $R_v$ provides an excellent means of varying the frequency of oscillation of the circuit. Further, since the duty cycle (ON-OFF ratio) is determined only by the relative magnitudes of $i_1$ and $i_2$, adjustment of $R_v$ provides control of frequency without modifying the duty cycle. This feature is most attractive, since a considerable amount of additional circuitry must normally be added to conventional oscillators to achieve equivalent performance.

When a voltage-controlled oscillator (VCO) or voltage-to-frequency converter (VFC) is required, $R_v$ may be replaced by a transistor, as shown in Fig. 2. The basic circuit of Fig. 2 was used with $C=100$ pF and 2N2369 transistors in a closed-loop, frequency-control application involving control in the range 2 to 5 MHz.

**Acknowledgment:**
The author would like to thank Burroughs Corp. for permission to publish this circuit note.

**Reference:**

J. J. Pinto, Director of Engineering, Bissett-Berman Corp., E-Cell Product Div., Santa Monica, Calif.

**VOTE FOR 314**

**Auxiliary power supply uses IC gates**

In a single-supply logic system, the need sometimes arises for a second dc supply of opposite polarity to furnish a small amount of power to interface circuits. This second supply can be constructed using IC gates as choppers (see diagram).

The power supply shown here uses one-half of an Amelco 321 quad gate, which provides full-wave chopping. The gate may be driven by the system clock. This supply furnishes 5 V at 2 mA, when driven with a 5-kHz system clock.

Lanny L. Lewyn Sr., Research Engineer, Jet Propulsion Lab, Calif. Institute of Technology, Pasadena.

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**Domestic Representatives:** Compag Corporation at the following locations: Scottsdale, Arizona (602) 947-4336; Denver, Colorado (303) 781-0921; Southfield, Michigan (313) 357-5360; Haddornefield, New Jersey (609) 479-1556; Albuquerque, New Mexico (505) 265-1020; Albany, New York (518) 489-1408; Endwell, New York (607) 723-8743; Fairport, New York (716) 271-2230; Saratoga, New York (518) 471-3356; Rocky River, Ohio (216) 333-4212; Faribana, Ohio (513) 878-2831; Dallas, Texas (214) 685-1256; Houston, Texas (713) 667-9450; Quick Electronic Marketing, Inc., St. Louis, Missouri (314) 423-7200.

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INFORMATION RETRIEVAL NUMBER 47

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ACCURACY
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AC ± 4.5%

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$84.50

FE16 HI ACCURACY FET METER

ACCURACY
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AC ± 3%

* 4½-inch high-styled meter, high-styled knobs, and special meter-titting metal handle. Vinyl-clad steel case.
WHEN ONE INSTRUMENT MEASURES RETURN LOSS, VSWR, GAIN, INSERTION LOSS, FREQUENCY RESPONSE, ABSOLUTE POWER, AND LOCATES FAULTS, TOO...

YOU'VE GOT A MICROWAVE LAB IN A BOX!

Look what $1830 will put on your bench. The Alfred 8000/7051 Sweep Network Analyzer is the economical, convenient way to do all of the functions of a SWR meter, power meter, ratiometer, lin log converter, precision attenuator and oscilloscope. One low price includes everything but the directional coupler and crystal detectors. All measurements are made over a 60 db dynamic range with either direct db or dbm readout.

Fast measurements with high accuracy. Measure return loss and insertion loss or gain simultaneously at fast sweep speed for oscilloscope display. Digital readout for accurate measurements.

Applications notes 101 & 105 tell all. For complete information on the Alfred 8000/7051 Sweep Network Analyzer, please write for Applications Notes 101 and/or 105. Note 101 provides detailed applications data for all measurements, including noise. Note 105 offers information on the use of the analyzer to test microwave transmission systems, including coaxial cable and waveguide runs. Please address Alfred Electronics, 3176 Porter Drive, Palo Alto, California 94304. Phone: 415-326-6496. TWX: 910-373-1765.
Products

High-speed code converters translate 5-to-8-level inputs to any desired output. P. 122

Transistor curve tracer uses fiber optics to display parameter readout directly. P. 110

Reciprocal-taking counter directly measures rf carriers, from 0.125 Hz to 20 MHz. P. 110

Also in this section:

- Eight-channel multiplexer converts standard scopes to multiple-trace ones. P. 110
- Flip-chip and LID zener diodes dissipate up to 400 mW. P. 116
- Modular op amps increase stability with internal varactor bridge. P. 124

Design Aids, P. 140 . . . Application Notes, P. 142 . . . New Literature, P. 144
Reciprocal-taking counter reads rf carrier frequency


Measurements from 0.125 Hz to 20 MHz with automatic ranging, plus the capability of measuring the carrier frequency of rf pulses directly, are features of the model 5323A automatic counter. Accuracy of the counter is ±1 count (neglecting time-base error and noise) over the operating range.

The 5323A is one of the new class of automatic, reciprocal-taking counters, which measure the input waveform period, calculate the reciprocal of the period and display the result directly in terms of frequency.

Instead of the conventional decade values of measurement time, the 5323A can be operated over its full range with switch-selectable measurement times of 0.01, 0.04, 0.1, 0.2, 0.4, 1, 2 or 4 s. With an externally supplied gate, measurement times can be any value from a few microseconds up to four seconds. Regardless of the measurement time selected, the 5323A automatically fills its 7-digit readout to provide maximum resolution.

A hysteresis feature, built into the range-selection circuitry, stabilizes the readout at range-change points to reduce readout confusion. Should the selected measurement time be too short to obtain the required accuracy for 7-digit resolution, the counter displays only the significant digits and blanks the others.

Additional features of the new instrument include: the capability of displaying rpm directly; a BCD and print-command output; a buffer storage that holds the BCD output constant while the next measurement is being made. Also included are a hold-off input that inhibits data transfer to buffer storage, when the cycle time is less than required for external interrogation of the BCD output, and programmability of all front-panel controls by means of external circuit closures to ground.

The 5323A uses a time base that is derived from a 10-MHz crystal. A front-panel switch can apply the 10-MHz time base to the counting decades and to the reciprocal-taking circuitry for self-checking.

Input specifications include a decoupled range from 0.125 Hz to 20 MHz and an ac-coupled range of 10 Hz to 20 MHz. Sensitivity is 0.1 V rms for a sine wave and 0.3 V pk-pk for a pulse with a minimum width of 25 ns. Input impedance is 1 MΩ shunted by 35 pF.

Eight-channel device drives standard scope

JS Consultants, P.O. Box 5316, Oxnard, Calif. Phone: (805) 486-3710. P&A: $500; 4 to 6 wks.

A new electronic device accepts two to eight signal inputs; each has a gain control that is adjustable from 0 to 100% of input value—for converting a standard single-trace oscilloscope into an eight-trace scope. All traces are adjustable so that they can be positioned on the screen for comparison and phase-checking. Internal sampling rate is 200 kHz, adjustable by ±50%, to allow synchronization of input signals that lie close to the sampling frequency.

CIRCLE NO. 253

Transistor curve-tracer has digital readout

Tektronix, Inc., P.O. Box 500, Beaverton, Ore. Phone: (503) 644-0161. P&A: $2125; 1st quarter, 1969.

Direct parameter readout is offered by type 576 curve tracer. This parameter readout is a fiberoptic digital indicator of the vertical deflection factor, horizontal deflection factor, step generator amplitude, and beta/cm or transconductance/cm. Readout values are automatically corrected for changes in vertical or horizontal magnification and in step amplitude multiplication.

CIRCLE NO. 254
Our new AC Designer Line switches come in an endless variety of colors, sizes and styles.

Sure, we know you'd never order a switch with a painted body. Or a style quite like this.

But our turned-on switch helps demonstrate the customizing possibilities these new Designer Line AC switches offer. The choices just don't quit.

Three types of terminals. In 1-, 2-, 3-, and 4-pole models. With special configurations like momentary-contact and center-off.

As for the lever, pick one to your liking and we'll deliver. Our unique design permits our Distributors to supply a broad array of sizes, shapes and colors. Or have our factory build them to your own design at a truly modest tooling cost.

Select attractive new decorator nuts, too. Two smart styles, four stock colors. Dozens of other colors on request.

But we're not playing the numbers game. Just giving you unmatched flexibility to design our new AC switches into your products. Plus capacities from low-power dry circuits up to 25 amps, and Cutler-Hammer quality you know and expect.

Write for Brochure LA-136-Y217, or call your Cutler-Hammer Sales Office or Stocking Distributor. Even our off-the-shelf delivery will turn you on.

The switched-on switch

These are the building blocks that provide new flexibility in designing with Cutler-Hammer AC Designer Line Switches.
If you're still using manual tuning to make spectrum signature recordings, you're throwing away dollars...by the hatful.

How many? The do-it-yourself arithmetic is simple:

1) Enter here your estimate of 1968 hours required to make complete spectrum signature recordings with your present tune-by-hand EMI meter

2) Estimate the time you'll save by converting to semi-automatic operation* (often up to 50%/h, but do be conservative)

3) Subtract to obtain hours saved

4) Enter your cost per hour (industry standard is $25/hr.)

5) Multiply your cost per hour by the hours saved: Your gross saving

6) Subtract the modest cost of a Model APC-10B Auto-Plot Controller

7) Your net 1968 saving

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*THE APC-10B

AUTO- PLOT CONTROLLER

converts your manual EMI meter to semi-automatic operation in making radiated and conducted interference tests per MIL-STD-26B. Just connect the APC-10B to your EMI meter and X-Y plotter...you get a permanent record of signal amplitude vs. frequency in approximately 1 minute per band. Completely eliminates manual tuning, recording and plotting, as well as individual slide-back peak readings for transients. No chance of operator error, either.

If you'd like to save $ in 1968 (and every year thereafter) get in touch with us today!

INSTRUMENTATION

Digital panel meter shrinks its size

Analogic Co., 296 Newton St., Waltham, Mass. Phone: (617) 891-4708. Price: $199.50.

