Electronics World

JULY, 1967
60 CENTS

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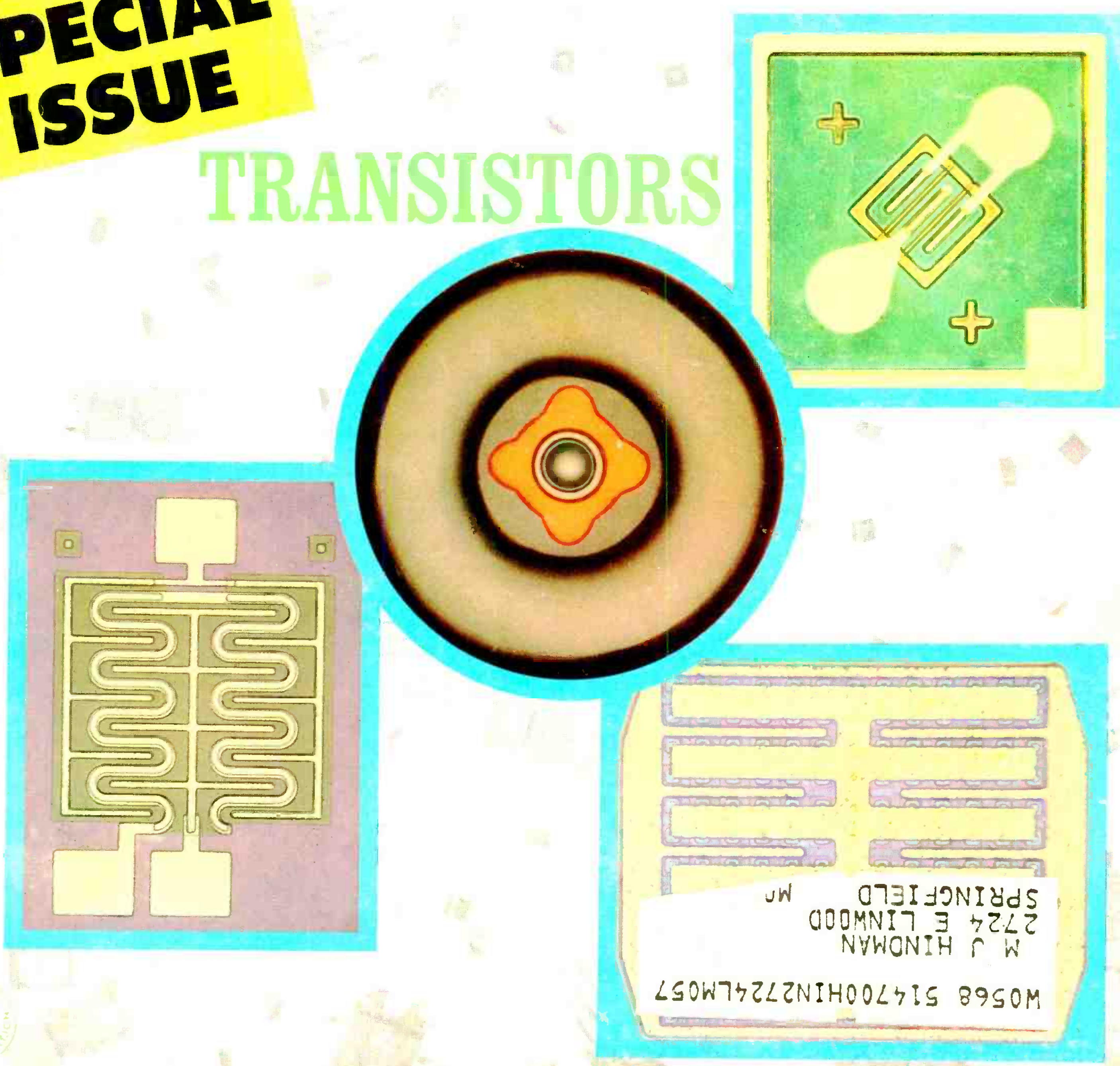
PROBLEMS AHEAD FOR TV TECHNICIANS—
Integrated Circuits Will Force Major Changes

SPECIAL ISSUE

TRANSISTORS



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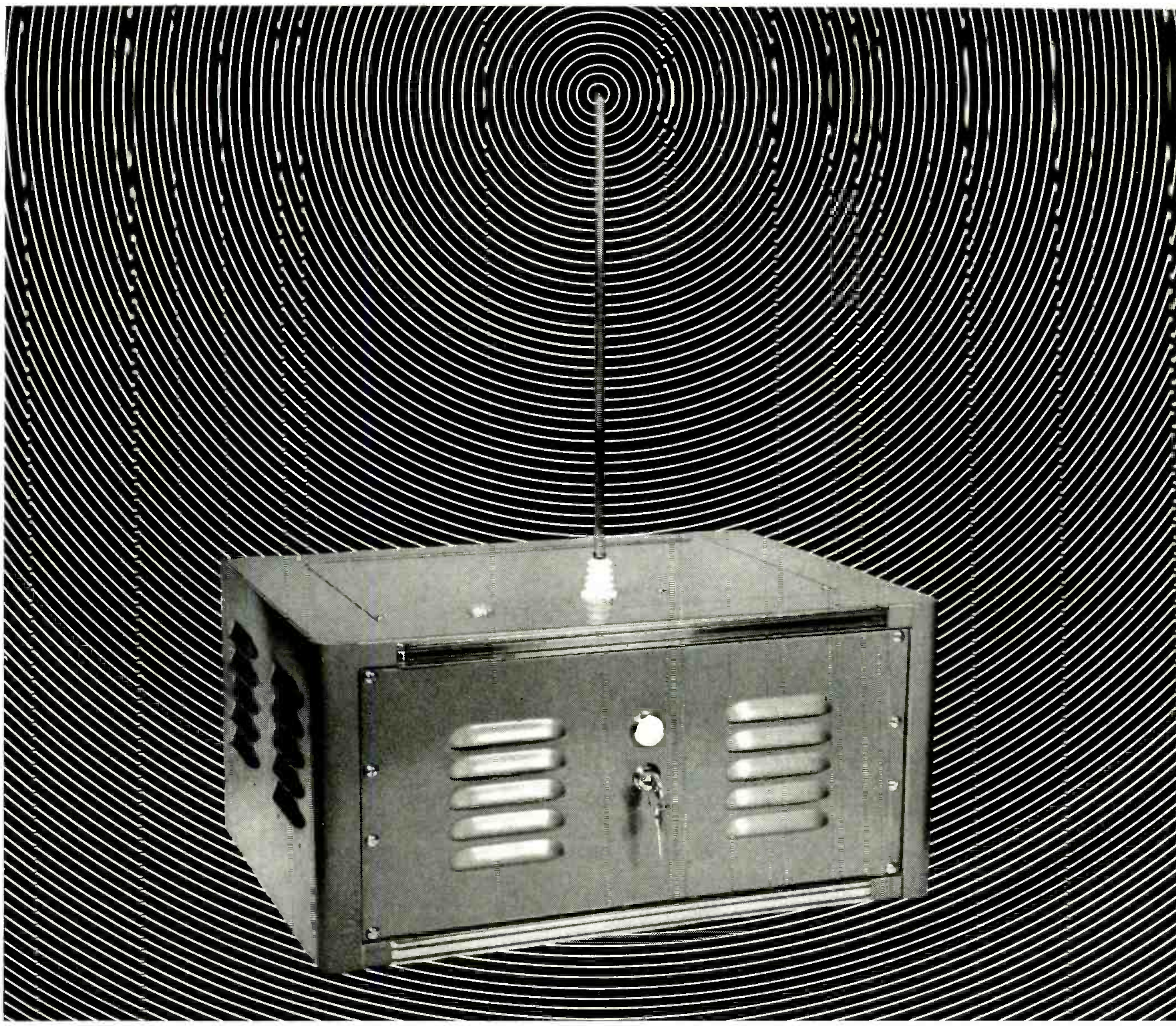

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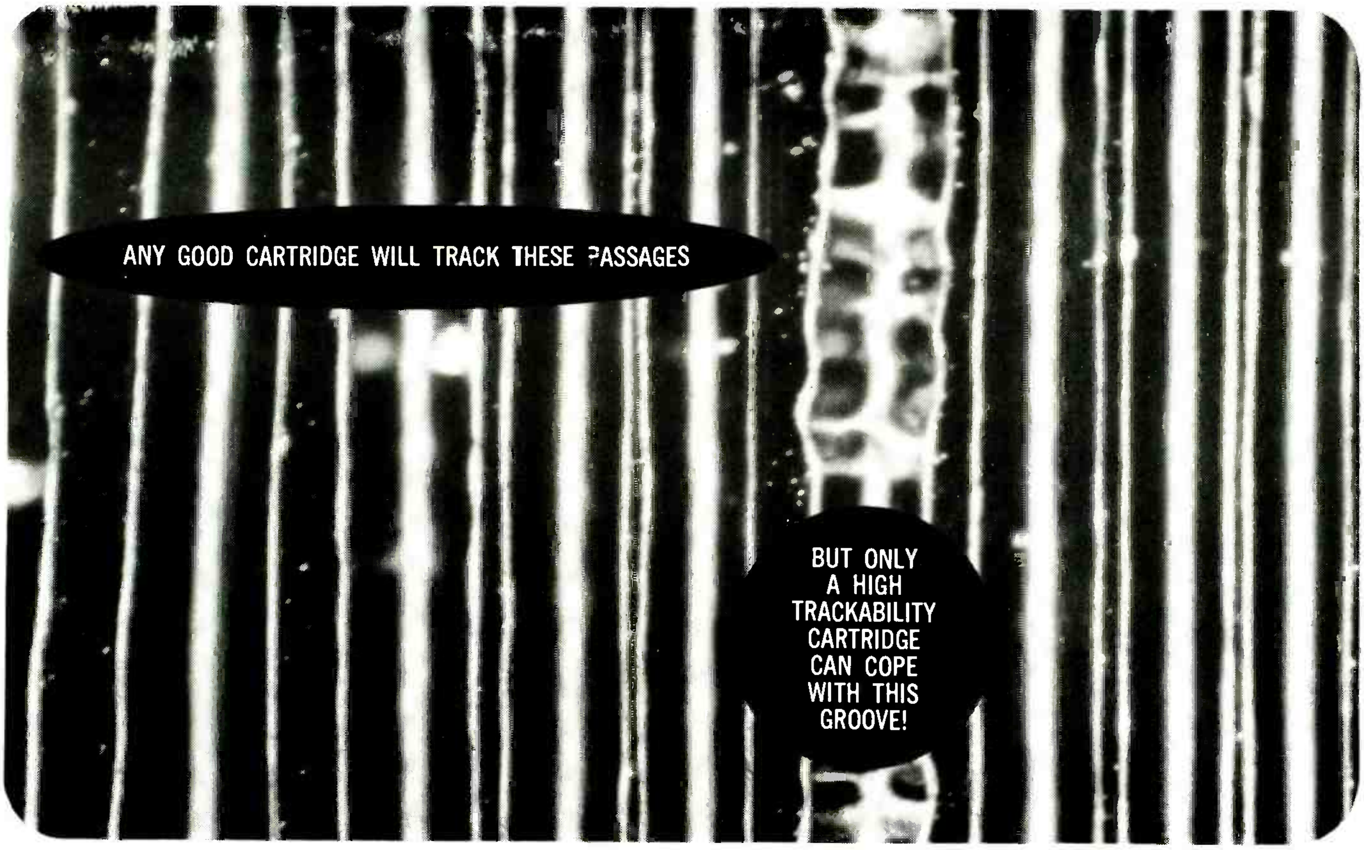

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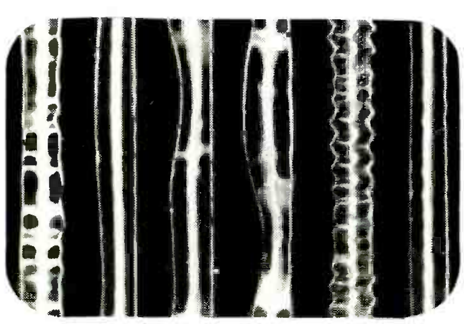

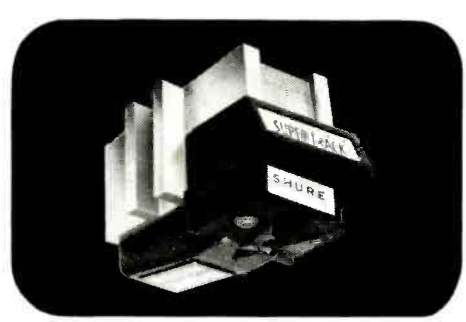

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OUR COVER this month symbolizes our special issue on "Transistors." We have shown four interesting and colorful photomicrographs of some of the newer transistor structures. The circular photomicrograph is that of a Motorola selective-metal-etch high-frequency germanium transistor. Above and to the right is a Siliconix diffused epitaxial junction field-effect transistor. Below and to the right is an RCA "overlay" high-frequency power transistor. The photomicrograph at the lower left is of a Fairchild MOS field-effect transistor. Our background for these photomicrographs consists of a grouping of the new, inexpensive plastic (epoxy) packaged transistors from General Electric, Motorola, RCA, and Siliconix.

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Electronics World

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MONTHLY FEATURES

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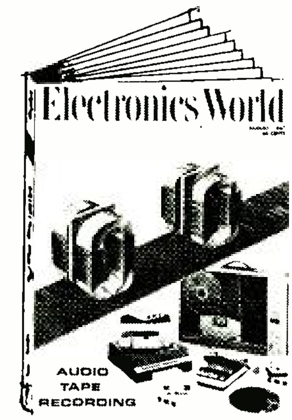
COMING NEXT MONTH



SPECIAL FEATURE ARTICLES ON:

Audio Tape Recording

Two timely articles of interest to audiophiles and professional sound men will cover **Selecting the Right Tape** by Joseph Kempler of Audio Devices and **Biasing in Magnetic Tape Recorders** by John G. McKnight of Ampex. The audio tape article provides up-to-the minute information on the many varieties of tape available, including the cartridge units which are becoming so popular in both car and home. Also covered are valuable hints on recording so as to avoid print-through and distortion, along with proper storage methods to preserve valuable recordings. The article on biasing includes practical information on the biasing circuits used in home and professional tape recorders. The effect of various amounts of bias current is discussed along with the pro's and con's of different biasing schemes and frequencies.

VALUE ENGINEERING FOR THE ELECTRONICS INDUSTRY
A management philosophy of applying a forced organized approach to reducing costs while maintaining product quality is discussed in detail by Fred H. Possner, Director of Value Engineering at Airborne Instruments Labs. Striking examples of the efficacy of this approach are included.

CATV: PAST, PRESENT & FUTURE
Jerry Hastings of Jerrold's CATV Division provides a comprehensive report on the current status of community antenna television systems and their potential in the near and distant future.

THE OPERATIONAL AMPLIFIER: CIRCUITS & APPLICATIONS
An in-depth discussion of these highly versatile controllable-gain modular or IC packages which have been widely used in computer and military circuits in the past but are now appearing in commercial and consumer products. New price and size reductions should stimulate use.

*All these and many more interesting and informative articles will be yours in the **August** issue of ELECTRONICS WORLD . . . on sale **July 20th.***

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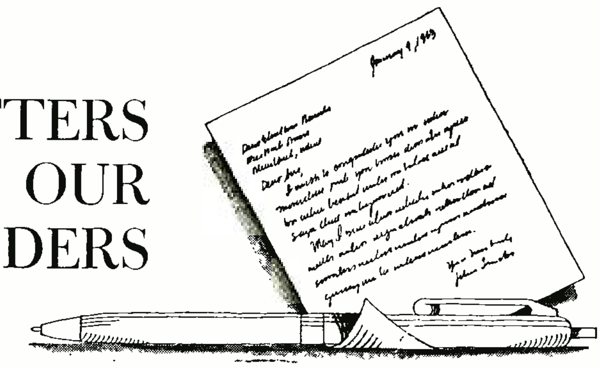
LETTERS FROM OUR READERS



SILICONIX FET'S

To the Editors:

Your May issue contained an article on "Field-Effect Transistor Circuits" by Wujek and McGee. Most of these circuits use field-effect transistors produced by *Siliconix*. However, in contacting the company to get some of these FET's, I have learned that the low prices quoted at the very beginning of the article are no longer in effect. As I recall, these prices were $1.00 for the U-110 transistor or $2.75 for a package consisting of the U-110 and U-112.

ROBERT G. SIMPSON
Los Angeles, Calif.

Reader Simpson is quite correct in that these low prices were the ones quoted in a Siliconix *ad that appeared several months ago in* ELECTRONICS WORLD. *The ad represented a limited time offer and was intended to stimulate use of the new FET's. The prices quoted in the ad actually expired at the end of February, and the company reports that their mission has been accomplished in introducing FET's to a large number of people.*

For those readers who are interested in using these transistors now, the U-110, U-112, U-146, and U-147 are available from local Siliconix *distributors at prices of $5.25, $4.55, $3.25, and $2.95, respectively, in quantities from 1 to 29. The manufacturer will be glad to direct all inquiries for these transistors to their local distributors or will furnish the name of the nearest distributor where such transistors may be obtained. Write to* Siliconix Inc., *1140 West Evelyn Avenue, Sunnyvale, California 94086.—Editors*

* * *

ELECTRONIC EAVESDROPPING

To the Editors:

Apropos of your article on electronic snooping, I thought a recent editorial in *Life* magazine on the subject "Ways To Control Snooping" expressed my sentiments exactly. One paragraph in this editorial is as follows:

"But if lawmen have the power to tap wires and bug rooms of people they believe guilty, what is to prevent them from overhearing the private words of the innocent? Who has the right to overhear, and for what purpose? 'We act differently if we believe we are being observed,' Vice President Humphrey has written. 'If we can never be sure whether or not we are being watched and listened to, all our actions will be altered and our very character will change.' Associate Justice William Brennan has limned another threat: 'Electronic surveillance, in fact, makes the police omniscient; and police omniscience is one of the most effective tools of tyranny.' "

PAUL BRADFORD
New York, N.Y.

To the Editors:

Your article on electronic eavesdropping (April issue) was very enlightening. However, I have some questions. (1) An Attorney General once said that banging on the floor will disable a bug for 15 minutes or so. Any truth to this? (2) If I suspect that a room is bugged, how can I hold a private conversation? (3) Why do some bugs claim a hundred feet of range while others mention thousands of feet? (4) How far away can a bug detector find a bug? (5) How effective are the tailing devices mentioned in the article? (6) "The Man From U.N.C.L.E." uses exotic communications systems. Are they for real?

JOHN W. HOLLANDER
Brooklyn, N.Y.

These are just a few of the questions we have received on our eavesdropping story. Very brief answers follow:

1. Only if you bang directly on or near enough to the bug to damage it will you stop operation. Otherwise nothing will happen except that you may hurt your hand.

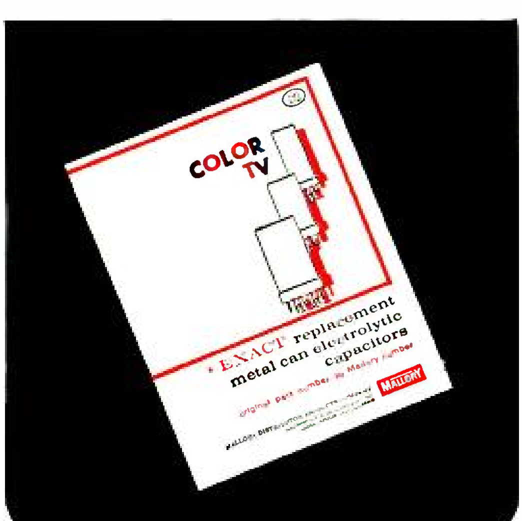
2. Whispered conversation can take place if a radio, TV set, or music system is turned up to a reasonable volume. The louder background overshadows the conversation. The safest place to avoid eavesdropping is in the center of a large room away from furniture, walls, and overhead fixtures. Another ploy sometimes used is to converse in the bathroom with the shower running.

3. Despite all claims, most r.f. bugs commercially available can only reach out 100 feet or so with any reliability.

(Continued on page 12)

MALLORY **Tips for Technicians**

Choosing electrolytic capacitors for color TV



When you need to replace an electrolytic capacitor in a color television, it pays to select the best. Your customer has a lot of dough invested in his color set, and he won't settle for less than top performance. And his eye can see sub-standard performance in color that would go unnoticed in black-and-white.

Color TV is tough on electrolytics. Ambient temperatures run hotter, because of the greater number of tubes and resistors inside crowded cabinets. Ripple currents are higher, so the capacitor has to do a better job of getting rid of internally generated heat. Voltage ratings are higher, too; most electrolytics in color TV are 400 volts or higher.

It's no surprise that leading color TV makers are pretty darn particular about the electrolytics that they use as original equipment. They demand a true high-voltage, high-temperature, high ripple capacitor . . . not one that's simply made to sell at bottom price. And meeting these demands is the way Mallory got to be the top supplier of electrolytics for color TV. We're the guys who pioneered the 85°C capacitor, who have consistently increased ripple current capacity, and who have the reputation of leadership in high voltage ratings.

Here's our tip of the month. To save yourself time, get a copy of our new cross reference, "Exact Replacement Metal Can Electrolytic Capacitors for Color TV". It lists the original part number and the catalog number of the corresponding Mallory replacement for 38 leading color TV manufacturers. To save yourself costly call backs, use only the best . . . and that's one of the Mallory FP-WP series, made to original equipment specs. To get everything you need for color TV service, see your Mallory distributor. He stocks Mallory power resistors, circuit breakers, carbon and wire-wound controls and Discap® ceramic capacitors.

For a copy of the Color TV cross reference, ask your Mallory Distributor, or write to Mallory Distributor Products Company, a division of P. R. Mallory & Co. Inc., Indianapolis, Indiana 46206.

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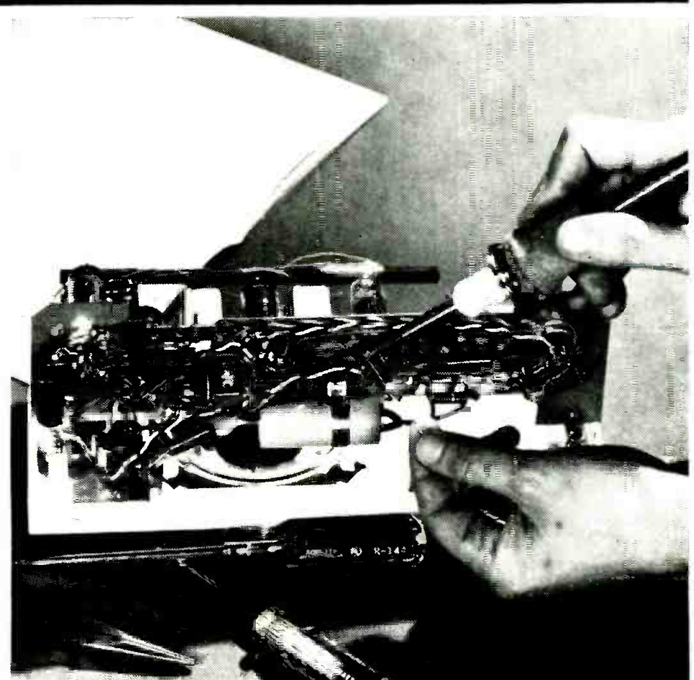


(Continued from page 6)

Speech quality is passable in many cases, borderline in most, and unintelligible in a few.

4. Because of the very low power output and range of r.f. used, detector pickups must be nearly in direct contact with the bug before they can detect the presence of the bug.

5. If you have ever listened to the Citizens Band (especially in a large urban area), you will realize how difficult it is to trail someone using a very low power transmitter.

6. The requirements of the story line usually exceed electronic development. At present, these exotic systems do not exist. Neither do we know of any radiotelephones in shoes.—Editors

* * *

LASERS FOR CARS

To the Editors:

Your May issue had an excellent lead article on "Automotive Electronics" which described a short-range laser ranging device for reducing the possibility of accidental rear-end collisions. As I understand it, this device, being developed by *General Electric*, is a pulse-echo-ranging system that uses infrared light pulses in much the same way that pulse radar is able to determine distance (range).

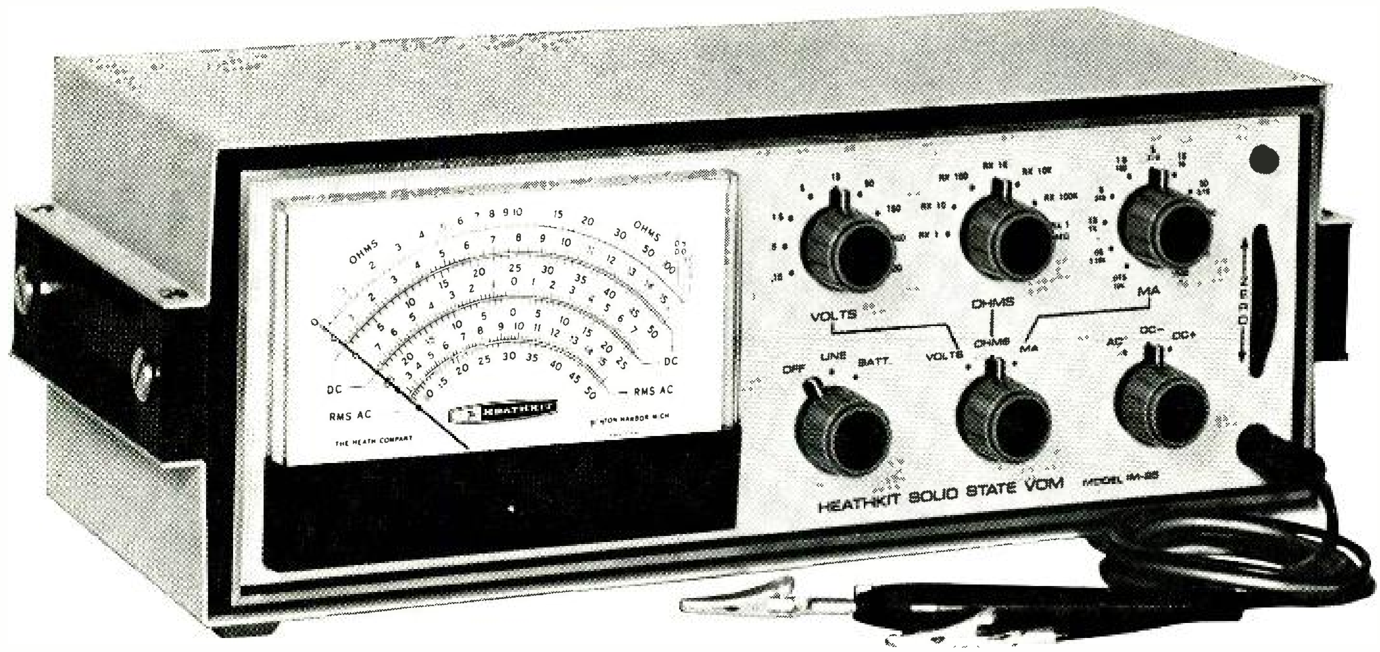
Readers may also be interested in another approach involving a laser for automobiles which is being developed by *Airborne Instruments Laboratory*. In this system, a car would carry a gallium-arsenide light-emitting diode laser which would radiate infrared pulses at about 200 Hz at all times. These pulses would be confined by means of inexpensive optics to a pencil beam about 15° wide with a range of perhaps 700 feet behind the car. Trailing automobiles would then pick up the radiated laser energy and indicate it in some simple way to the driver of the following car.