Series AN2500 digital panel meters occupy approximately one-half the space of competitive units and offer superior accuracy specifications. The basic AN2510-1B offers non-blink 1/2-in. display of three digits, plus overrange and automatic polarity. Self-contained in a behind-panel case that is only 2 by 3-1/2 by 2-3/4-in. deep, the unit's small size permits it to be directly substituted for conventional moving-pointer meters.

---

Three-inch scope saves shelf space


A low-cost miniature oscilloscope with a 3-in. CRT, measures only 5-1/2 by 7-1/2 by 14 in. Model 536A is intended for applications where panel and shelf space are critical. Sensitivity is better than 20 mV/cm over a 1.5-MHz bandwidth and a 4-by-6-em display area. Amplifiers are solid-state, multi-stage and de-coupled and are fully compensated for optimum response.

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INFORMATION RETRIEVAL NUMBER 50
Performs more tests with no adjustments than any other IC or discrete op amp tester

Philbrick/Nexus Model 5102 Integrated Circuit Tester performs all tests automatically without calibration or manual programming. The only time you touch a dial is to select the desired test and for a minimum of scale changing for offset voltage and current measurements. Everything else is automatic, including offset zeroing. What's more, it is the only tester that performs CMRR and PSRR tests.

For only $1400 you get all these additional features in a single instrument: direct reading meter displaying values of all parameters including large signal DC gain, external terminals for displaying IC output, selection of output resistors to match load, oscillation indicator, internal supply of ±15 VDC programmable for ±6 VDC — plus many more features.

Contact your Philbrick/Nexus sales representative for complete details and specifications. Or write Philbrick/Nexus Research, 46 Allied Drive at Route 128, Dedham, Mass. 02026.
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The Kepco hybrid technique for taming high voltage uses high voltage tubes in high voltage control circuits and low voltage transistors in small signal gain circuits. A natural division of labor that places no undue strain on any component — the secret of high reliability.

*Model HB 4 AM — $365.00*

We also get reliability by using hermetically sealed metal can TO-5 transistors plugged into nylon sockets, on coated glass epoxy plug-in circuit boards. Filter capacitors are all high temperature aluminum types; rectifiers are of silicon and all wiring is harnessed. HB models are available from 0–250 volts at 1 ampere to 0–525 volts at a half amp. All have built-in coarse/fine voltage controls and are, additionally, programmable.

For complete specifications, write Dept. AS-5

**with KEPCO**

**IT'S CONTROL!**

---

**INSTRUMENTATION**

**Transistor tester handles FETs, too**

*SenCore, Inc., 426 Westgate, Addison, Ill. Phone: (312) 543-7740. Price: $129.50.*

A combination FET-and-transistor tester, the TF151, is the first instrument on the market that tests both transistors and FETs. Flip the large function-control knob to the left and the tester is a regular in- and out-of-circuit transistor tester; flip the knob to the right and the tester becomes an in- or out-of-circuit tester for field-effect transistors. It also tests enhancement-type FETs.

---

**Low-cost instrument has sine/square out**

*Heath Co., Benton Harbor, Mich. Phone: (616) 983-3961. P&A: $99.50 ($67.50 kit); 30 days.*

Sine or square waves at frequencies variable between 1 Hz and 100 kHz are provided by the low-priced IG-18 generator that offers features usually found only on more costly instruments. Sine-wave output can be varied between 0.003 and 10 V rms; square-wave amplitude is switch-selected between 0.1, 1.0 and 10 V. Distortion in the sine-wave output is less than 0.1% within the audio range. Square-wave rise time is less than 50 ns.

---

**Handheld test probe checks logic circuits**


A handheld probe checks the performance of logic circuits; it shows when pulses occur, and indicates whether logic levels are in high or low states. Logic-level indication is given by a light near the probe tip. Model 10525A operates automatically; triggering or threshold adjustments are not required. Threshold level is +1.4 V. Above this level, the light is on; below it, the light is off.
After more than three decades and untold billions of hot-molded resistors, Allen-Bradley has accumulated manufacturing “know-how” which cannot be approached by anyone else. The fact that the resistors made by A-B over the years—if placed side by side—would more than reach to the moon and back, may be impressive. But “how” they are made is the key.

Allen-Bradley resistors are produced by an exclusive hot-molding technique—developed by A-B. They’re made by completely automatic machines—also developed, built, and used only by Allen-Bradley. The human element of error is removed. Uniformity is so precise from one resistor to the next—year in and year out—that long-term resistor performance can be closely predicted.

And there has been no known incident of catastrophic failure of an A-B hot-molded resistor.

The reputation for quality and performance established by Allen-Bradley hot-molded resistors is reflected in the fact that they have been an integral part of virtually every U.S. space probe. And they are “on” the moon. No other resistor applications demand a higher measure of reliability.

Unijunction transistor operates at 4 V

Motorola Semiconductor Products Inc., P.O. Box 20924, Phoenix, Ariz. Phone: (602) 273-8466. Price $3.25.

Characterized for operation on source voltages (V_{BB}) as low as 4 V, the 2N5431 UJT is fabricated by a surface-passivated, all-diffused process. One advantage is the device's low emitter-leakage current, of only 20 nA maximum.

---

Chip zeners take 400 mW


Satisfying the packaging demands of thick-film and thin-film circuits, as well as of monolithic ICS, 400-mW zener diodes are now available in flip-chip and LID configurations. They cover a zener-voltage range of 6.8 to 33 V. The flip-chip unit, which is only 0.027-in. square, has a completely passivated junction. The LID unit, which measures 0.04 by 0.075 in., uses a die that is mounted in a ceramic package and then coated.

---

Transistor complements match dual amplifiers


Two new complementary families of dual transistors form precisely matched differential amplifiers. The TD-400 family, which has pnp polarity, matches base-to-emitter voltages within 2.5 V, tracks within 6 μV/°C, and provides minimum current gains of 120 at 100 μA. Its complementary counterpart, the TD-600 family, features maximum noise levels of 2 dB and gain-bandwidth products of 200 MHz.
Foxboro engineers select A-B hot molded potentiometers

“Best repeatability—component-to-component and setting-to-setting”

Allen-Bradley Type J hot molded variable resistor rated 2.25 watts @ 70°C. Available in single, dual, and triple units. Standard total resistance values from 50 ohms to 5 megohms. Special resistance values and tapers can be supplied.

Widely used throughout the process industries, the Foxboro Model 62H Universal Controller is a highly dependable precision instrument. During the years of painstaking development, Allen-Bradley engineers worked closely with Foxboro to provide a potentiometer having unusually high resistance values, which would provide the precise performance required.

Allen-Bradley Type J potentiometers were the answer. They have a solid hot molded resistance track which is produced by an exclusive A-B molding technique that assures extremely long operating life. Accelerated tests—exceeding 100,000 revolutions—show very slight resistance change. Control is smooth at all times with adjustment approaching infinite resolution. There are none of the abrupt turn-to-turn resistance variations inherent in wirewound controls. Furthermore, Allen-Bradley Type J potentiometers are—for all practical purposes—noninductive, permitting their use throughout the frequency spectrum.

Whether your particular circuit design can be best satisfied with one of the millions of standard Type J variations or whether it calls for unusual resistance characteristics, it will pay you to look first to A-B Type J potentiometers. Their more than 25-year history of providing superior performance is your guarantee of complete satisfaction. For full details, please write for Technical Bulletin 5200: Allen-Bradley Co., 1344 South Second Street, Milwaukee, Wisconsin 53204. In Canada: Allen-Bradley Canada Limited. Export Office: 630 Third Avenue, New York, N. Y., U.S.A. 10017.

ALLEN - BRADLEY
QUALITY ELECTRONIC COMPONENTS
This probe lights up when a pulse goes by.

Even a pulse as short as 30 ns—positive or negative—will cause this logic indicator to flash a signal. You can trace pulses, or test the logic state of TTL or DTL integrated circuits, without taking your eyes off your work. In effect, the probes act like a second oscilloscope at your fingertips.

No adjustments of trigger level, slope or polarity are needed. A lamp in the tip will flash on 0.1 second for a positive pulse, momentarily extinguish for a negative pulse, come on low for a pulse train, burn brightly for a high logic state, and turn off for a low logic state.

The logic probe—with all circuits built into the handpiece—is rugged. Overload protection: -50 to +200 V continuous; 120 V ac for 10 s. Input impedance: 10 kΩ. Price of HP 10525A Logic Probe: $95, quantity discounts available.

Ask your HP field engineer how you could put this new tool to work in logic circuit design or troubleshooting. Or write Hewlett-Packard, Palo Alto, Calif. 94304; Europe: 54 Route des Acacias, Geneva.

ICs & SEMICONDUCTORS

Schematic arrays substitute for relays

Electronic Control Corp., 1010 Pamela Dr., P.O. Box J, Euless, Tex. Phone: (214) 264-2429.

Employing a new packaging concept, substrate-mounted semiconductors can be used as solid-state replacements for electromechanical relays and in thyristor applications. The new substrate semiconductors contain multiple-chip 1.6-A triacs (with or without triggers) or SCRs in a choice of configurations. These functions may be laid down as single devices or with a common electrode. The substrate can be hand- or flow-soldered.

CIRCLE NO. 264

Fast-firing 80-A SCRs turn on with 100 mA

International Rectifier, Semiconductor Div., 233 Kansas St., El Segundo, Calif. Phone: (213) 678-6281. Price: $59.50 to $223.

A series of 80-A fast-firing SCRs (types 81RLA50 through 81RLA-120) features the industry’s highest available di/dt capability, 800 A/μs. These SCRs can be turned on with 100-mA gate drive. They can handle high inrush currents with minimum current surge suppression and minimum drive complexity.

CIRCLE NO. 265

Power transistors switch in 450 ns

Solid State Products, 1 Pingree St., Salem, Mass. Phone: (617) 745-2900.