It is planned to make the repetition rate of the radiated pulses vary inversely with the radiating car's speed. For example, when the car is moving slowly or standing still, the rep rate will be high; as the car speeds up, the rep rate will be reduced. If the detector in the following car is made to respond to these changes, it will be possible to signal the radiating car's speed and hopefully prevent a rear-end collision.

Richard Parkhurst
San Francisco, Calif.

Thanks to Reader Parkhurst for telling us about this interesting laser application. Many other companies, including the automobile manufacturers themselves, are hard at work on prototype and experimental equipment to improve the safety of their products. Interestingly enough, much of this equipment is electronic.—Editors. ▲

New Solid-State High Impedance V-O-M



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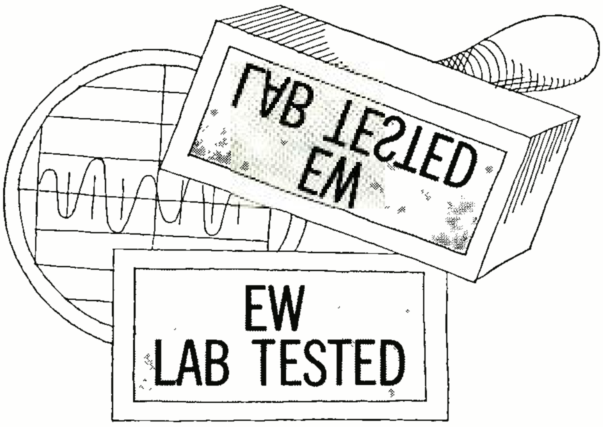

HI-FI PRODUCT REPORT

TESTED BY HIRSCH-HOUCK LABS

Bogen TR-100X Stereo Receiver
Wharfedale W20 Speaker System

Bogen TR-100X Stereo Receiver

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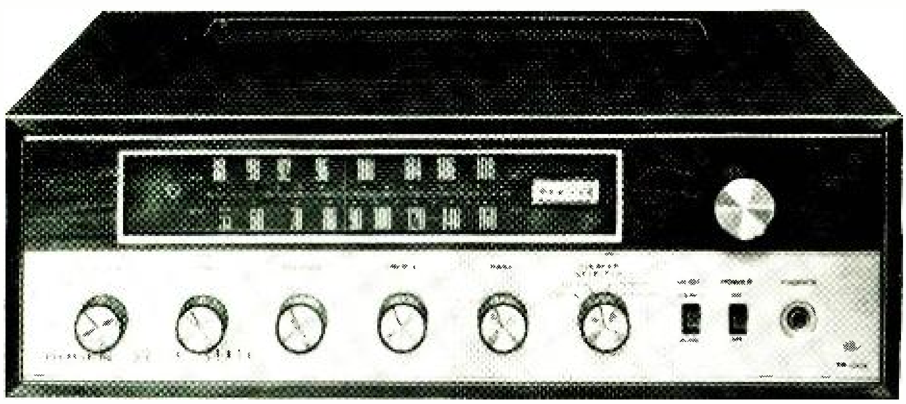


THE *Bogen* TR-100X solid-state AM-FM stereo receiver combines operating simplicity with ample control flexibility for most users, and at a moderate price. Using silicon transistors throughout, the TR-100X has a sensitive, stable FM tuner, an AM tuner, dual preamplifiers, and a pair of 30-watt (music power) amplifiers.

The FM tuner has a tuned r.f. amplifier, three i.f. stages, and a ratio detector. The shielded front-end also contains the AM oscillator and the tuning capacitor for the AM r.f. amplifier. Two of the FM i.f. stages do double duty as AM i.f. amplifiers. The tuning meter (which is tuned for maximum reading) operates from the AM detector or from a diode detector in the FM i.f. section.

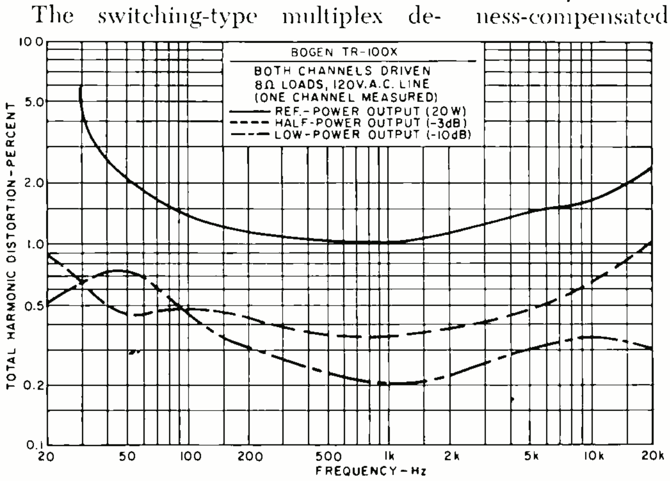
The switching-type multiplex demodulator has traps which very effectively eliminate SCA interference (whistles and birdies) from the background of FM-stereo broadcasts. The 38-kHz oscillator is gated on automatically by the 19-kHz pilot carrier, which also synchronizes it. A separate transistor operates the incandescent stereo-indicator lamp on the dial face.

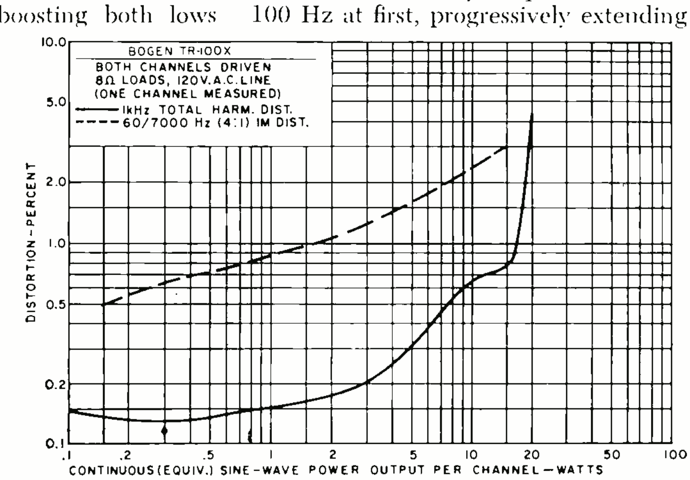
The audio section has a pair of two-stage feedback-type phono equalizing preamps and switched inputs for AM, FM, Phono, and Aux. The Tape-Output jacks supply the selected signal to a tape recorder, unaffected by volume or tone controls. There is no provision for monitoring from the tape. The tone controls act on both channels simultaneously. The volume control is loudness-compensated, boosting both lows and highs as the setting is reduced. There is no provision for disabling the loudness compensation. A separate balance control adjusts channel balance.

The driver transistors are transformer-coupled to the output transistors which, in turn, are direct-coupled to the speakers, without blocking capacitors. A fixed-response roll-off below 20 Hz prevents damage to transistors or speakers by subsonic transients. A front-panel switch selects either or both of two pairs of speakers or switches the outputs to a front-panel headphone jack. The control complement is completed by two slide switches for a.c. power and stereo/mono selection (effective on all inputs).

The FM tuner of the TR-100X is rated at 2.7 microvolts IHF usable sensitivity. We measured it as 2.9 μV, well within the limits of normal measurement tolerances. The TR-100X was non-critical to tune and had a little over 1% distortion at 100% modulation. The FM frequency response was ±1.5 dB from 30 to 15,000 Hz. Stereo channel separation was better than 30 dB from 150 to 1000 Hz and better than 20 dB from 30 to 10,000 Hz.

The amplifier frequency response was ±1 dB from 20 to 20,000 Hz at maximum volume setting. At normal listening levels the loudness compensation boosted lows by about 10 dB and highs by about 5 dB. The bass tone control affected only frequencies below 100 Hz at first, progressively extending



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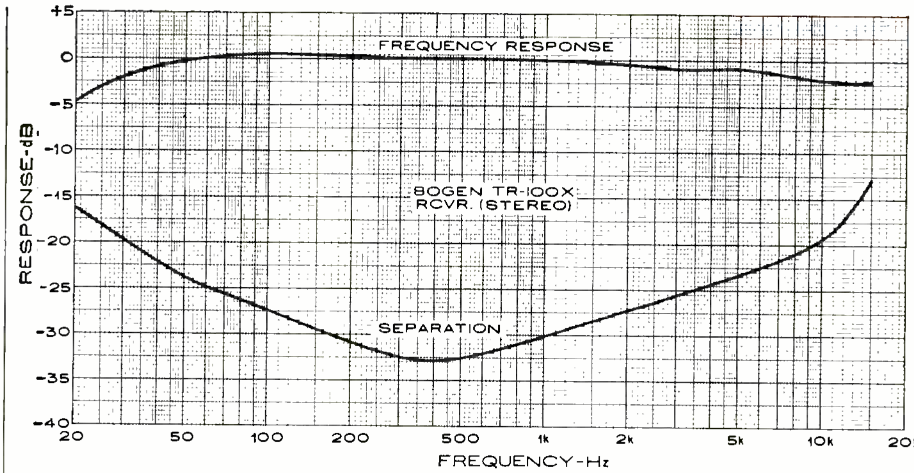
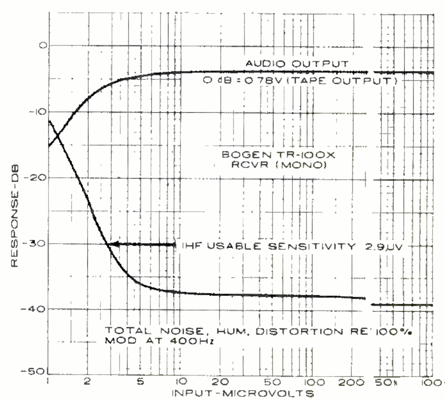


to about 300 Hz as it was rotated to its limits. This is an excellent characteristic, well suited to removing the effects of the loudness compensation if this is desired. The RIAA phono equalization was flat within ±1 dB from 150 to 15,000 Hz, rising to +4 dB in the vicinity of 40 Hz.

We measured a maximum power output of 20 watts per channel into 8-ohm loads, with both channels driven. Into 4 ohms, the power was reduced about 50% and into 16 ohms it was increased about 20%. The manufacturer does not supply continuous power ratings, so it is not possible to correlate these figures with his 30-watt music-power rating.

At 20 watts, the harmonic distortion was about 1% from 200 to 2000 Hz, rising to 2% at 50 and 15,000 Hz. At half power, distortion was under 1% from 20 to 20,000 Hz, and less than 0.4% over most of this range. At 2 watts output (a normal maximum listening level) the distortion was between 0.2% and 0.3% over most of the audio range, reaching a maximum of about 0.7% at 50 Hz.

The 1000-Hz harmonic distortion was under 0.15% at power levels below 1 watt, rising to 0.3% at 5 watts and to 1% at about 17 watts. Heating of the output transistors during the high-power measurements affected the distortion somewhat making a direct comparison between the two distortion curves difficult. The IM distortion rose smoothly from 0.5% at low levels to



2% at 8 watts and to a value of 3% at 15 watts.

The TR-100X audio amplifiers could be driven to 10 watts output by as little as 2 millivolts on phono inputs or 0.14 volt on Aux. inputs. Hum was inaudible, about 76 dB below 10 watts on Aux. and 57 dB below 10 watts on Phono (the latter being almost entirely hiss).

We found the unit to be a very satisfactory FM-stereo receiver which tuned easily and has excellent sensitivity and audio quality. The loudness compensation produced excessively bassy sound with relatively efficient speakers which required low volume-control settings. However, the bass tone control was able to restore a satisfactory balance.

The *Bogen* TR-100X sells for $249.95. Walnut-finished cabinets are available in metal for $14.95 and in wood for $24.95. ▲

Wharfedale W20 Speaker System

For copy of manufacturer's brochure, circle No. 35 on Reader Service Card.

A NEW addition to the growing list of what might be termed "miniature" loudspeaker systems is the *Wharfedale* W20. Measuring only 14" x 9¾" x 8½" deep, this diminutive box delivers a very respectable amount of good-quality sound.

The W20 is a two-way system, with an 8" high-compliance woofer and a 3" dome-radiator tweeter. The tweeter level is adjustable by means of a continuous control on the rear of the enclosure. The cloth grille is removable, being held in place by hook-and-pile fastener strips. The speaker impedance is rated at 4 to 8 ohms.