Two new switching transistors, types 2N5487 and 2N5488, have maximum turnoff times of 450 or 550 ns, respectively, when operating at 1 A. Minimum collector-to-emitter sustaining voltage is 80 or 100 V, minimum current gain is 100 or 40, and maximum collector saturation voltage is 0.25 V.

CIRCLE NO. 266

Dual comparators sink over 5 mA


Supplied as both DIPs and flat-packs, monolithic dual differential comparators meet the sink-current demands of high-speed logic forms. Types TDC 4711 and 5711 have a minimum sink current of 5 mA to directly drive up to four TTL input loads. Because types TDC 6711 and 7711 offer dual independent circuits, they double the sink-current capability. Types TDC 8711 and 9711 combine high sink-currents with independent outputs.

CIRCLE NO. 267
there is no end to what you can do with Optima enclosures — for new brochures on consoles and cases call or write OPTIMA — a product of Scientific-Atlanta P.O. Box 13654 Atlanta, Ga. 30324 404 938-2930.
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WIN 2 ROUND-TRIP TICKETS BETWEEN

HERE'S ALL YOU HAVE TO DO Examine the January 4 issue of Electronic Design with extra care. Pick the ten advertisements that you think will be best remembered by your 69,000 fellow engineer-subscribers. List these advertisements (not necessarily in rank order) on the special entry blanks bound in the Jan. 4 issue, and mail to our Contest Editor. Your selections will be measured against the ten ads ranking highest in the "Recall Seen" category of Reader Recall—Electronic Design's method of measuring readership. Remember . . . in making your choices be sure to consider not only your own tastes and interests in the subject matter of each particular advertisement, but also those of the other engineer and engineering manager readers of this magazine. All Electronic Design subscribers may enter the contest (see rules in Jan. 4 issue). Good Luck! If you study the ads with care, you might wake up one morning in Paris!

FIRST PRIZE
Round-trip tickets for two between New York and Paris via AIR FRANCE. You can schedule your flight anytime you wish—stay up to 21 days before returning.

2ND PRIZE
DELUXE HEATHKIT®/THOMAS "PARAMOUNT" TRANSISTOR THEATER ORGAN
19 Organ Voices, 200 Watts Peak Power, Chimes, Color-Glo Key Lights, Rotating Leslie Speaker, Horseshoe-Shaped Console, Plus Many Other Features.
Here is a truly sophisticated organ with a wide variety of deluxe features to give professional playing versatility. Kit comes complete with all parts, step by step assembly instructions, and alignment tools.

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NEW YORK AND PARIS VIA AIR FRANCE!

3RD PRIZE
DELUXE HEATHKIT® "180" COLOR TV WITH CONTEMPORARY WALNUT CABINET
Kit comes complete with all parts including chassis; hi-fi 90° 180 sq. in. rectangular color tube with anti-glare safety glass; 24,000 volt regulated picture power; rare earth phosphors; 27 tube, 10 diode, transistor circuit; automatic color control circuit; gated automatic gain control; extra B+ boost, etc. etc. All critical circuits are pre-wired and tested.

4TH THROUGH 10TH PRIZES
7 BULOVA ACCUTRON® “SPACEVIEW” ELECTRONIC TIMEPIECES
The “Spaceview” is an ideal timepiece for electronic engineers. Its clear-view dial reveals transistorized electronic circuit and tuning fork assembly. Accuracy guarantee is 99.9977% during actual wear on the wrist. Stainless steel case with luminous hands and dots.

PLUS 100 ADDITIONAL PRIZES
“ELECTRONIC DESIGN TECHNIQUES” edited by Edward E. Grazda
Contains a comprehensive collection of over 55 articles from Electronic Design covering almost all areas of interest to electronic design engineers. The articles are grouped in sections considering the use and design aspects of amplifiers, resistor networks, filters, control devices, power supplies, microwave systems, oscillators, and pulse and switching circuits. Hard cover, 312 pages.

TOP TEN CONTEST

WATCH FOR ENTRY BLANKS IN JAN. 4 ISSUE

There's a separate contest for electronic marketers. In addition to the valuable prizes listed at right, if you are a winner in the contest for marketers, and have an ad in the January 4 issue, that ad will receive a free re-run! Complete information, rules, and entry blanks will be bound in the January 4 issue of Electronic Design.

PRIZES—MARKETER CONTEST
1ST PRIZE: Round-trip tickets for two between New York and Paris via Air France.
2ND PRIZE: RCA “Carry-ette” portable 14" color TV set.
3RD PRIZE: Bulova Accutron® “Spaceview” electronic time-piece.
DATA PROCESSING

Fast code converters deliver any output

Measurement Technology Corp., 7124 Owensmouth Ave., Canoga Park, Calif. Phone: (213) 887-9300.

Designed for use with data processing equipment, a new line of high-speed solid-state code converters translates any 5-, 6-, 7- or 8-level input code to any desired output code. The units will I/O interface between paper-tape or card readers, typewriters, magnetic tape decks, optical readers and computers, in any combination, for one-way or two-way code conversion. Conversion speed is greater than 10,000 codes/s and essentially depends on the speed of I/O devices and voltage levels.

CIRCLE NO. 268

Digitizing camera system converts optical images

Westinghouse Astroelectronics Laboratory, P.O. Box 245, Newbury Park, Calif. Phone: (805) 498-3651.

When focused on any scene, display, image or graphical representation, a data reader camera converts these optical images to precise digital signals by producing a corresponding series of electrical impulses. The camera follows any desired pattern when scanning an image. Scanning commands can be supplied by any digital computer or by the camera's own optional image conversion control unit. The camera and control unit together form a complete optical image-digitizing system.

CIRCLE NO. 270

Printing calculators self-check accuracy

Victor Comptometer Corp., Business Machines Division, 3900 N. Rockwell St., Chicago. Phone: (312) 539-8210. Price: $1775 to $2375.

High-speed desk-top electronic printing calculators feature the same type of internal accuracy control systems that are usually found only in computers. As problems and solutions are printed out at 60 characters per second in logical arithmetical order, models in this 1500 series internally check the accuracy of their own calculations.

CIRCLE NO. 269

Digital data modems double line utility

International Communications Corp., Sub. of Miltgo, 7620 N.W. 36th Ave., Miami. Phone: (305) 691-1220.

Two new data sets, models 4400/20H and 440/20L, significantly reduce the cost of computer communication by transmitting two separate 2000-bit/s messages at the same time over a single telephone line. Each message stream is transmitted independently, as if two individual phone lines were being used.

CIRCLE NO. 271
How many Mil-Spec counter-timers now provide performance to 3.3 GHz?

ONE!

And it’s the CMC 880 with two new plug-ins!

The CMC Model 880 is the only high-frequency counter-timer commercially available that has been designed, tested, and field-proven to meet all pertinent military specifications.*

This rugged, completely portable instrument, with its drip-proof clip-on cover and valise handle, has already proven itself in the toughest military and industrial applications. And the CMC 884, a companion heterodyne converter, has been right there when needed to boost the 880’s 100-MHz direct-counting range up to 555 MHz. So what else is new? Plenty!

Here are two new plug-ins that further set the 880 apart as the only Mil-Spec counter-timer offering performance in the gigahertz range. The Models 882 and 885 Heterodyne Converters will now boost the 880’s frequency range to 1.3 GHz and 3.3 GHz respectively, and both feature built-in video amplifiers providing a sensitivity to 10 mV, the use of all solid-state components, and an accuracy equal to that of the basic counter.

So when you’ve got a job to do where the going’s rough— try the 880. You’ll be in good company if you do. And for your copy of CMC’s new 12-page Military Counter brochure with complete specifications, circle the reader service card.

*The Model 880 meets all requirements of MIL-E-16400, Shock Spec MIL-S-901, and RF1 Spec MIL-I-16910.
**Varactor-bridge op amps replace electrometers**


Models 310 and 311 varactor-bridge operational amplifiers embody a voltage-controlled capacitor that simultaneously upgrades voltage and current stability. These varactor-bridge op amps match the electrometer tube's current stability and impedance and provide better voltage stability and noise. Models 310B (inverting) and 311B (noninverting) feature 10 µV/°C maximum voltage drift, 10 fA maximum initial bias current, and 1 fA current drift.

**Solid-state relays isolate contacts**


Closely approximating the contact isolation of electromechanical relays, series SSA solid-state relays offer a predictable threshold voltage for both pull-in and dropout. They operate on any input voltage within the range of 0 to 140 V ac, or 0 to 200 V dc. The units can withstand momentary current surges that are ten times greater than rated.

**Modular rf switch has 50-MHz range**


Modular, expandable, and offering excellent frequency coverage, a solid-state switch is available in any size or configuration using a 1 × 2 through a 10 × 10 basic matrix. In the frequency range of dc to 50 MHz, the switch offers minimal crosstalk and maximum isolation—typically 50 dB at 30 MHz. Noise contribution is normally less than 0.1 µV in a 4-kHz bandwidth. VSWR is 1.2 or less.
This hookup wire was wrapped around a mandrel and heat-aged for 88 hours at its rated temperature. When it was unwrapped, cracks developed and exposed the conductor.

This won’t happen with insulation of Du Pont TEFLON® (TFE). At its own high rated temperature (up to 500°F, depending on the specification), TEFLON shows excellent resistance to cracking after much longer periods of heat aging.

That’s only one of the reasons we call TEFLON the sure one. Among others: TEFLON is nonflammable. It’s inert to virtually all chemicals and corrosives. It resists solder-iron damage. And it provides weight and space savings without sacrificing performance.

In short, when you specify insulation of TEFLON, you minimize risk.

For detailed data on the resistance of TEFLON to thermal stress cracking and other hazards, write Du Pont Company, Room 6670C, Wilmington, Delaware 19898.


TEFLON®...the sure one
At 12.4 GHz, forget about crosstalk.