We averaged data taken at eight locations in our room to derive a composite frequency response curve. A rather prominent peak occurred at about 100 Hz, followed by a slight depression at around 200 Hz. (*This was partly the result of room resonances which we have observed around 100 Hz with previous*

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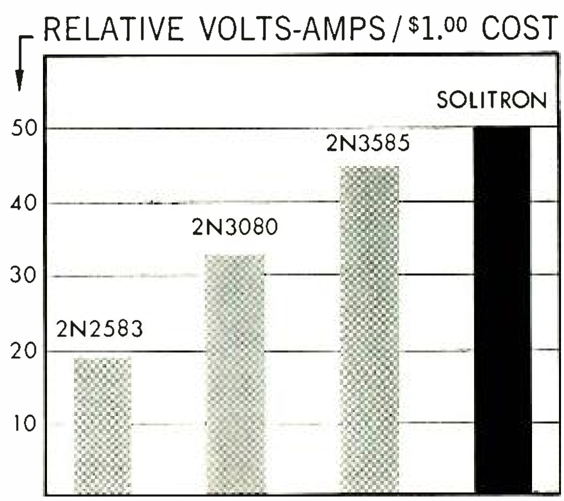
Solitron, now in full production of the SDT 8950/ SDT 8650 families, has reduced the price of these fast switching, high power silicon transistors. As shown on the comparison Volt-Amp chart, these transistors provide more power-handling capabilities per dollar than multiples of similar, limited-source devices. In order to meet various size and weight requirements, they are available in either 1 1/16" hex or TO-68 packages. A few of their many uses include visual display circuits, converters, inverters, voltage regulators and/or space flight applications.



Type Number TO-68	Type Number HEX-CASE	DESIGN LIMITS			PERFORMANCE SPECIFICATIONS					
		$V_{(BR)CBO}$	$V_{CEO(SUS)}$	$V_{(BR)EBO}$	h_{FE}		V_{BE} (sat)	V_{CE} (sat)	I_{CBO}	f_T
		Volts	Volts	Volts			Volts	Volts	μA	MHz
		$I_C = 1mA$	$I_C = 0.2A$	$I_E = 1mA$	$I_C = 40A$,	$V_{CE} = 10V$	$I_C = 40A$,	$I_B = 6A$	$V_{CB} = 100V$	
		Min.	Min.	Min.	Min.	Max.	Max.	Max.	Max.	Typ.
SDT8651	SDT8951	200	200	8	10	40	2.0	2.0	10	20
SDT8652	SDT8952	225	225	8	10	40	2.0	2.0	10	20
SDT8653	SDT8953	250	250	8	10	40	2.0	2.0	10	20
SDT8654	SDT8954	275	275	8	10	40	2.0	2.0	10	20
SDT8655	SDT8955	300	300	8	10	40	2.0	2.0	10	20

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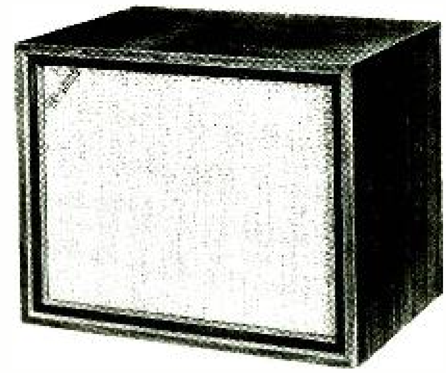
speaker response curves.—Editor) Above that frequency the response was very smooth and flat, rising slightly to +6 dB at 12,000 Hz. This was measured with maximum treble level, and can be adjusted downward as desired by the listener.

The harmonic distortion at a 1-watt drive level was very low down to about 70 Hz, rising smoothly to 10% at 55 Hz. We would judge the effective lower limit of the W20's frequency response to be about 50 Hz, which is very respectable for a speaker encompassing only about ⅔ cubic foot. The tone-burst response was good throughout, with no sustained ringing or spurious output frequencies, as shown below.

The efficiency of the speaker system is moderate, which means that it can be driven by an amplifier of 20 or more watts, rated output. We would not suggest its use with the very low-power, budget-priced amplifiers which can only deliver 8 to 10 watts, since the speaker thrives on surprisingly large amounts of drive power. As an example, we used it with a 40-watt transistor amplifier, and it withstood the full output of the amplifier without any signs of breakup or excessive distortion—and, at the same time, the loudspeaker delivered an astonishing volume level.

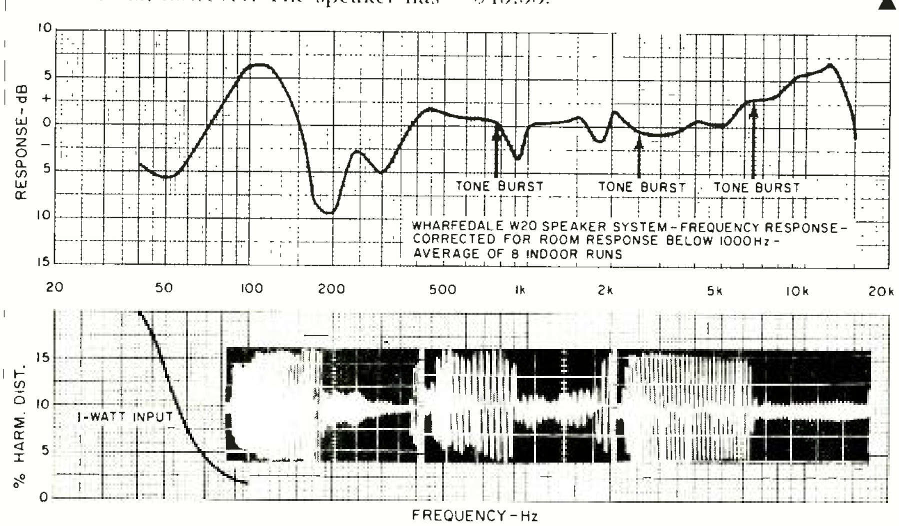
There is an illusion of more bass than the W20 actually puts out, which is probably due to the emphasis in the 100-Hz region. It does not sound tubby or unnatural, however. The speaker has



a very pleasing easy sound, with excellent definition in complex orchestral passages. We found it preferable to operate it with the treble level control turned down considerably for over-all balance, but this can be expected to vary with the characteristics of the individual listening room.

A speaker of this size and price must not be judged by the same critical standards as far larger and more costly systems. For use in limited space applications, it should acquit itself admirably. It sounds good and is thoroughly listenable even if it will not convince the listener that he is in the concert hall. We feel that its low distortion is a strongly contributing factor to its "listenability" and it is unlikely to wilt under the full drive of most powerful integrated receivers.

The price of the *Wharfedale* W20 is $49.95. ▲



LASER MEASURES OCEAN WINDS AND WAVES

A recent demonstration by Electro-Optical Systems, Inc., has shown that a c.w. laser operating within an aircraft flying at high altitudes could be directed to an ocean area directly beneath the aircraft and, by recording the reflected intensity of the beam as a function of the viewing angle, a three-dimensional intensity pattern could be constructed to show prevailing wind fields existing at the surface. By further imposing a microwave frequency on the optical carrier, a reflective phase displacement signal can be detected which is directly translatable into wave amplitude. The readout then becomes, in effect, three dimensional.

It was pointed out that if used aboard observation-type aircraft, the surface evaluation system could detect build-up of heavy seas and winds almost instantaneously in those areas of the Atlantic and Pacific not normally covered by existing meteorological networks and could thus give valuable aid to the tactical deployment of both surface and sub-surface vehicles. ▲

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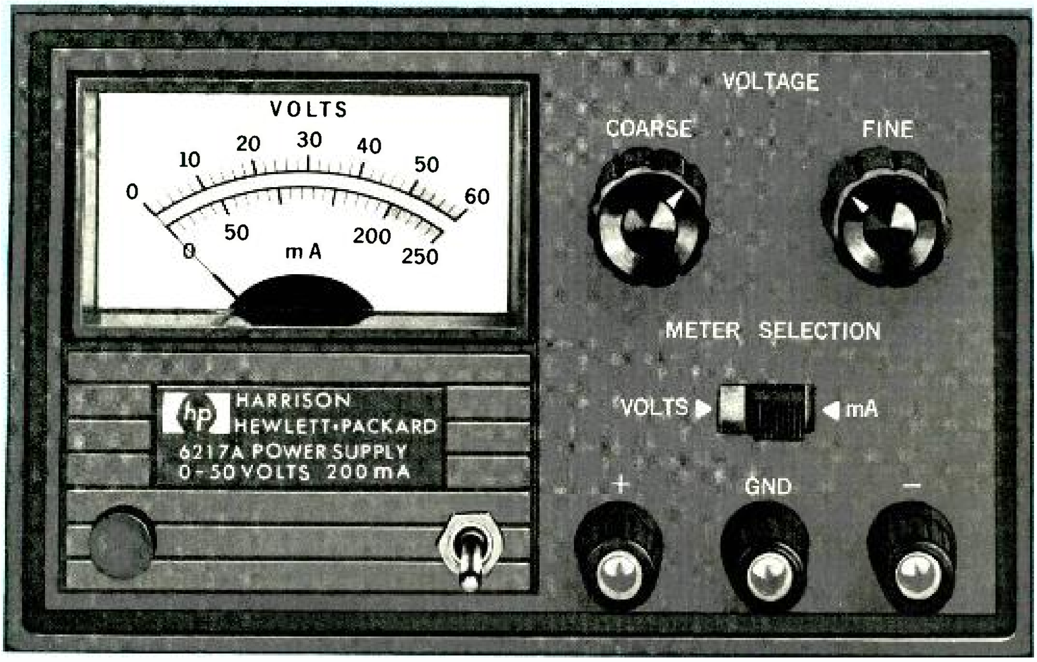

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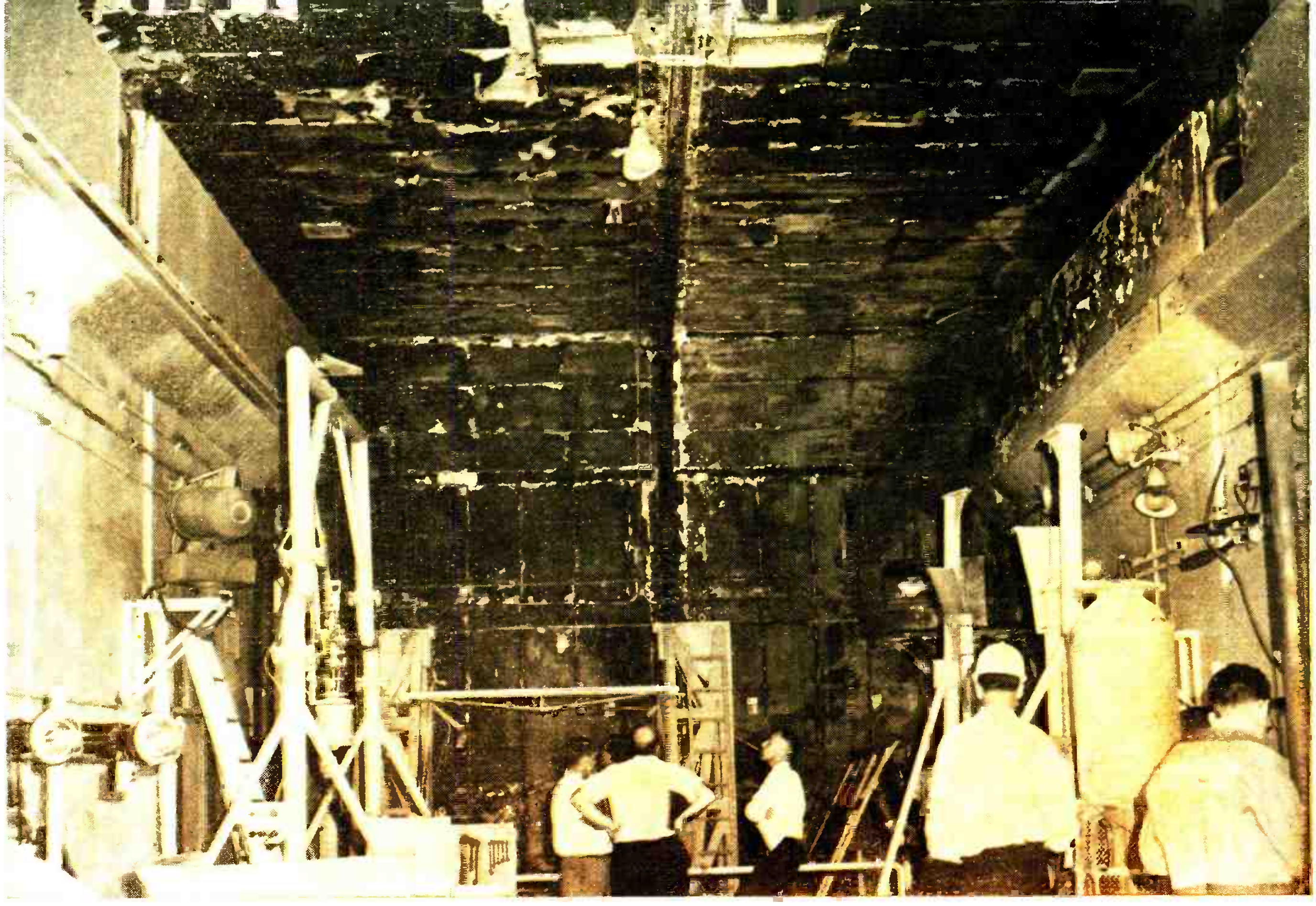


Interior of spin balance facility at Cape Kennedy, following the accidental ignition of an X-248 rocket motor on April 14, 1964. The Orbiting Solar Observatory B spacecraft was mounted on top of the motor and alignment tests just completed when the accidental ignition occurred. The spacecraft was badly damaged and 11 persons working in the building were injured—two fatally. The X-248 rocket was the third stage on a Delta launch vehicle which had been scheduled to orbit OSO B.

STATIC ELECTRICITY: The Space Age's Billion-Year-Old Gremlin

By EDWARD A. LACY

Discharges from static electricity have accidentally fired missiles, damaged semiconductors, and produced aircraft explosions. Here is how danger is detected and minimized.

BACK before the Gemini experiments, space engineers believed that a spacecraft could acquire a substantial charge of static electricity from rubbing against the atmosphere on the way to space and from engine operation while in space. Such a charge could destroy sensitive semiconductor circuits, they reasoned, or cause a circuit to turn on at the wrong time. As bad as this may seem, it was nothing compared to another nagging worry of the designers.

Imagine, they said, an astronaut walking in space approaching another spacecraft or perhaps his own ship. Just as he starts to touch it, a fat spark of static electricity jumps from his hand to the craft, burning a hole in the thin skin of the spacecraft and possibly causing the fuel on board to explode.

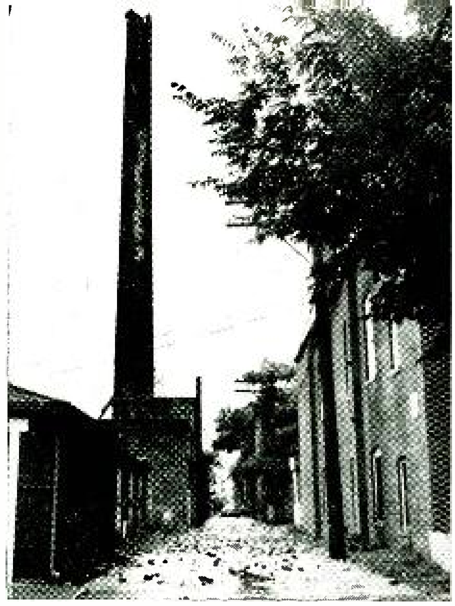
Just to make sure it didn't happen, the engineers installed three copper fingers on the Agena target docking adapter so that any potential difference between it and the Gemini could be slowly bled off through a resistor bank. Naturally, the engineers were greatly relieved when the static discharge monitor on the Agena told them that static electricity simply is not a problem in space.

But while static electricity may not be a problem in space, this billion-year-old gremlin nonetheless presents difficulties for the space age and particularly for the missile industry. At Cape Kennedy, for example, no one wants to be working around live missiles when lightning—a form of static electricity—is nearby. Unfortunately for the safety engineers, lightning is often close by at the Cape, since Florida has more thunderstorms than any other area in the country. Not only are these thunderstorms frequent but they are also powerful. In 1965, one of the launch gantries was struck by a stroke which registered 151,000 amperes.

As dangerous as these strokes may be, it is significant to note that only a slight discharge of static electricity can cause disaster, as the missile engineers have learned from tragic experience. For instance, early one spring morning in 1964 at the Cape, technicians and mechanics in the spin-test facility were preparing to move the third stage of a NASA Delta rocket. Someone had just removed a protective plastic sheet from the motor when the motor suddenly ignited, lifted off, and flew to the end of the 100-foot-long building. In the process five men were burned critically (two later died) by the 3000° exhaust from the motor. The suspected cause of the whole affair: static electricity from the protective plastic cover used.

Fortunately, when we encounter static electricity the results are not so tragic. On dry winter days we may get a tingle or perhaps a jolt if we shuffle across a carpeted floor and then touch a metal desk or doorknob. Self-protection is simple: slap the metal object with the palm of your hand before attempting to use it, or touch the doorknob with a tightly held key before opening the door.

However, while static electricity may sometimes be a source of shocking discomfort, it may also be a source of joy and comfort, according to recent studies. At the *Stanford Research Institute*, scientists recently used a sensitive static detector called a "feed mill" to measure the electrostatic processes associated with the breakup of water droplets in a bathroom shower. The results of their study show that the exhilarating effect of a shower may be due to negative electricity instead of the warmth and force of the water.



Chimney shows severe damage which was caused by a lightning stroke.

Electronics enthusiasts have long been familiar with the problems of static electricity in phonograph records, transistors, instrument meters, and automobile tires.

It is no secret, for example, that the plastic used in phonograph records can be given high static electricity charges which, unfortunately, attract dirt, dust, and fluff to the grooves. Naturally, such particles cause noise and distortion as well as damage to the record. The problem has become even more acute with stereo records and with modern pickups which track so lightly that they ride over the dust particles instead of pushing them aside.

What are the record manufacturers doing about the problem? One company has added the anti-static agent Catanac SN to its high-quality records to stop the problem at its source. It is interesting to note that another major manufacturer says such agents are costly and that still another manufacturer claims that the use of sufficient additives to eliminate static electricity causes the sound quality of the records to suffer.

Additional electronics problems with static electricity involve transistors. Some years ago it was noticed that when transistors were inserted into Styrofoam blocks for temporary storage, the very act of pushing the leads into the Styrofoam sometimes generated a static charge great enough to destroy the device.

Although this problem has generally been overcome, it is still present with the new insulated-gate field-effect transistors. The gate insulation on these devices can be destroyed by the static electricity generated by (1) the transistor sliding around in its plastic shipping container or (2) by the electrostatic body potential of the technician who is wiring the unit into a circuit.

Electrostatic discharger mounted on side of fuselage of helicopter.

One semiconductor manufacturer is planning to place a zener diode across the gates in its FET's in the near future to alleviate this problem. Until this is common practice, however, technicians are advised to discharge their bodies and to ground the tips of their soldering irons when working with FET's.

In most cases, static electricity is generated by friction. When the plastic face of a test instrument is polished, for example, enough electricity may be created to attract the needle of the meter to the face and result in an inaccurate reading.

However, static electricity can be produced by electrostatic induction and by contact and separation of materials. In the latter case, electrons may move from one material to another as when belts pass over pulleys or when automobile tires run on highways. If the materials are then separated, one object will have a surplus of electrons (negatively charged) and the other will have a deficiency of electrons (positively charged). A surface is considered to be very strongly charged if it has a deficiency or excess of only one electron in 100,000 atoms.

Shock Hazard and Explosion

A static charge may have a potential from a few volts to several hundred thousand volts. Since the human body can develop up to 10,000 volts under certain conditions, it is not uncommon to find charges measuring from 5000 to 10,000 volts.

A static voltage as low as 1500 volts can be felt if the little finger is slowly and carefully brought to within a few thousandths of an inch of a charged body, says the Bureau of Mines. Why, then, don't such high voltages cause serious injury or death? Simply because the current is so small. The Bureau explains it as follows: "A current of ½ ampere (that is, ½ coulomb of electricity per second) is needed to light an ordinary 4.5-volt flashlight to full incandescence. It would require 500,000 people, charged to 5000 volts each, to hold a total quantity of ½ coulomb of electricity."

The static electricity on one's body may be enough, however, to ignite highly flammable dusts, gases, and vapors. In fact, a charge that can barely be felt, seen, or heard has more than enough energy to ignite flammable mixtures.

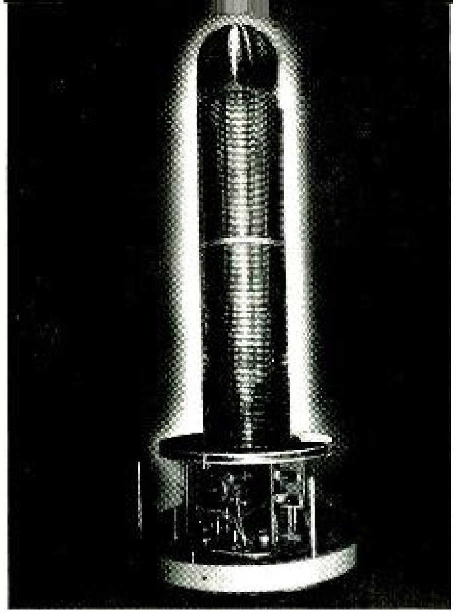
Annual fire and explosion losses from static electricity have been estimated as high as $100,000,000. This figure takes into account such diverse explosions as those in hospital operating rooms, munitions factories, and airliners. For example, an inquiry board concluded that the 1959 crash of a *TWA* plane in Italy was caused by a gasoline explosion touched off in flight by static electricity.

Lightning

Lightning causes many explosions and fires. As a tremendously powerful static electricity spark, a single bolt may have a potential of 100 million volts and produce a current of 200,000 amperes. Such bolts are classified as either "hot" or "cold." A hot strike lasts up to a tenth of a second and sets fire to flammable materials in its path, while a cold strike is faster and has an explosive rather than an inflammatory effect.

The lightning-protection industry has gone undercover with much of its equipment. Five-foot-tall lightning rods with ornamental colored glass balls have given way to 10-inch-tall "air terminals" which may be the only parts that show in a modern system. The conducting cables to ground are hidden from sight either in the framing or behind ridge rolls or downspouts.

Does a grounded TV antenna provide lightning protection? No, says the Lightning Protection Institute, which is sponsored by the lightning-protection industry. The Institute says that the average antenna does not have a long enough ground wire and does not have enough paths to ground. Ordinary antenna grounding, the Institute states, protects against accidental energization from electrical service but it cannot be expected to ground lightning, which has an amperage that may be more than one thousand times greater than ordinary house current.



Van de Graaff generator shown here with the pressure vessel removed.

Static Detectors

To effectively eliminate or control static electricity, it is necessary to use sensitive instruments to detect and measure it. Such instruments include the gold-leaf electroscope, neon lamps, electrostatic voltmeters, and vacuum-tube electrometers. All these devices are characterized by very high input impedance.

The simplest of these and the one so often seen in elementary science demonstrations is the gold-leaf electroscope. In this device, the gold leaf is attached to a metal rod. When the rod is brought near a charged body, the leaf is repelled from the rod (or itself) because like charges repel. With the electroscope, charges as low as 350 volts can be detected.

A neon lamp or fluorescent tube can be used in some applications to indicate the presence of static electricity since it will light feebly near voltages of 100 volts or more if one terminal is grounded or held in the hand. Even a burned-out fluorescent tube can be used.

Electrostatic voltmeters are employed to measure very high voltages such as those encountered around radar, oscilloscopes, and Van de Graaff generators. These voltmeters derive their torque from the attraction of charged metallic surfaces; the stationary surface or vane is highly insulated with materials such as polystyrene. With insulation resistance as high as 3×10^{15} ohms, the leakage current of these voltmeters is so low that sometimes they must be shunted by a resistance in order to measure varying static voltages.

The vacuum-tube electrometer is a simple vacuum-tube circuit with a meter in the plate circuit to indicate current flow. An antenna or probe is connected to the grid of the tube; when the probe is brought near a charged body, the plate current will increase if the body is positively charged, or the plate current will decrease if the body is negatively charged.

Control of Static Electricity

Once a static electricity problem has been detected and measured, it can be controlled or eliminated by (1) grounding and bonding, (2) humidification, (3) static eliminators, and (4) anti-static sprays.

Grounds and Bonds. When two (or more) conducting bodies are connected together with a conducting wire, there will be no potential difference between them and static sparking will not occur. In this condition, the objects are said to be bonded. Although bonded, these objects may still have a potential compared with ground. By simply connecting a wire from the objects to ground, they become *bonded and grounded.*

Since static electricity currents are measured in microamperes, a very low resistance ground, as normally required in electrical work, is not needed. In fact, in hospital operating rooms, where anesthetic gases can be ignited by a spark, low-resistance grounds are deliberately avoided. The floors in these rooms are made just conductive enough to drain off static charges but not conductive enough to be a standard electrical hazard.

Humidification. During the winter months when the relative humidity goes down, static electricity becomes obvious, especially when one walks across a carpet and touches a metal doorknob. On the other hand, during the summer when the humidity is high, static electricity may scarcely be noticed.

When the humidity is high, some materials may absorb moisture, become more conductive, and thereby allow static charges to leak off. Such a condition, it should be noted, has nothing to do with the conductivity of air since water vapor does not make air electrically conductive.

At one time it was thought that this high humidity could be used to reduce the hazards and nuisance of static electricity. Thus, in some factories and hospital operating rooms, the humidity was raised to 70%. Not only was this hard on the workers and expensive machinery, but it didn't work often enough to make it worth the expense and discomfort.

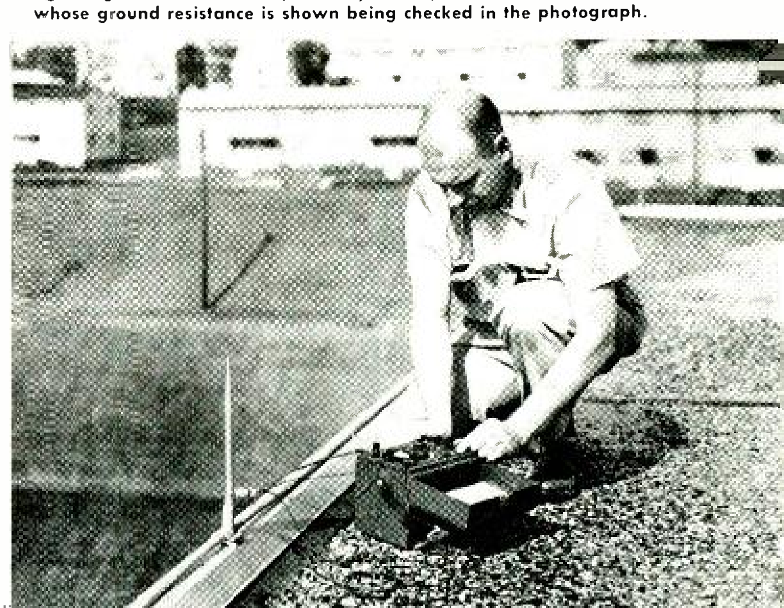
Static Eliminators. Radioactive static eliminators use radium or polonium to ionize the air. While such devices offer safety from explosions, they are naturally a hazard to anyone working nearby and therefore must be carefully shielded when installed.