This new switch gives 60 db of isolation at 12.4 GHz. You can forget about crosstalk at high frequencies because it’s held to an absolute minimum.

Besides excellent isolation across its entire operating range (zero to 12.4 GHz), electrical characteristics are well suited to high-frequency applications. VSWR at 12.4 GHz is 1.5 max. Insertion loss is only 0.5 db max.

Mechanical characteristics make Amphenol’s high-isolation switch easy to use. Switches come with standard N or TNC connectors. They measure a small $2\frac{1}{8}'' \times 2\frac{3}{16}'' \times 1''$ and can be easily stacked. Temperature range is from −55° to 85°C. Altitude range goes from zero to 70,000 feet. Shock and vibration performance meets MIL-S-3928B.

For high-isolation, high-frequency switches, talk to Amphenol RF Division, 33 E. Franklin St., Danbury, Conn. 06810.
Active filters span 100 kHz


Negative impedance converter techniques are used to provide a stable, accurate bandpass filter. The resulting circuitry is small and simple, yielding in a less costly and more reliable design. Units are available in frequency ranges from 0.1 Hz to 100 kHz with Q up to 50. Size is less than 1.3 in.²

CIRCLE NO. 276

Battery monitor regulates charge


Specifically designed for monitoring and for controlling the charging of standby battery systems, model 926 provides both direct and remote readout of per cent of discharge. The unit's sensors automatically turn it on when a preset discharge point is reached and shut it off when the battery is recharged.

CIRCLE NO. 277

A specialty of the house...

cooking up new ideas in electric motors.

Like the GT1612 that runs up to 60,000 rpm on hydrostatic air bearings. Extreme accuracy in locating the beryllium shaft helps make this possible. Other specialties to help you serve up exactly what's needed include induction, hysteresis, torque, synchronous, AC drive, DC drive and servo motors, in the milli- to integral-horsepower range, and without the compromise of run-of-mill mass-produced motors. For motors for spacecraft, avionics, control, computer peripherals and other systems, contact IMC Magnetics Corp., Eastern Division, 570 Main St., Westbury, N.Y. Phone (516) 334-7070 or TWX 516 333 3319. If you need information for future projects write IMC's Marketing Div., at the same address, or circle the bingo number at the bottom of this ad.

INFORMATION RETRIEVAL NUMBER 61

This is our 3 step.
Give us a call and see all the steps in our routine.

If you really want to swing you can also step 4, 8, 12, 24, 48, and 200 increments without gears.
Or to indicate, Measure and Control using flag and remote angle indicators, synchros, resolvers, steppers, or solenoids. They are in stock at IMC Magnetics Corp., Western Division. For quick service contact the Applications Section at Western Division, 6058 Walker Ave., Maywood, Calif. 90270. Phone 213 583 4785 or TWX 910 321 3089.
If you need data sheets for references or consideration for future projects, write IMC's Marketing Division at 570 Main Street, Westbury, New York 11591.

INFORMATION RETRIEVAL NUMBER 62
Desoldering tool uses tinned braid

Using a specially treated tinned braid, a desoldering tool quickly draws up solder when heat is applied with an ordinary soldering iron. The unit acts as a heat sink to protect delicate components, and its tinned braid leaves the joint ready to be resoldered. It is available as a service kit and in spool rolls.

Pocket-sized lubricator works in any position

Completely leakproof, a pocket-sized lubricator lubricates in any position, including upward. Using a controlled-flow applicator, model 05-84 dispenses the exact amount of lubricant required and automatically draws back any excess.

Flexible oven bags epoxies

Ideal for use on multi-wire connectors, a portable bag-like oven cures potting compounds at accelerated rates, while maintaining heat accuracy to within 10°F. The flexible oven uses a silicone sponge lining for thermal insulation. A drawstring at the top closes the oven, and a thermostat controls the temperature from ambient to 300°F.

A number one company exists in almost every industry. In some fields the identity of the concern is surmised, while in others it is strongly established. The following facts clearly define the position of Andersen Laboratories in the delay line field.

Andersen designs and develops many more different types of delay devices (including optical and microwave) than any other concern.

Andersen is the only firm producing delay devices for the entire range of frequencies. (DC through 5 GHz.)

Andersen is the sole major manufacturer of delay devices specializing in signal processing systems.

Andersen supplies a substantially greater volume of delay equipment than any other source.

Send for free literature describing theory of various types of delay devices.

Andersen Laboratories, Inc.
1280 Blue Hills Avenue
Bloomfield, Conn. 06002

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INFORMATION RETRIEVAL NUMBER 63

INFORMATION RETRIEVAL NUMBER 64
"We will offer a total service from equations to completely coordinated computer systems."

Charles Russ, V.P. and General Manager, Inter·Pak Electronics

- Inter·Pak Electronics, the newest division of the Litton components group, was formed to fill a widespread need for total control of electronic packaging programs.
- Right now, we offer a unique service supplying you with complete packaging systems. We'll take your wiring diagrams and lists, program for the wire-wrap machine—make drive deck—assemble hardware, and, using the Accur Frame* packaging concept of molded connector assembly—deliver the whole package. Fast.
- And we plan to offer much more.
- We know that computer manufacturers have contracted electronic drive systems piece by piece. Devoted engineering time to design concepts, evaluated individual suppliers, followed up on many delivery promises, and spent large amounts of time and effort in areas peripheral to their basic product.
- Inter·Pak computer technology will augment the mathematics of new computer design at the initial stage. We're storing in our computers the specifications of all known components to permit automated logic design. We will engineer circuitry and software—program the wire-wrap deck—provide a total service.
- Our job is to lighten the computer manufacturer's engineering and manpower load. And we will do that best by supplying completely coordinated systems. We will, of course, provide any part of the systems spectrum desired.
- We welcome the opportunity to work with you. For further details, please contact Mr. Charles Russ at Inter·Pak Electronics, 341 N. Maple Drive, Beverly Hills, California 90211. Phone 213-273-7209.

*Patent Pending

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CIRCLE NO. 281

MIC chips use thin films


Load terminations and chip resistors that are fabricated with microwave thin-film techniques are now available for microstrip circuit applications such as isolated combiner/dividers and diode bias networks. The load terminations, which measure 0.075 by 0.025 by 0.025 in., are 50-ohm devices with typical VSWR of 1 to 1.15. The chip resistors, which measure 0.075 by 0.025 by 0.012 in., are mounted in a flip-chip arrangement. Standard resistance values are 50 or 100 Ω, ±1%.

CIRCLE NO. 282

Rf power transistors offer 1 W at 1 GHz

Solitron Devices, Inc., 1177 Blue Heron Blvd., Riviera Beach, Fla. Phone: (305) 848-4311. Availability: stock.

Silicon rf power transistors, types 2N3375, 2N3632, 2N4440, 2N5090 and 2N5108, operate at frequencies from 100 MHz to 1 GHz. Power ratings are from 13.5 W at 175 MHz to 1 W at 1 GHz. The devices are packaged in TO-5 and TO-60 cases. A wide variety of rf power transistors are available in plastic stripline cases as well.

CIRCLE NO. 283

Semi-rigid waveguide can be 500-ft long

Airtron, div. of Litton Industries, 200 E. Hanover Ave., Morris Plains, N.J. Phone: (201) 539-5500.

A semi-rigid field-assembled, continuous waveguide called Ellipta-guide is available in continuous lengths up to 500 feet. It has a frequency band of from 5.925 to 6.425 GHz. Attenuation is less than 1.5 dB per 100 feet. Untuned VSWR is 1.15 max.; tuned, 1.08 max. The patented construction offers high impact-strength.

CIRCLE NO. 284

Three oscilloscopes span 14-GHz range

Tektronix, Inc., P.O. Box 500, Beaverton, Ore. Phone: (503) 644-0161. P&A: $560 to $1125; 4 wks.

Three solid-state oscilloscopes are compatible with over 25 plug-in units. These include dc to 15-GHz, 25-ps sampling, 10 μV/div differential, and spectrum analyzer capabilities. The 561B oscilloscope, the 564B storage oscilloscope and the 564B with automatic erase all feature 8-by-10-cm cathode-ray tubes, 1-1/2% amplitude and 1% time calibration, and reliable operation with low heat dissipation.

CIRCLE NO. 285

Wideband switches hold VSWR to 1.5


From dc to 12.4 GHz, series SRM coaxial switches exhibit a maximum insertion loss of 0.4 dB and a maximum VSWR of 1.5. In addition, they maintain a high isolation of 60 dB minimum over the same frequency range. Rf power rating is 50 W average, and nominal operating voltage is 28 V dc at 200 mA. Over-all volume is less than 0.75 in.³, and weight is 2 oz.

CIRCLE NO. 285
General Electric introduces a faster, more convenient and less costly technique for production line encapsulating and potting. And the RTV's used in the process are as tough as any previously available.

Called the RTV-800 series, the new liquid silicone rubbers do not need a catalyst to activate them, so no premixing is needed.

They cure at temperatures ranging from 200°F to 450°F, so pot life is far longer than is customary with RTV's. A typical deep section cure would be one hour at 300°F. For really rapid cure, components can be preheated and dipped into the RTV.

These three new products are supplied in both opaque and clear grades, with viscosities ranging from very pourable to pourable. They can be blended with one another to suit your particular encapsulating job.

For more information about these new encapsulating RTV silicones (they also make good short-run molding-materials), write Section 300, Silicone Products Dept., General Electric Company, Waterford, N.Y. 12188.

TYPICAL PROPERTIES

<table>
<thead>
<tr>
<th>Uncured</th>
<th>RTV-815</th>
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<tr>
<td>Tear Strength, lb/in.</td>
<td>15</td>
<td>100</td>
<td>20</td>
</tr>
</tbody>
</table>

Now. Heat-curing, no-mixing, high-strength RTV silicones.
Solid-state attenuators have flat response

Octave-bandwidth diode variable attenuators cover the frequency range from 0.5 to 11 GHz. Insertion loss at zero bias is 0.8 dB from 0.5 to 7 GHz, and 1 dB from 7 to 11 GHz. Full attenuation is over 80 dB for frequencies below 4 GHz.