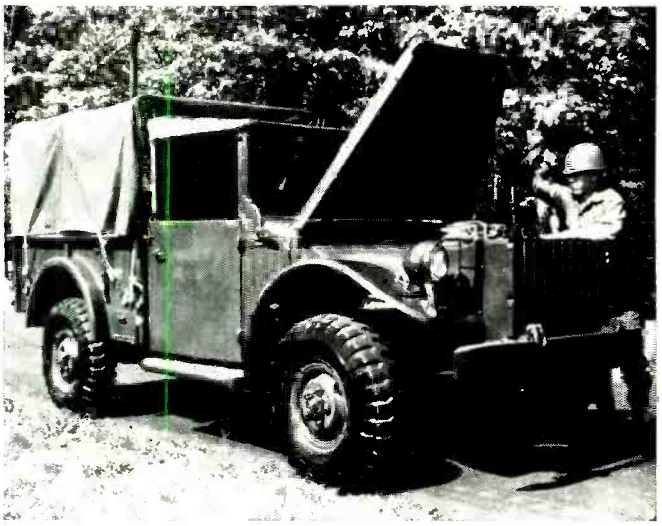
High-voltage eliminators apply a high voltage (5000 to 15,000 volts) to a series of points close to a grounded surface. The voltage across this gap will discharge most charged items that are placed in the gap.

Static combs are grounded metal bars with needles or wire brushes. When a charged body (such as a flow of paper) goes by such a comb, the charged body ionizes the gap between it and the comb, thereby discharging itself.

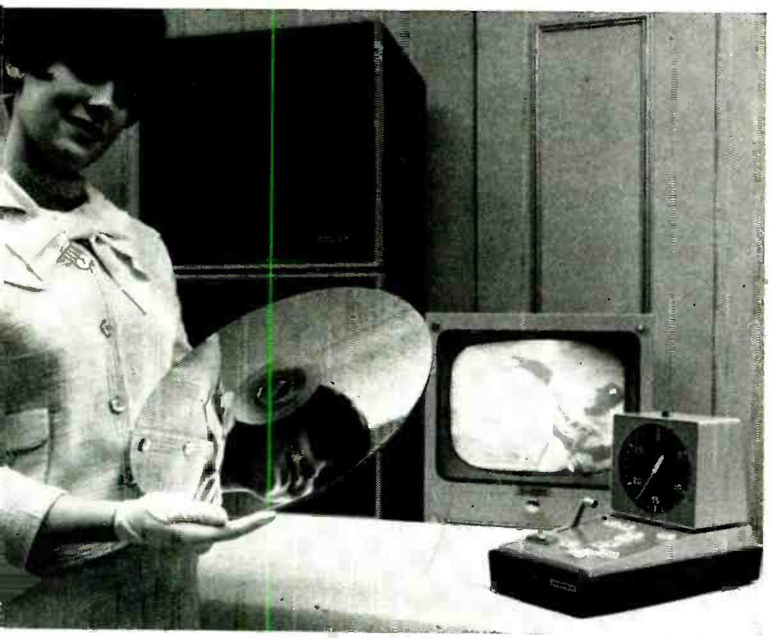
Air guns combine an air stream with an anti-static spray in a hand-held air gun which is useful for cleaning plastic parts. (*Continued on page 67*)

Lightning rods have been replaced by inconspicuous "air terminals", whose ground resistance is shown being checked in the photograph.





RECENT DEVELOPMENTS IN ELECTRONICS

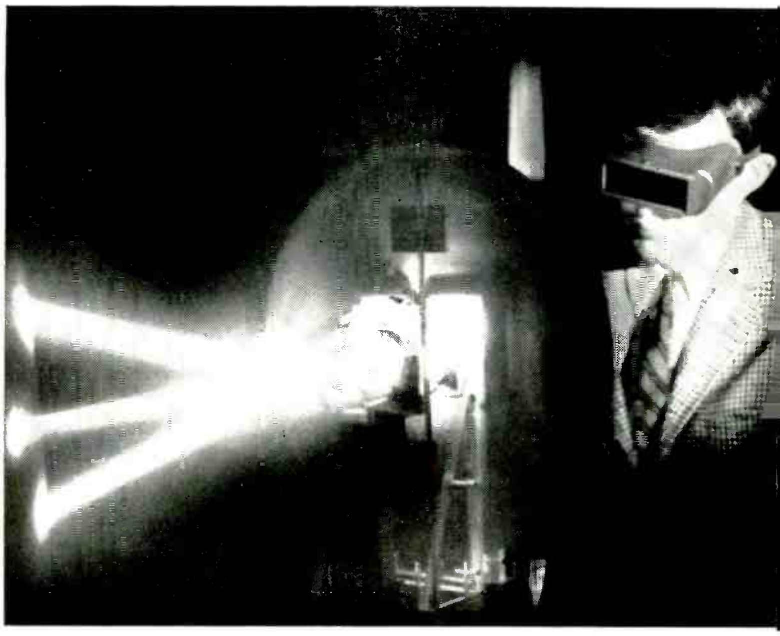


Fuel Cells Under the Hood. (Top left) An electrically driven army truck which derives its power from fuel cells, was demonstrated recently. Four fuel cells supply power for the vehicle which has a gross weight of four tons. In each cell hydrazine is combined with oxygen from the air to produce 5000 watts of electricity. Unlike batteries that must be recharged periodically, cells produce electricity as long as they are supplied with fuel, much as an internal-combustion engine runs as long as it receives fuel. Exhaust from fuel cells is harmless water vapor and nitrogen. Power from the cells feeds a 3900-rpm d.c. series traction electric motor through a solid-state voltage controller. The motor provides the equivalent of about 27 horsepower, and replaces the regular 94 horsepower gasoline engine. Cells were developed by Monsanto Research.

Video Disk Records Color TV. (Center) The model's face is reflected in the highly polished metal disk used to record color television pictures in a new recording system. The disk is able to record and play back 30 seconds of action in high-band color, and any part of the recording may be cued for on-the-air use in four seconds. Designed primarily for use in televising sports action, the new system may also be used for rapid low-cost production of color commercials and special-effects material. Capabilities also include reverse-action playback at either normal or slow-motion and frame-by-frame advance for animation or analysis of highlights. Rapid playback of recordings is made possible by use of rare metal disks with extremely long life instead of conventional reels of tape. Disk recordings may be mixed with tape and film recordings in production. Ampex developed system at the request of ABC.

Road-Surface Profiler. (Left) Precise measurement of road-surface profiles is the purpose of the new road profilometer shown here. Consisting of a light truck modified to accommodate sophisticated electronic instrumentation and measuring equipment, the profilometer uses two trailing wheels (one at each side of the truck as shown in the upper photo) to sense changes in the road's profile. Instrumentation in the truck (lower photo) converts this information into a permanent record on magnetic tape or a strip chart. General Motors engineers use the taped data as input for vehicle testing devices in the laboratory, simulating actual road surfaces. Highway engineers also find the data helpful in checking the effects of aging on road surfaces and in planning safer highways. The Texas State Highway Department has already purchased one of the instruments.

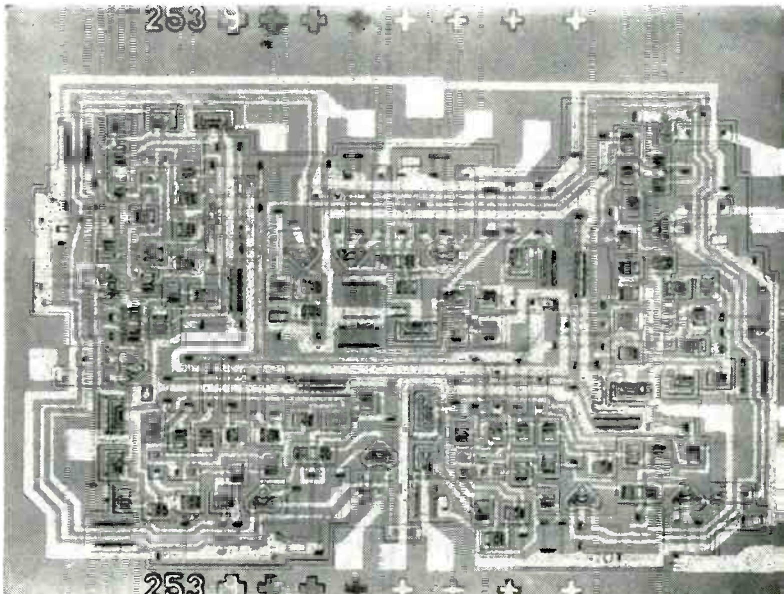
Rainbow Liquid Laser. (Right) Scientists have developed a simple liquid laser which can produce a rainbow of different colors. So far green, yellow, orange, and red laser light have been produced, and in principle it should be possible to produce all wavelengths in the visible and infrared spectrum. The color of the beam is changed simply by refilling the liquid laser with different solutions of organic dyes. In the multiple-exposure photo, the laser has been filled with three organic dyes producing green, yellow, and red laser light. The beams were separated by rotating a prism in the path of the laser beam. A special wide-spectrum flash lamp is the pumping source in the experimental laser which was developed by IBM.

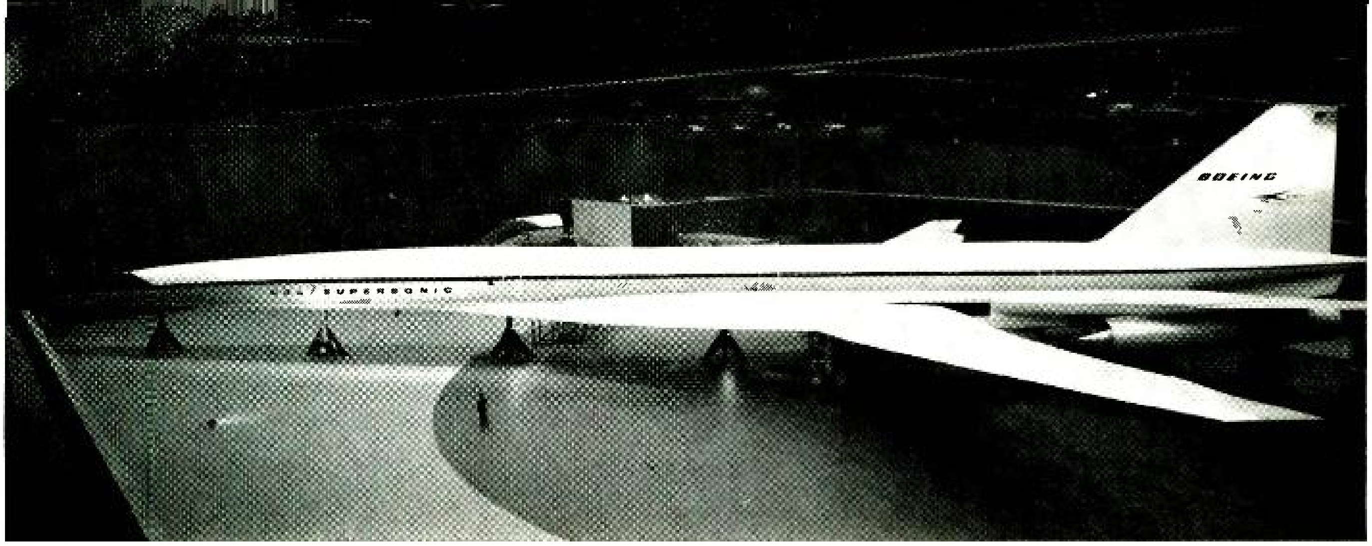


Two-Passenger Electric Car. (Center) Westinghouse has announced that it is manufacturing a two-passenger electric vehicle called the "Markette". Powered by 12 six-volt lead-acid batteries, the small car has a top speed of 25 mi/h and a range of 50 miles between chargings. The company is producing only a few hundred of the vehicles which are expected to be purchased mainly by community developers, electric utilities, and government agencies for experimental purposes. Batteries should last for at least two years before they need replacement at a cost of about $300. The "Markette" weighs 1730 lbs including batteries. It is driven by two 4½-horsepower d.c. motors. A retractable power cord is plugged into a 117-volt outlet for recharging. Price is expected to be under $2000.

Large-Scale Integrated-Circuit Array. (Below right) A universal 4-bit shift register containing the equivalent of 175 components on a single 60 by 85 mil chip is shown here. This IC, produced by Sylvania, is the most complex single chip produced by this company. The new register is a true universal logic element and not just a storage element and is designed to simplify digital system design. Incorporated in a computer, each of the new units replaces eight devices formerly needed.

Low-Cost Weather Photos From Space. (Below left) A new low-cost ($3500 to $5000 depending on accessories) weather satellite picture taker is now available. The system is within the reach of colleges and schools, small weather stations in remote areas, countries with an interest in space research, ships at sea, and commercial organizations interested in obtaining up to 15 high-resolution cloud-cover photos per day from our ESSA and Nimbus meteorological satellites. The satellites, in polar orbit, are within range of a given location on earth for three passes a day. Photos are displayed on a high-resolution CRT which is then photographed on Polaroid film. The system is available from Electro-Mechanical Research, Inc.





Electronic Challenges in the SST Program

By JOSEPH H. WUJEK, Jr.

Flying faster than twice the speed of sound, and requiring close control of flight conditions for passenger safety and comfort, the SST will use vastly more complex and reliable electronics system than presently used.

THE decision by the United States to proceed with the development of the supersonic transport (SST) holds the promise of a significant advance in transportation. In competition for the basic airframe, the *Boeing Company* design proposal was chosen, while in the engine competition, *General Electric* was selected. Although the panel of government experts took several months to painstakingly review the detailed proposals, it is impossible at this time to anticipate all the technical problems which will arise and require solutions. In this article we shall examine some of the more obvious difficulties, focusing particular attention on those which may be solved by electronic systems. As we shall see, the problems will indeed provide a challenge to our electronics industry.

The SST

To place these problems in a frame of reference, it will be useful to gain some background in the SST—what it is and what it hopes to accomplish.

Each *Boeing* B-2707, as the SST is designated, will cost over $35 million. For comparison, two of the familiar DC-3 aircraft cost about $50,000 in 1950, while the jet engines for the SST are expected to cost $50,000 each. A typical DC-3 carries electronic systems which cost about $12,000, while each SST is expected to contain about $400,000 in electronics. It is estimated that the SST program will provide employment for more than 650,000 people over the next 18 years. These employment figures include all the support activity required to develop, build, test, and operate the aircraft, as well as those personnel involved in airport preparation, etc. Since it is anticipated that world airline traffic will increase fivefold between 1966 and 1980, a large segment of the traveling public is expected to benefit directly from this venture.

The airplane will have a useful life of approximately 50,000 hours, which at the projected rate of 3000 hours in the air each year means about 17 years of operational status. In 50,000 hours of SST operation, the aircraft will have traveled about 90 million miles, based upon the cruising speed of 30 miles per minute or 1800 miles per hour.

The B-2707 is a huge aircraft, as shown in Fig. 1. With a length of 306 feet, the SST is longer than the distance between the goal lines of a football field. The maximum height of 48 feet, measured at the vertical stabilizer, is roughly equivalent to that of a five-story building. Each engine and associated pod is nearly as long as a DC-3 transport. The aircraft in fully loaded configuration will weigh 675,000 pounds, of which 367,100 pounds will be fuel. The fuel capacity of the SST is thus approximately equivalent to that of three railroad tank cars.

The aircraft is to be powered by four *General Electric* GE4 engines, each developing about 60,000 pounds of thrust. This power is a significant increase over the 20,000-pound thrust engines in use on commercial transports today.

With a cruising speed of *Mach* 2.7 (2.7 times the speed of sound at the altitude specified) or 1800 mi/h at 60,000 feet, the B-2707 will have a range of over 3700 miles under full load (farther under less load). Depending upon the seating configuration (first class, tourist, or mixed), the airplane can carry up to 350 passengers.

Table 1. Comparison of flying times for modern jets vs SST.

Route	Modern Jet	SST
New York—London	6 hrs., 9 min.	2 hrs., 30 min.
New York—Los Angeles	4 hrs., 40 min.	1 hr., 50 min.
San Francisco—Tokyo	11 hrs., 35 min.	4 hrs., 45 min.

The ability to vary wing sweep will allow the aircraft to take off and land with the wings swept forward, giving the airplane characteristics not unlike those of today's jet transports. For high-speed cruising, the wings will be swept back to the familiar delta configuration, which means less drag at supersonic speeds.

To appreciate more fully what the SST will mean in terms of travel convenience, refer to Fig. 2. which is a typical flight profile for the aircraft. Altitude is shown as a function of nautical miles (NMI). The distance of 3800 NMI is roughly equivalent to a trip from New York to London, or from Chicago to Honolulu. The *M* numbers refer to speed in *Mach* numbers; hence the cruising speed is *Mach* 2.7, as shown in the figure. The time for the entire trip will total about 2½ hours. Table 1 compares flying times of today's jets with those of the SST for three important cross-country and transoceanic routes.

Now that we have gained some insight into what the SST is all about, let's examine in detail some of the problems facing our electronics technology.

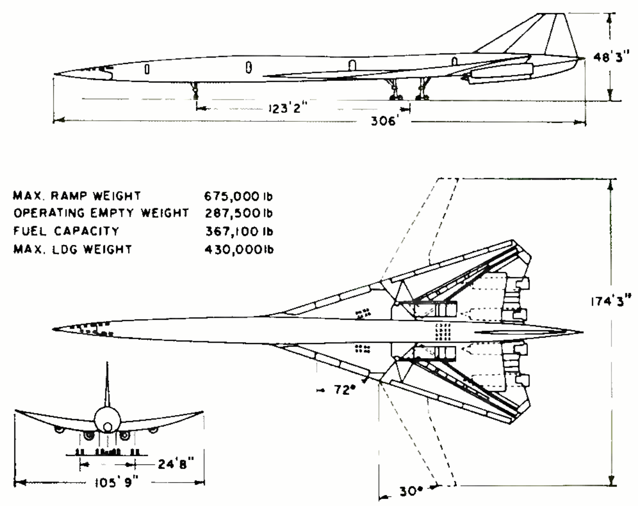


Fig. 1. Longer and wider than a football field, as tall as a five-story building, and weighing nearly 338 tons, the SST (Boeing B-2707) will carry up to 350 passengers.

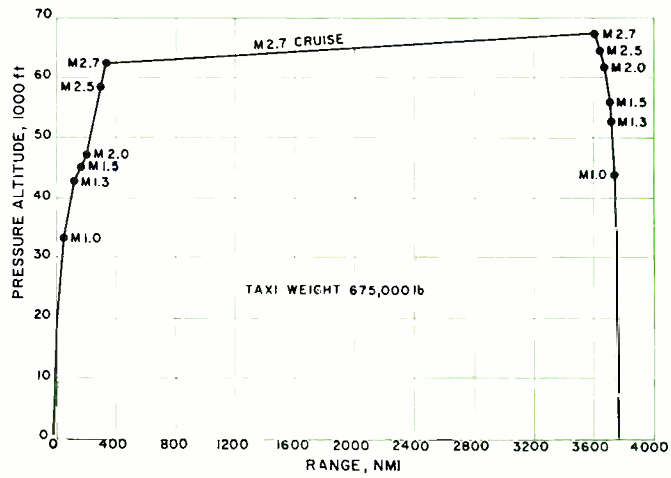


Fig. 2. SST flight profile shows it cruising at Mach 2.7.

Electronic Challenges

We might begin our discussion with a very common but nonetheless important element of nearly every electronic system—wire. Thousands of feet of wire will distribute power and transmit signals to virtually every portion of the aircraft. Since the temperature of the aircraft's skin will rise to over 450° F, wiring exterior to the passenger cabin and baggage-hold may be exposed to high temperatures. Moreover, such wiring will undergo many hot/cold cycles and must not become brittle and break under these stresses. If it were not for the weight penalty, ordinary industrial boiler-room wire might fill the need. But a sophisticated aircraft can hardly be weighed down by bulky wiring. One solution may be found in the use of the new lightweight polymer plastics used for insulation. These plastics can withstand high temperatures and are extremely flame-retardant. Recently developed for aerospace use is a coaxial cable weighing one ounce per foot and capable of withstanding temperatures 1100° F. Related to this hot/cold cycle problem is the task of providing motors and servos which can also survive this environment.

A more difficult research and development problem is that of automatic control, or the automatic pilot, for the SST. True, autopilots for both military and commercial aircraft have been in existence for many years, and nearly all commercial transports are so equipped. But the SST poses new problems for the autopilot designer.

"Dead time," or the time between the sensing of a needed correction and the full implementation of the correction, must be reduced. At supersonic speeds, the shortcomings of an autopilot system are magnified. Just as the driver of a racing car must be more alert to the task of control at 150 mi/h than at 30 mi/h, so too the autopilot must be more "alert" as operational speeds increase. A system which is adequate for a military aircraft where crew personnel may be required to undergo a rough ride is not acceptable for commercial operation. A slowly reacting autopilot might impart a wave-like vertical motion (pitch) to the aircraft at *Mach* 2 plus, with a resultant altitude variation of one hundred feet or more. Few passengers would be willing to take a roller-coaster ride such as this, no matter how fast they could span the nation.

Several electronic systems in use and/or undergoing development find application in the SST as well as in contemporary aircraft. Distance measuring equipment (DME) is already standard on most airlines. DME provides the pilot with precise information as to the distance and rate of closure to the DME station. This system takes on added importance in the SST, since flight-plan decisions must be made with a minimum of delay. With the ever-growing density of air traffic, new demands will be placed upon DME. Each station must be capable of handling more traffic in its region than is presently possible.

With the increase in air traffic, the danger of aircraft collision becomes ever more acute, particularly in the air space near major terminals. A collision avoidance system (CAS) is thus required to insure the safe passage of air traffic under all conditions of visibility and turbulence. Ideally, a CAS measures position and rate of closure between aircraft occupying a given region and warns the pilot of the collision course. A more advanced system might also transmit collision-avoidance courses to the aircraft heading for trouble and perhaps even automatically correct to a safe heading. Several mid-air crashes and near-crashes over the past few years furnish a grim reminder of the need for a dependable CAS.

Another cause, or at least a suspected cause, of aircraft mishaps is clear air turbulence (CAT). The nature of CAT is not well understood, except to note that this weather phenomenon can quickly alter the altitude of an aircraft, placing heavy demands on the autopilot and/or the pilot's ability to control the aircraft. Severe buffeting may result, which may in turn trigger structural failure of the airframe or cause the airplane to go out of control. Electronics may provide the key to understanding and avoiding this hazard. Radar and lasers have been suggested as possible tools in this area of research.

Still another problem which stems from the continued increase in air traffic is that of all-weather flying. The grounding of planes due to weather (*Continued on page 74*)

ONE-TUBE LOW-FREQUENCY CONVERTER

By K. H. SUEKER, W3TLQ
Westinghouse Electric Corp.

Construction of a single-tube converter operating from 15 to 2000 kHz for use with receiver tuned to 10 meters.

ANYONE who has listened to a short-wave receiver is well aware of the vagaries of high-frequency radio transmissions. While average propagation conditions can be predicted with reasonable certainty, high-frequency circuits are still plagued by erratic signals and sudden black-outs. Only with the advent of synchronous satellites has dependable high-frequency transmission over long hauls become a reality. The terminal equipment required, however, is rather cumbersome.

The glamour of the satellites and the space age has tended to overshadow the less known but vitally important v.l.f. services which have offered dependable, world-wide communications for over forty years. Operating on frequencies from 15 kHz to 30 kHz, super-power transmitters handle a steady flow of press, naval traffic, and special services. Since propagation is entirely by ground wave at these frequencies, there is no sky-wave interference and no dependence on ionospheric conditions. The v.l.f. waves hug the earth's surface and can cover the entire globe.

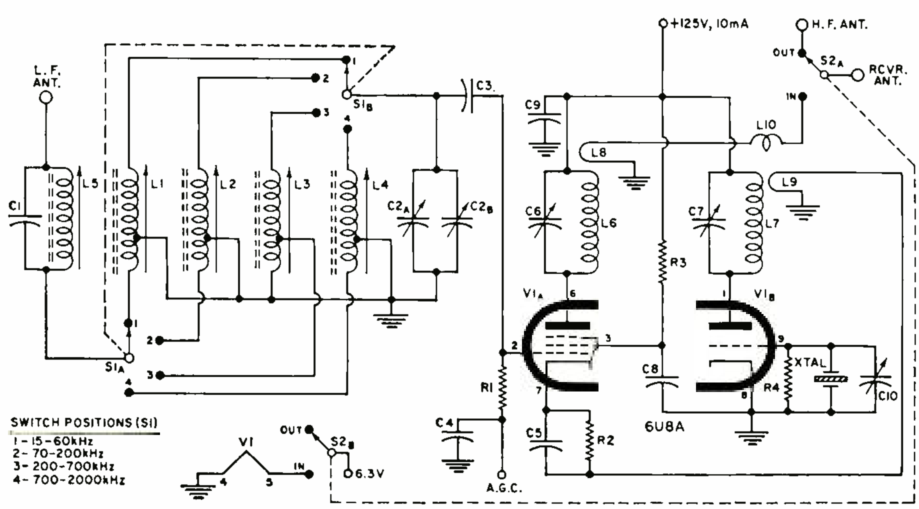
The author's interest in v.l.f. was stimulated by articles describing the 2000-kW installation of NAA at Cutler, Maine. Workbench experiments using a Wien-bridge audio oscillator as a regenerative detector proved successful at receiving NAA so the decision was made to build a good receiver for v.l.f. Since a faithful general-coverage communications receiver had just been retired, a second objective was to provide broadcast and 160-meter amateur band coverage as well as v.l.f. This meant that the receiver had to tune from 15 kHz to 2000 kHz—a 133:1 frequency ratio.

Circuit Design

Such an extreme range posed some interesting design problems. A simple regenerative receiver could handle the v.l.f. but could not provide the selectivity needed for broadcast reception with strong local stations. Adding tuned r.f. stages would improve selectivity but would impose difficult ganging problems to say nothing of requiring a lot of large inductors. A fixed i.f. superheterodyne offered much the same sort of problems.

The solution, surprising in its simplicity, was to use a single-tuned input circuit feeding a converter stage with fixed oscillator and tunable i.f. This arrangement allowed

Fig. 1. Schematic and parts list for the one-tube converter. The triode section of the 6U8A serves as a crystal oscillator whose output is applied to cathode circuit of mixer section.