CIRCLE NO. 286

Can you do this?

These new Johanson glass capacitors are designed to bridge the gap between conventional trimmers and high frequency air capacitors. They have high Q—low inductance; they have high RF current characteristics, they can be soldered together with components to simplify circuitry and they are strong.

Models include:
- Series II: High RF voltage low cost units with Q> 1200 and TC; 0±50 ppm.
- Johanson 7168: High voltage quartz capacitors which feature 7000 VDC; 2500 V peak RF at 30 mc and current capacity > 2 amps.

Also available are:
- Tuners and ganged tuners; linear within ±.3%
- Differential capacitors
- Mil spec capacitors
- Microminiature capacitors .075" diameter and .1-1 pf

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Rf signal generator sweeps four bands

Completely self-contained, a four-band microwave swept signal generator supplies rf signals for any or all frequency segments in the 1-to-12.4-GHz range. Model 404 automatically and continuously sweeps through the four bands of L, S, C and X. The multi-band rf signals are available at a single output connector. Rapid band switching allows four-band sweep to be completed in 100 ms.

CIRCLE NO. 287

Coax diode switches span 1 to 18 GHz

Microwave diode switches, at any octave range between 1 and 18 GHz, select attenuation levels of 40, 60, or 80 dB max. Assembled from off-the-shelf parts, the switches can be quickly tailored to meet particular requirements at low cost. The switches are p-i-n diode reflective types in an spst configuration. They are useful as attenuators, levelers, pulse modulators, T-R switches, and in other low-power microwave applications.

CIRCLE NO. 288
If You Think The New Zeltex Model 148 'Op Amp' Is Expensive, (((((You're In For A Shock))))))))

This Chopper-Stabilized Amplifier Costs Only...

$58

Model 148 has greater gain and is faster than anything comparable. Take a look at the next best thing.

| DC Voltage Gain, Minimum | 10⁸  | 10⁷  |
| Gain Bandwidth          | 1 MHz | 500 kHz |
| Input Bias Current, Maximum | 50 pA | 100 pA |
| Full Output Frequency, Minimum | 100 kHz | 3 kHz |
| Input Voltage Drift     | 0.5 µV/°C | 0.5 µV/°C |
| Slew Rate               | 6 V/µs | 0.2 V/µs |
| Temperature Range       | -25° to 85° C | 10° C to 60° C |
| Price (10-24)           | $58.00 | $84.00 |

Ask for more information today, or better yet, order several for evaluation. You really will be shocked at how fast we ship them.

1000 Chalmar Rd., Concord, Calif. 94520. Phone (415) 686-6660.

A REDCOR CORP. Subsidiary
Dual-in-line socket accepts 28 pins

SAE Advanced Packaging, 1357 Edinger Ave., Santa Ana, Calif. Phone: (213) 849-5000. P&A: $1.82; stock.

A multipurpose receptacle mounts on a metal (wire-wrap) plate or printed-circuit board. The receptacle has 28 beryllium spring sockets that mate with either a dual-in-line flatpack or a male plug. Input/output is provided through the receptacle or by a module with 0.02-in. diameter pins.

CIRCLE NO. 289

Clear acrylic spray halts corrosion

Sprayon Products, Inc., 26300 Fargo Ave., Bedford Heights, Ohio.

A high degree of rust and corrosion protection for critical circuit components is offered by a clear acrylic spray. It dries quickly to form a flexible film that seals and waterproofs the treated area. Sprayon 2000 is one of a line of Aerosols for Electronics that are sold locally by both electronic supply and industrial distributors.

CIRCLE NO. 290

Woven ribbon-cable has 102 conductors

Zippertubing Co., 13000 S. Broadway, Los Angeles. Phone: (213) 321-3901.

Versatile ribbon-cable supplies a broad range of design capabilities due to a loom-weaving production process. The flexible cable is flat, lightweight and economical. As many as 102 conductors of any type can be woven; they may be shielded, unshielded or both. Twisted pairs are also available.

CIRCLE NO. 291

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PACKAGING & MATERIALS

Nylon grommets fit any opening


Nylon grommets provide excellent electrical insulation in a wide range of stock sizes. Three sizes are available from stock, to fit 10- to 24-gauge steel and aluminum sheets. Free evaluation samples are available.

CIRCLE NO. 292

Epoxy adhesive bonds Teflon

Lead Co., 1716 S. 6th St., Camden, N.J. Phone: (609) 365-0098.

CC Epoxy serves to bond treated Teflon to metals, ceramics and other substrate materials with a bond strength of 2000 psi in lap shear. In peel failure, the adhesive removes the etched layer from the Teflon, indicating a cohesive failure in the Teflon before bond failure. The adhesive features a heat-cure system that changes color at temperatures ranging from 200 to 500°F when cured. It resists exposure to 500°F temperatures indefinitely.

CIRCLE NO. 293

Copper-filled epoxy rivals silver epoxy

Ablestik Adhesive Co., 833 West 182nd St., Gardena, Calif. Phone: (213) 321-6252.

A 0.004 Ω-cm resistivity copper-filled adhesive exhibits a lower resistivity than do most silver-filled adhesives. Costing about 20% less than typical silver-filled adhesives, this conductive adhesive eliminates problems associated with silver migration. Ablebond 163-4 is a strong epoxy/amine adhesive with shear strength of 1350 psi. Available as a three-component 1-lb kit, the adhesive cures in one hour at 200°F, and in two hours at 150°F.

CIRCLE NO. 294
HERE'S HELP FOR YOUR COST-REDUCTION PROGRAM

Cedar's new

JETLINE

Servo Motor

With Cedar's traditional high quality and performance but at far less cost than conventional motors

The new Jetline motors are a family of standard motors available from stock for quick delivery. Modifications and special designs on request. Size 8, 10 and 11 servo motors and Size 8 and 10 motor-tachs are available for both 26-volt and 115-volt applications.

These new motors are an extension of Cedar's more than 10 years experience in the transfer-molding of stators. Molded plastic replaces the case and end cap resulting in fewer parts. Efficiency is maximized through the use of larger stator laminations. The larger flanged bearings fit against the molded plastic, run cooler and provide greater reliability.

Thorough testing of these motors has proven them to meet traditional Cedar quality standards. Our normal warranty applies. Jetline motors have, however, demonstrated over 3500 hours at 100°C ambient.

The important difference to you when you specify Cedar's Jetline motors is that they cost less. For example, a standard Size 10 Servo Motor costs only $16.50 in quantities up to 1000. To get all the facts on how Cedar's new Jetline servo motors can help in your cost-reduction efforts, write or call today.

ANOTHER DATA CONVERSION SOLUTION BY ANALOGIC

AN EXPANDABLE 12 BIT HIGH SPEED A/D CONVERTER WITH POWER SUPPLY AND DISPLAY FOR ONLY $1595

Analogic's AN5200 series converter systems offer complete data reduction capability in a single 3½" x 8½" x 12" enclosure. Utilizing standard Analogic data conversion modules, the basic unit at $1595 includes the AN2212 12 bit high speed A/D converter, the AN713B binary display, and the AN3001 power supply. Basic systems are also available at even lower cost, incorporating AN2208 8 bit or AN2210 10 bit A/D converters.

Plug-in modules add:
- Up to 32 multiplex channels
- 0.01% Sample & Hold
- 13 bit accuracy and resolution

Total 32 channel 13 bit system cost with Sample & Hold... only $3140

AN5200 series converter systems include all pre-wired connectors and controls required to also accept AN4100 series 8 channel multiplexer modules, the AN250-01 0.01% Sample and Hold module, the AN2200-AVS Sign & Absolute Value module to provide a 13th bit for increased accuracy and resolution, and AN550 series code translator modules to provide special output codes with additional buffering. Features of a complete system include:

- Up to 32 internal multiplex channels expandable to 256 channels with external Analogic multiplexer expander
- Random address, sequential, or manual multiplexing
- 2000 megohm input Z with 0.005% multiplexer transfer accuracy
- Sample & Hold settling time 5 μs (max.) to 0.01% with less than 50 ns aperture and 15 μs/mus. Hold decay
- Guaranteed A/D relative accuracy (ISA) 0.015% F.S. ±1/2 LSB ± 0.001% /°C @ 2 us/bit: variable internal clock permits optimum combinations of speed vs. accuracy (up to 0.01%)
- Internal reference accuracy (ISA) 0.005% ± 0.0005% /°C
- Both parallel and serial NRZ outputs @ 12 ma/line sink current
- 12 bit system throughout speed (including multiplexer and Sample and Hold) up to 40 kHz standard; even higher speeds available
- Operates from 117/234 VAC; 47-420 Hz
- Also available in BCD configurations with decimal display
- Operates over 0°C to +70°C temperature range.

Write for complete specifications on AN5200 series converter systems, and on Analogic's complete line of data conversion products.

© 1968, Analogic Co.
COMPONENTS

**Miniature 3-pole switch double-breaks 6 circuits**

Plessey Components Group, Microswitch Unit, Titchfield, Hampshire, London.

Type 36 3-pole miniature switch can be used for triple-pole change-over or for 6-circuit double-break switching. A special linkage between mechanisms assures simultaneous operation of all three poles. The unit is rated at 10 A, 250 V ac, 28 V dc. It measures 25/32 by 13/16 by 1/4-in.

CIRCLE NO. 295

**Small inertia switch senses all directions**

Inertia Switch, Inc., 311 W. 43rd St., New York City. Phone: (212) 687-7215.

Measuring less than 5/16 in. and weighing 3/4 oz, model 3RO-499 inertia switch responds to acceleration forces from any direction. Model 3RO-499 is hermetically sealed and operates over a temperature range of -55 to +125°C. It complies with the requirements of MIL-E-5272. Its two turret-type terminals and threaded stud provide greater mounting density.

CIRCLE NO. 296

**Printed-circuit heaters break thermal barrier**

Rama Industrial Heater Co., 39651 Esplanade, San Jacinto, Calif.

Available in silicone rubber, Kapton and other materials, Rama-flex printed-circuit heaters reduce the thermal barrier between heater circuit and the surface to be heated. The units' flat surfaces, which can be flexible or rigid, reduce the possibility of dielectric failure. They are supplied in 30-in. widths, in thicknesses as small as 0.006 in., and to any desired length.

CIRCLE NO. 297

---

**POWER MATE CORP.**

**UNI-128**

UNIVERSAL POWER SUPPLIES
TWO MODELS AVAILABLE

SAME DAY SHIPMENT

**$128.00**

- O to 16 volts at 4 AMPS. (UNI-128 - 16)
- 15 to 30 volts at 4 AMPS. (UNI-128 - 30)
- Ripple 250 microvolts
- Meets MIL-E-5272 specs
- Short circuit proof
- 100,000 hours MTBF
- 5 year warranty

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INFORMATION RETRIEVAL NUMBER 76

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**Print Bars and Drums**

At Buckbee-Mears we etch the entire drum in one operation. Costly assembly problems are eliminated because there are no segments to line up. We are also geared to etch print bars faster at lower costs. Our print drums and bars are made of hardened tool steel for extra long life.

For more information, see your nearest Buckbee-Mears representative. Or contact Bill Amundson, our industrial sales manager. You'll be glad you did.

BUCKBEE-MEARS COMPANY
245 E. 6th St., St. Paul, Minn. 55101 / (612) 227-6371

INFORMATION RETRIEVAL NUMBER 77

ELECTRONIC DESIGN 26, December 19, 1968
Helipot's new, economy dc voltage regulators are only $10^{80}$ (100 piece quantity)

Helipot's new positive (Model 809) and negative (Model 859) self-contained hybrid cermet units are designed to give you high performance at budget prices.

- 5 to 28 volts fixed outputs
- 0.003%/ma maximum load regulation
- 2 volt minimum $\Delta V$ across regulator
- 750 ma load capability
- 34 db ripple attenuation to 100 kHz
- $-55^\circ$ to $+125^\circ$C operating temperature range

Add-on capabilities include: short circuit protection with an external transistor, loads over 5 amps with an external pass transistor, and adjustable outputs with an external resistor.

These regulators are small (1" x 0.5" x 0.170" high), fully sealed (1 x 10^{-7}) and compatible with flat pack and dual inline packaging. And, they're available from local stock. For more information, call your local Helipot sales representative or circle the reader service number.
Bulova ovens are the smallest going

—but they do a big job!

Simply stated, the Bulova BDX series is the smallest and most versatile in the miniature oven field!

Now, for the details. External dimensions are just 1.5” x 1.19” x .46” (or up to .9375”, for larger models). Yet, the BDX can hold 1 to 6 tubular devices such as diodes, capacitors or resistors, up to .25” in diameter and length.

Controller is an RFI-filtered snap-action thermostat, meeting MIL-6181B. You get the BDX with your components installed and encapsulated in fluoro-carbon blown polyurethane foam insulation and hermetically-sealed. Result: a unit with minimal thermal leak that will withstand the most severe shock and vibration specifications.

The BDX is available with stud mounting, printed circuit board mounting, flange mounting or captive nut. Temperature settings from 50 °C to 100 °C are available, with a range of operating voltages from 6.3 to 117 VAC or DC. Temperature stabilities are as fine as .5 °C over a -55 °C to 90 °C with a power drain as low as 5 watts.

This is just one of a complete line of Bulova ovens, including bi-metal thermostat, transistat, solid state switched mercury, and AC or DC proportional controls. For more information, write today to Dept. ED-28.

Try Bulova First!
FREQUENCY CONTROL PRODUCTS

ELECTRONICS DIVISION
OF BULOVA WATCH COMPANY, INC.

61-20 WOODSIDE AVENUE
WOODSIDE, N.Y. 11377, (212) DE 5-6000
INFORMATION RETRIEVAL NUMBER 84

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COMPONENTS

Plug-in line monitor detects power faults

Dearborn Wire and Cable Co., 3333 W. Ohio St., Chicago. Phone: (312) 638-6711.

Called Circuit Guard, a plug-in line monitor indicates proper ground and ac polarity for 115-V 3-wire outlets. About one-half the size of a cigarette pack, the device pinpoints circuit conditions by discretely illuminating three letters. Both O and K indicate that the circuit is okay; O only, improper ground; K only, improper neutral; O and X, reversed polarity; both K and X, reversed ground and power; no indication, power is off.

CIRCLE NO. 321

Monolithic filters resonate at 30 MHz

Hughes Aircraft Co., 500 Superior Ave., Newport Beach, Calif.

Over the center-frequency range of 3 to 30 MHz, monolithic coupled-mode crystal filters use a quartz crystal element as both resonator and coupling medium for pairs of film-deposited electrodes. Filter networks, such as Butterworth, Chebychev and linear phase, can be achieved through various designs and combinations of the coupled resonators. The new filter line is available with 2-, 3- or 4-resonator elements in single or cascaded configurations.

CIRCLE NO. 322

Photocell-lamp modules provide total isolation

Clairex Electronics, Inc., 1239 Broadway, New York City. Phone: (212) 684-0940.

Combining hermetically sealed photoconductive elements with long-life lamps, Photocell-lamp modules completely isolate electrical and mechanical circuits. A low-current model, CLM5H10A, supplies lamp current with low-level transistors for switching and analog applications. Another model, CLM7H16A, is designed for interfacing solid-state power supplies to measurement or computer circuitry.

CIRCLE NO. 323

Flexible tubes transmit images

Van Denenser Co., P.O. Box 1251, Laguna Beach, Calif. Phone: (714) 494-4310. Price: $25/ft.

Series 3000 image light tubes remotely read numbers, scale markings and other symbolic information. Each light tube consists of hundreds of plastic fibers that divide the image into dots of light. Since the fibers at one end of the tube correspond in arrangement to those at the other end, the image is identically recreated at the viewing end. A standard light tube contains 625 fibers in a 1/4-by-1/4-in. image face.

CIRCLE NO. 324
Get technical literature on new solid state, portable dual-beam oscilloscope. Choice of two plug-in Y-amplifiers. Features differential input, internal voltage calibration, and both signal and time delay.

Write to Motorola Communications & Electronics Inc., 4501 W. Augusta Blvd., Chicago, Ill. 60651.

**POWER/ MATE CORP.**

**POWER TWIN-99**

**DUAL OP AMP SUPPLY**

- Dual output 12.0 to 18.0 VDC at 400 ma.
- ± 0.05% regulation
- 1.0 Mv rms ripple
- Overload and Short Circuit protected
- Meets MIL-E-5272 specs

**SAME DAY SHIPMENT**

Send for Literature describing thousands of Power Supplies to 400 Volts and to 50 Amps.

New Dale Arrester Provides Reliable, Low-Cost Surge Protection

Dangerous transient voltages get nowhere when you put Dale's new Surge Protector in their path. For a few dollars, this new design provides the best insurance you can buy against damage from direct lightning strikes, and from transients induced by lightning and switching. Here are just a few of its advantages over other low-cost protectors:

**SENSITIVITY** Typical breakdown voltage is 1500 volts when subjected to a voltage pulse rising at 10 kv/msec. Power-follow current is extinguished within ½ cycle or less.

**REPEATABILITY** Will bypass repeated overvoltages without significant change in breakdown level.

It's weatherproof, mounts anywhere, meets all applicable NEMA, USAS and IEEE standards. For a few bucks, it can save you a bundle. Write for complete information.

DALE ELECTRONICS, INC.
SIOUX DIVISION Dept. ID
Yankton, South Dakota 57078

IC cost counter

The cost of defective digital ICs can be quickly estimated with a new two-scale calculator. When the scale indicating the number of ICs used per year is set opposite the estimated percentage of defective ICs shown on the top scale, this digital IC cost estimator gives annual replacement cost as a function of replacement cost per defective unit. Teradyne

Galvanomogram

A pocket-size reference guide lists galvanometer characteristics and provides a nomogram to calculate related circuit values. The front side of the plastic design aid contains convenient galvanometer tables. Characteristics of both electromagnetic and fluid damped galvanometers are given. On the back is a handy galvanometer circuit nomogram to determine relationships between current, resistance and source voltages. When two values are known the third can be found by intersecting the two known points by a straight line. Honeywell Test Instruments Division.

Photomultiplier tubes

A 17 by 22-in. two-color wall chart gives details on more than 70 photomultiplier tubes. The chart, which may be folded for filing, shows mechanical, cathode, and operating specifications for each tube, including easy-to-read curves for UV transmission, spectral response and typical over-all sensitivity vs. over-all voltage. Other relevant information is included. Whittaker Corp., Gencom Div.

IC dictionary

Most engineers can remember a moment when their recall powers failed and they just couldn't remember the meaning of a technical term. Here's a handy little item that can come to the rescue. This pocket dictionary contains definitions of most of the terms used in the integrated circuit field. It clearly defines such expressions as CML (current mode logic), diffusion, J-K flip-flop, R-S flip-flop, skewing, wired OR and many others. The dictionary also contains an appendix of standardizations for input-output switching signals. Sylvania Electronic Components.

Angular conversion chart

A wallet-size plastic card displaying an angular correlation table is offered free of charge. Providing ready reference for technical people, the tabulation proves particularly useful when making analog-to-digital and digital-to-analog conversions. Kearfott Products Div., General Precision Systems Inc.

Coax calculator

Characteristics of Styroflex coaxial cable can be quickly determined with this handy slide rule. When over-all size and desired impedance are set opposite a pointer, all pertinent mechanical and electrical specifications appear in windows on the rule. Phelps Dodge Electronic Products.

Electronic materials

A 26-by-11-in. wall chart lists a wide variety of materials for electronic applications. They are broken down into categories with electrical, mechanical, physical and chemical properties listed for each item. The chart folds for insertion into a looseleaf binder. Dow Corning Corp.
THE COMPLETE LINE OF MODERN SWEEP SIGNAL GENERATORS

1968 CATALOGUE
Send for the complete 64-page Catalogue and Technical Brochure of Texscan products. Includes information on all four series of sweep/signal generators plus:
• Definition of Specifications
• Interpretation of Specifications
• How Hidden Specifications Affect Measurements
• Application Techniques
• 24-page Section on RF Attenuators
• Oscilloscopes

RS SERIES—Range from 1 MHz to 2000 MHz
An extremely sophisticated, solid state line of instruments. Includes all features of the VS series plus additional features such as triggered sweep, start-stop frequency indicator, dual trace sweep width, dual trace sweep time, logarithmic detection and internal AM modulation.

LS SERIES—Range from 1 MHz to 1000 MHz
A low priced, line rate sweep generator designed for specific test situations not requiring the versatility of the VS and RS lines. This series is most competitive for production, broad sweep requirements.

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A solid state instrument line which features variable sweep rates, low distortion and high stability. Many options are available to increase the capabilities of this instrument line.

HS SERIES—Range from 20 MHz to 1000 MHz
High power sweep/signal generators providing up to 8 watts swept RF output. These instruments are line rate sweep generators with CW and amplitude modulation capabilities.

Texscan’s complete line of sweepsignal generators offer the modern electronic engineer the widest choice of generators in the industry. The instrument you want, with the features you need, at a price you can afford, are now available in the four basic series of solid state generators by Texscan.

Contact your nearest Texscan Field Application Engineer... a specialist in electronic instrumentation.

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INFORMATION RETRIEVAL NUMBER 83
Application Notes

Computer-aided design

Application Note 4.2, "Modeling Transistors and Diodes for Computer-aided Nonlinear Circuit Analysis," reprints three articles from ELECTRONIC DESIGN. This note helps anyone who uses computer programs for circuit analysis to model his transistors and diodes correctly. Proper modeling is crucial to obtaining correct answers from the computer and often proves to be one of the most difficult obstacles facing new users of computer-aided circuit analysis. Design Automation, Inc.

CIRCLE NO. 332

Magnet design

A 4-page guide reviews loudspeaker-magnet design, as it evolved from long, small-area alnico to the short, large-area Indox 5 used today. Six drawings illustrate this historical transition. A design procedure presented for Indox 5 includes a design example. Another example shows how to predict magnet performance in a specific air gap and includes a nomograph for determining safe operating temperatures with given flux density and permeance coefficient. A large, easy-to-read demagnetization curve—with energy-product curves and permeance coefficient points—can be used to solve a design problem. A checklist of parameters is included. Indiana General Corp. Magnet Division.

CIRCLE NO. 333

Plexiglas techniques

Describing methods of working with Plexiglas, a 20-page brochure contains techniques for cutting, machining, finishing, forming and joining acrylic sheet. Also described are filing, scraping, sanding and buffing methods. Plug, ring, blow and vacuum forming techniques are included. Cadillac Plastic and Chemical Co.

CIRCLE NO. 334

Data handling

"Data Handling in a Transmission Network" is a technical discussion that begins at the origins of data transmission and continues on to consider contemporary methods of character coding, data formats, and the effective rates of data transmission. The 12-page booklet is illustrated with charts, graphs and drawings. Tally Corp.

CIRCLE NO. 335

Zener diodes

Comprehensive information is offered on the characteristics, testing, and reliability of temperature-compensated zener diodes. An 8-page application note is a valuable aid for designing circuits that require the use of these devices. After first defining reference diodes, the note discusses the three most important characteristics of reference diodes: reference voltage, voltage temperature stability, and voltage time stability. Motorola Semiconductor Products Inc.

CIRCLE NO. 336

Spectral density

An application work sheet describes the use of a constant percentage bandwidth analyzer to reduce to only 42 minutes the time required for sweeping frequencies from 20 Hz to 19 kHz. Conventional methods would require seven hours. Work sheets on a variety of other topics are also available. B & K Instruments, Inc.

CIRCLE NO. 337

Meter movements

A free reprint describes the various aspects and properties of a patented bifilar suspension. The bifilar suspension reprint is important reading for anyone interested in unusual sensitivity or frictionless movement. The 4-page text discusses in detail the physics involved in the coil's swing, relative to the two-wire bifilar suspension.

CIRCLE NO. 338

Magnetron data

Voltage-tunable magnetrons are described in a 15-page booklet that covers modulation and power-supply requirements. The handbook also covers the key features and advantages of the VTM, its types and general applications. General Electric Co.

CIRCLE NO. 339

Magnetic drives

Magnetic drives that can transmit torque through a barrier without the use of a mechanical connection are discussed in a two-page bulletin. Drive characteristics, general considerations and design requirements are given for synchronous axial and radial, eddy-current and hysteresis drives. Line drawings of each type illustrate drive configuration and proper positioning of component parts. Indiana General Corp.

CIRCLE NO. 340

Ultrasonic assembly

Using the programed learning concept, a 63-page text covers basic ultrasonics, assembly equipment and techniques. Information is broken down into small units called frames with each frame placed in a logical learning sequence. Most of these require the reader to write in certain essential information in order to reinforce his learning process. Branson Sonic Power Co.

CIRCLE NO. 341
Problem: 80 milliamps minimum per bar is required to drive a 15 volt seven segment display. One integrated circuit package is to be used. Input to the package is BCD. Pick the best Custom IC capability for the job.

---

**THE CUSTOM MSI SEVEN SEGMENT DECODER/DRIVER**

One of our customers had the exact problem stated above. Radiation solved the problem reliably and economically with dielectric isolation and medium scale integration. BCD to decimal to seven-bar with built-in drivers...three hundred elements on a single chip! And an 80 MA per bar minimum drive current. The best IC solution for the job.

Radiation has mastered dielectrically isolated MSI. We would like to work with you on your particular application. Medium scale integration is the best solution to the packaging density problem. Dielectric isolation is the best approach.

Contact your nearest Radiation sales office. State your problem. Let us help you pick the Best IC for the job.
ECCOFOAM® PLASTICS/CERAMICS FOAM CHART

Complete physical and electrical data are displayed for eighteen foams—liquids, powders, sheet stock—plastics, ceramics and even artificial dielectrics. Fold-out chart in full color for notebook or wall mounting is yours.

INFORMATION RETRIEVAL NUMBER 231

STYCAST® CASTING RESINS CHART COMPLETELY REVISED

This chart for notebook or wall mounting has just been brought up to date. It contains comparative property data on over 20 Sty­cast® epoxies and urethanes.

INFORMATION RETRIEVAL NUMBER 232

ECCOBOND® ADHESIVES FREE WALL CHART

Fully illustrated fold-out chart gives complete physical and electrical data on over 20 adhesive systems—conductive, nonconductive—liquids, powders, pastes—for electrical or mechanical applications—various chemical types.

INFORMATION RETRIEVAL NUMBER 233

Emerson & Cuming, Inc.
CANTON, MASS.
GARDENA, CALIF.
NORTHBROOK, ILL.
Sales Offices in Principal Cities
EMERSON & CUMING EUROPE N.V., Oevel, Belgium

New Literature

Instrument catalog

Instruments, systems and components are described in a 16-page catalog. Ratiometric techniques—a concept for measuring and controlling resistance, voltage, current and ratio—are used throughout the line. Automated instruments and precision components are emphasized. Julie Research Laboratories, Inc.

CIRCLE NO. 342

Fastener catalog

A new 12-page catalog and selection guide contains application and specification information for a line of four new fasteners. Two are for use in blind-hole applications; two are designed for fastening honeycomb or sandwich panels. A special application section is designed to assist engineers in solving unusual fastening problems. Paneloc Corp.

CIRCLE NO. 343

Rectifier modules

A 12-page application note describes the uses of self-stacking silicon rectifier modules in high-voltage and high-current power supplies, in high-voltage pulse circuits, and for tube replacement purposes. Presented are details of the module's construction as well as circuit application information. Unitrode Corp.

CIRCLE NO. 344

Load cells

Technical information on bonded strain gauges for use in research, industrial, and aerospace applications is given in a 62-page catalog. Mechanical and electrical specifications on eleven different series of load cells in ranges from one to 10 million pounds, are included. Recommended practices and a description of load cell terminology assist the design engineer in selecting the proper strain gauge for his application. Visual reference curves are furnished. Transducer.

CIRCLE NO. 345

Motor speed controls

A 28-page catalog on motor speed controls contains detailed information on many brands and types. Included is an extensive list of hundreds of variable-speed motors that can be used with the controls. B & B Motor and Control Corp.

CIRCLE NO. 346

Dc motor catalog

A 32-page bulletin gives complete engineering data for a line of dc motors and gearmotors that provide continuous-duty power outputs from 0.004 to 0.3 horsepower. Diehl Div., The Singer Co.

CIRCLE NO. 347

INFORMATION RETRIEVAL NUMBER 85
This time try EECOSWITCH...

...on your front panel

Why settle for second best on your equipment when at no extra cost you can have EECOSWITCH.

With EECOSWITCH you get:
- **7 complete lines** with dozens of coded outputs to choose from.
- **Off-the-shelf** delivery of standard models.
- **Interchangeability** with other makes of rotary thumbwheel switches without panel alterations.
- **Answers** for your application problems generated by EECO's 20 years of switch and digital system experience.
- **Sample assemblies** for new design prototypes.
- **EECO's exclusive 2-year warranty.**

The EECOSWITCH catalog describes our complete line and includes 15 pages of useful application data. Send for your copy today.

There's an EECOSWITCH for almost any application

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ELECTRONIC ENGINEERING COMPANY OF CALIFORNIA
1441 EAST CHESTNUT AVENUE · SANTA ANA, CALIFORNIA 92701 · (714) 547-5651
DMS 3200
DIGITAL MEASURING SYSTEM
(Fully solid state with IC's)

This all-solid-state precision measurement system offers unlimited expansion capability through plug-in additions, resulting in a specialized instrument for each type of measurement. New plug-ins now broaden the measurement capability of this field-proven unit. Over 10,000 are in use at present.

Scaling controls make possible resolution of up to seven digits on the three-digit display by utilizing the overrange capability of many of the plug-ins, thus providing high resolution and accuracy with minimum investment.

DC VOLTMETER PLUG-IN DP 100
$175
0.01 mV to 999 volts
± 0.1% rdg ± 1 digit

DC MICROVOLTMETER PLUG-IN DP 110
$450
0.001 mV to 999.9 volts
± 0.05% rdg ± 1 digit
4-digit resolution

AC VOLTMETER PLUG-IN DP 130
$375
0.01 mV to 999 volts
± 0.1% rdg ± 1 digit
22 Hz to 1.0 MHz

EVENT COUNTER/SLAVE PLUG-IN DP 140
$80
Up to 1,000,000 counts/sec
Cascade with second DMS to obtain 6-digit display

1 MHz COUNTER PLUG-IN DP 150A
$230
0.01 Hz to 999.9 kHz
± 0.0005% rdg ± 1 digit
7-digit resolution

80 MHz COUNTER PLUG-IN DP 160
$395
0.1 Hz to 80.0 MHz
± 0.00005% rdg ± 1 digit
7-digit resolution

OHMMETER PLUG-IN DP 170
$275
.001 ohm to 999.9 megohms
± 0.1% rdg ± 1 digit
Microamp test current

CAPACITY METER PLUG-IN DP 200
$275
.001 picofarad to 9,999 mfd
± 0.1% rdg ± 1 digit
Low DC test voltage

TIME INTERVAL METER PLUG-IN DP 210
$230
0.01 ms to 999 seconds
± 0.00005% rdg ± 1 digit
Period or time interval

DC CURRENT METER ADAPTER D 310
$90
.0001 microamp to 9.999 amps
± 0.15% rdg ± 1 digit

Pneumatic tools
A complete handbook on pneumatic assembly tools for screw and nut sizes from #00 to #10 includes a table of torque values for determining proper fastener tension. Also offered are guidelines for proper tool selection; special information on a complete line of straight and pistol-grip screwdrivers, as well as illustrated descriptions of over 70 time-saving accessories. Standard Pneumatic Motor Co.

CIRCLE NO. 348

Aluminum enclosures
A 24-page catalog lists a new line of aluminum enclosures. Parts are carefully indexed to facilitate ordering. While standard material for these enclosures is 3003-0 aluminum alloy, 6061-0 is optionally available, and alloy 1100-0 is also offered in certain sizes. Parts are deep-drawn on hydraulic presses; they feature good wall uniformity and smooth finish. Halliburton Enclosures.

CIRCLE NO. 349

Component selector
The 1968-1969 Cornell-Dubilier Electronics Component Selector, completely revised and updated, is now available. This 120-page catalog fully describes an entire product line of capacitors, filters and relays. The book includes application charts, selection charts, and standard rating tables arranged to ease the designer's task. Cornell-Dubilier Electronics.

CIRCLE NO. 350

Computer-aided drafting
How a computer, teamed with closed-circuit television, aids large-scale drafting is discussed in a new technical application bulletin titled, "Computer-Aided Drafting with CCTV," Seven photographs and a case history of one such system are included. Cohn Electronics, Inc.

CIRCLE NO. 351
Circular connectors

Standard military and commercial circular power connectors are described in a new 80-page catalog, which contains specifications and illustrations of a complete connector line. Complete assembly instructions, accompanied by step-by-step drawings, are included for each connector type. Design information—compiled in handy guidebook sections—includes quick-reference pages on insert specifications, and product availability. A valuable data section on MIL-C-5015 connectors defines nomenclature, constructions, shells, finishes, inserts and contact types. Easy-to-use reference charts detail compatible connector plugs and receptacles. Amphenol Connector Division.

CIRCLE NO. 352

Capacitor catalog

General characteristics of capacitors for numerous applications are detailed in a 40-page catalog. Information given includes sizes and configurations in each series, temperature ranges and coefficients, capacitances, tolerances, types of leads and electrical parameters. San Fernando Electric Manufacturing Co.

CIRCLE NO. 353

Relay catalog

Relays, solenoids and stepping switches are described in a 32-page catalog. Hundreds of different relay types are listed. Universal Relay Corp.

CIRCLE NO. 354

Indicator lights

A 12-page, two-color catalog describes a series of two-terminal subminiature indicator lights, designed for mounting in 15/32-in., 1/2-in. and 17/32-in. clearance holes. Data, specifications, drawings and ordering information are provided for all units. Dialight Corp.

CIRCLE NO. 355

**HICKOK ELECTRICAL INSTRUMENT COMPANY, 10514 Dupont Ave., Cleveland, Ohio 44108**

INFORMATION RETRIEVAL NUMBER 87

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**HICKOK CRO 5000 25 MHz Oscilloscope**

*(all solid state)*

$65000

This high-precision laboratory oscilloscope equals the basic performance of higher priced, sophisticated 'scopes, yet meets the industry need for such performance in the $600 price range. Emphasis has been placed mainly upon those characteristics most important in precise measurements, eliminating some of the more exotic and somewhat superfluous functions found in higher priced instruments. The result is an all-solid-state instrument in the medium price range with extraordinary stability, sensitivity, bandwidth, sweep-speed range, trigger capability, reliability, and ruggedness.

- 25MHz vertical bandwidth (to 3db down points)
- Usable to 50MHz
- All solid state for high stability and reliability
- 12 calibrated vertical attenuator ranges
  - 10 mv/div to 50 volts/div (±3.0% accuracy)
- 24 calibrated sweep ranges
  - 0.05 microseconds/div to 2 sec/div (±3.0% accuracy)
- Vertical delay line assures viewing of full leading edge of pulses
- "Sweep Delay" of up to 40 divisions
- Sweep speed continuously variable between ranges
- X-axis channel bandwidth DC — 5MHz
- 4" flat-faced CRT, 6 x 10 division graticule
- 3.8 kv HV provides sharp, bright trace
- Vertical amplifier will handle overloads, with negligible distortion of waveforms increased to 5 times screen height
- Internal 1.0% calibration squarewave
- Fast, convenient push-button selection of trigger modes
- Positive, solid triggering on all displays
- Small — 11½” W, 6½” H, 19” D; 24 pounds
Aircraft Flight Mechanisms:
4 weeks delivery.
MIL-SPEC quality.
The industry's lowest prices.

Nobody else but Ideal brings you all these benefits. Including high torque and sensitivities, up to 80° deflection, complete shielding, low weight, synchro or standard mounting, all shapes of pointers and flags—and customizing of all parameters. American-made.

We're known for experience and promises kept. Write for free 34-page catalog, Ideal Precision Meter Co., Inc., 218 Franklin St., Brooklyn, N.Y. 11222 (212) EVergreen 3-6904.


INFORMATION RETRIEVAL NUMBER 88

Unlocking the Future

Monday through Thursday

NEW LITERATURE

Chart recorders

Miniature strip-chart recorders are described in a 20-page catalog. Presented are more than 30 models that record parameters of current, voltage, power, pressure and temperature and convert recorded parameters to voltage or current. Rustrak Instrument Div., Gulton Industries, Inc.

CIRCLE NO. 356

Instrumentation

A 12-page two-color catalog on transmission measurement equipment includes detailed information on tunable voltmeters and tracking signal generators, wave analyzers and spectrum display units; line and cable fault locaters, cable carriers and semiconductor test sets. Engineering specifications include those pertaining to measurement accuracy, frequency, power requirements, and special features of each unit or instrument. Sierra Electric Operation, Philco-Ford Corp.

CIRCLE NO. 357
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Electronic Design 26, December 19, 1968

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What are you looking for in your linear and switching applications? 100 amperes pulsed current capability? 300 watts power dissipation? The highest second breakdown capability of any device on the market in a modified TO-3 package?

Look no further. Here's another first from the silicon power leader—RCA's new 2N5578 family...six high-power, high-current Hometaxial-base silicon n-p-n transistors designed for applications in military, industrial, and commercial equipment.

2N5575, for example, has a pulsed collector current of 100 A. Dissipation is 300 watts at 25°C with $V_{CEX}$ (sus) of 70 V. The useful beta range is 10-40 at 60 A.

For complete design flexibility, there are three terminal variations: 2N5575 and 2N5578 have heavy pins; 2N5576 and 2N5579 have soldering lugs; and 2N5577 and 2N5580 have flexible leads with solderless connectors.

This family of types all adds up to circuit cost savings in inverters, regulators, motor controls, and other linear and switching applications. Check the chart. For more information, see your RCA Representative or your RCA Distributor. For technical data, write: RCA Electronic Components, Commercial Engineering, Section No. IG122, Harrison, N. J. 07029.

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<table>
<thead>
<tr>
<th>Characteristic</th>
<th>2N5575</th>
<th>2N5576</th>
<th>2N5577</th>
<th>2N5578</th>
<th>2N5579</th>
<th>2N5580</th>
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<tbody>
<tr>
<td>$h_{fe}$</td>
<td>4</td>
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<td>$V_{CEO}$ (sus)</td>
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<td>$E_{/V}$</td>
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<td>0.5</td>
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<tr>
<td>$M_{/Q}$</td>
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<td>0.6</td>
<td>0.5</td>
<td>0.8</td>
<td>0.5</td>
<td>0.8</td>
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</tbody>
</table>

*With base forward biased
*With base reverse biased and $R_{b} = 100$, $L = 33mH