R1—470,000 ohm, ½ W res.
R2—1000 ohm, ½ W res.
R3—3300 ohm, ½ W res.
R4—100,000 ohm, ½ W res.
C1—See text
C2—Dual variable capacitor, 467 pF/sec
C3—0.005 μF ceramic capacitor
C4, C5, C8—0.05 μF ceramic capacitor
C6, C7, C10—3-30 pF trimmer
C9—0.1 μF paper capacitor
L1—65-300 mH adj. tapped coil (J.W. Miller 9018)
L2—520 mH adj. tapped coil (J.W. Miller 9015)
L3—0.5-3.5 mH adj. tapped coil (J.W. Miller 9013)
L4—0.15-1.0 mH adj. tapped coil (J.W. Miller 9012)
L5—Ferrite-core antenna (see text)
L6, L7—12 t #22, ⅜" dia. x ⅝" long
L8—1 t. on cold end of L6
L9—1 t. on cold end of L7
L10—1 t. on L7 (see text)
S1—D.p.6-pos. non-shorting sw. (Mallory 2226J)
S2—D.p.2-pos. non-shorting sw. (Mallory 3222J)
Xtal—28-MHz overtone crystal
V1—6U8A

the use of a high-stability communications receiver as the tunable i.f. so that a constant tuning rate, selectivity, and stability could be maintained over the entire 133:1 frequency range.

The schematic for the converter, as it finally evolved, is shown in Fig. 1. The incoming signal is passed by a tuned input circuit which covers 15 kHz to 2000 kHz in four switch-selected, capacitor-tuned ranges. The tuned input circuit provides image rejection and minimizes cross-modulation by local broadcast stations.

The triode section of the 6U8A is a tuned oscillator which provides 28-MHz output from a third-overtone crystal. Output from the oscillator is coupled to the cathode of the pentode section and mixed with the 15-2000 kHz input signal. The resultant mixer output of 28.015 MHz to 30.000 MHz is fed into the input of the communications receiver which supplies the tunable i.f., detection, b.f.o., and audio functions.

A few comments on the circuit are in order. *C1*-*L5* comprise a rejection trap which can be used to minimize interference from any one especially strong local broadcast station. *C1* is chosen in the range 10-400 pF to allow resonance within the adjustment range of *L5*. *L1* to *L4* are standard adjustable tapped coils selected for high "*Q*" and reasonable cost. Because of multiple resonances in the coils, several of them will tune two different frequencies at the same setting of the tuning capacitors. This feature is used to cover the range with just four coils. Approximate coverage of each coil is 15-60 kHz for *L1*, 70-200 kHz for *L2*, 200-700 kHz for *L3*, and 700-2000 kHz for *L4*.

Capacitor *C10* allows the crystal to be "pulled" to 28.00 MHz for calibration purposes. *L10* provides some out-of-phase signal to reduce the 28-MHz feedthrough to the receiver. A vacuum tube was used in preference to transistors so that a.g.c. could be used from the communications receiver. If a.g.c. is not used, the converter a.g.c. lead should be connected to a variable negative-voltage source to prevent overloading on strong signals. A one-megohm potentiometer across a 9-volt battery will serve the purpose.

The converter is designed for a high-impedance antenna. Any practical antenna at the low frequencies is a small fraction of a quarter-wave since a wavelength at 20 kHz is 9.3 miles! Capacitance to ground in the lead-in must be kept to a reasonable minimum. Coax cable can *not* be used. The antenna must be brought directly to the converter. As for antenna length—the longer the better in this case.

Construction and Adjustments

The entire unit is built in a 3" × 8" × 6" cowl-type chassis box. No special precautions need be observed in wiring except to keep the high-frequency leads reasonably short. Coils *L6* and *L7* are wound on short lengths of ⅜" diameter polystyrene tubing and supported on their leads. The high-frequency antenna and receiver antenna lead should be brought in through coax to minimize 10-meter amateur pickup. The low-frequency antenna can be brought in on any convenient type of binding post. The front panel of the unit may be marked with suitable decals or pressure-sensitive labels.

Initial adjustments of the converter are quite simple. *C7* is first set so that the 28-MHz output is slightly below maximum and the crystal oscillates every time when power is turned on. *C6* is peaked for maximum converter output on v.l.f. signals. The polarity and coupling of *L10* to *L7* is adjusted for minimum converter output on 28 MHz. Coils *L1* to *L4* are peaked on noise (with the antenna connected) at the low-frequency ends of their respective ranges with *C2* at maximum capacitance.

Note that tap connections to *L3* are different from the remaining coils. In each coil, however, the end with the greater number of turns (top of winding in diagram) is connected to *S1B*. In use, the communications receiver is tuned to the desired frequency (dial indication minus 28 MHz) and the converter tuning is peaked for the maximum signal.

Stations Received

The spectrum below 2000 kHz is alive with signals and the converter has enough sensitivity (when used with a good communications receiver) to perform surprisingly well with a short antenna. Station GBR in Rugby, England has been received at the author's Pittsburgh location using only a 30-foot vertical antenna. Incidentally, inquiry to the General Post Office in London revealed that GBR has recently been rebuilt and now operates with a transmitter power output of 500 kW. The 16-kHz frequency is accurate to 5 parts in 10^{10}. This historic station went on the air on January 1, 1926 and had, at the time, the highest power vacuum-tube amplifier in the world.

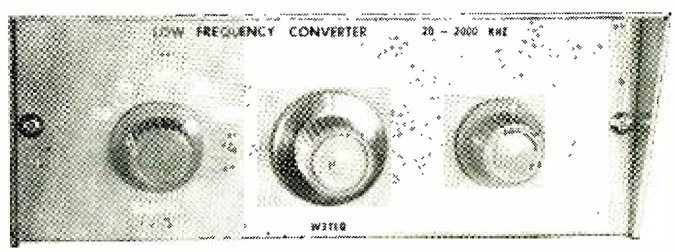
Other v.l.f. stations include NAA, NPG, and NSS, all of which handle Navy traffic. WWVL on 20 kHz and WWVB on 60 kHz provide standard frequency broadcasts from the Bureau of Standards' new transmitter site in Ft. Collins, Colorado.

The range 200-400 kHz is used for low-frequency aircraft direction-finding services. The low-power transmitters can be heard within a radius of 100 miles daytime and 1000 or more miles at night. Detailed aviation weather forecasts are broadcast in voice from the larger cities. Frequencies around 500 kHz are used for marine traffic and 500 kHz itself is reserved as a calling and distress frequency.

The advantages of tuning the broadcast band with a good communications receiver are quite striking. With this converter, the author has received Radio Belize, British Honduras on 834 kHz with 50-kW domestic stations on 830 and 840 kHz. Numerous Mexican, Canadian, and Cuban stations can also be heard.

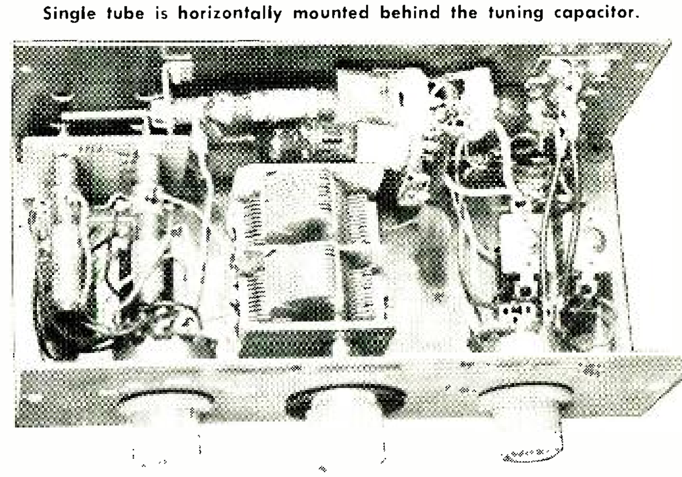
In the region above the broadcast band, marine navigation beacons, loran, and the 160-meter amateur band are available. Amateurs who want to add 160-meter coverage to restricted-range communications receivers can build this converter and get the other services as a bonus.

For amateur operators fed up with QRM, SWL's fed up with Radio Moscow, or those who are simply in search of something new, this converter can provide a lot of listening. There is always something doing from 150 meters down! ▲

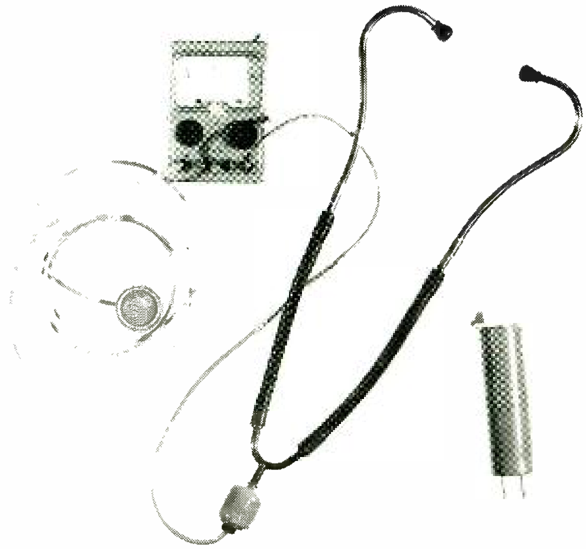


Entire unit is built into a 3" x 8" x 6" cowl-type chassis box.

Single tube is horizontally mounted behind the tuning capacitor.



ELECTRONIC STETHOSCOPE *and* CARDIAC RATE METER



By A. L. DUNN, R. N. WILGER, and R. A. MYERS
Veterans Administration Hospital, Omaha, Nebraska

Using this electronic stethoscope, the physician can hear the heartbeats and also observe the cardiac rate on a meter.

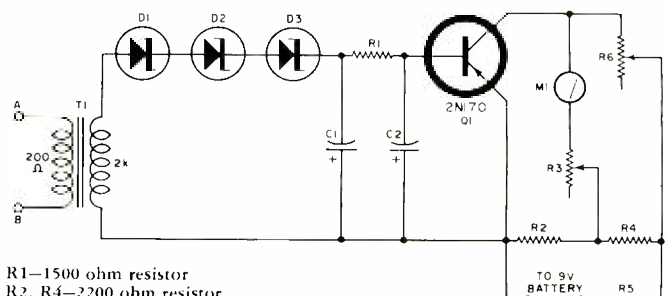
Fig. 1. Electronic stethoscope (left); calibrator on right.

THIS article describes the construction of a transistorized, battery-operated unit about the size of a pocket transistor radio which incorporates all the features of earlier stethoscopes with the addition of a direct-reading heart-rate meter.

The photograph (Fig. 1) shows the general aspects of the instrument with the calibrator at the far right. The circuit of the instrument, which is based on a five-transistor amplifier (available from *Lafayette Electronics* under catalogue number 99-R-9037), is shown in Fig. 3. The combination of *R1* and *C1* serves as a tone control to vary the frequency accepted by the amplifier. The gain control (*R16*) is located at the output of the amplifier. In this condition, the amplifier is running "wide open." Points "A" and "B" connect to "A" and "B" on the rate meter (Fig. 2) directly, while points "A" and "C" connect to the headphone system. The original gain control as shown in the diagram supplied with the commercial amplifier was taken out, and a 10-μF capacitor is used to couple transistor *Q1* to *Q2*.

The microphone which serves as the pickup device was constructed from an Air Force type HS-30 headphone. The case was ground down to the point where the diaphragm was separated from the pole pieces by no more than the thickness of a piece of tissue paper. This greatly increased the sensitivity. The low impedance of the microphone was a passable match for the input to the amplifier.

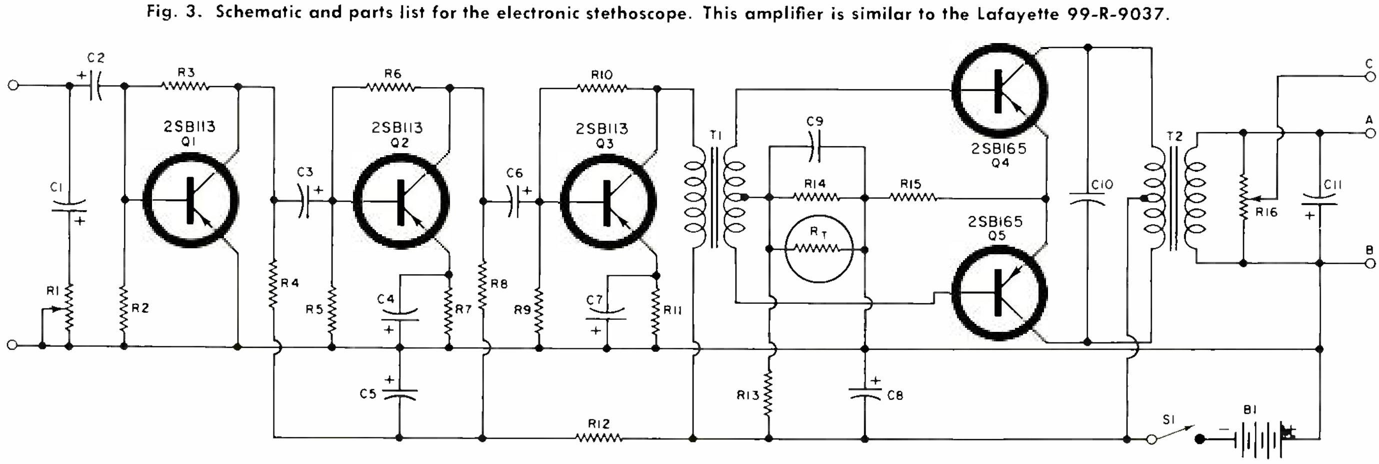
(*Continued on page 87*)



R1—1500 ohm resistor
R2, R4—2200 ohm resistor
R3—2000 ohm potentiometer
R5—4700 ohm resistor
R6—20,000 ohm pot.
(All resistors ½ watt.)
C1, C2—450 μF, 6 V cap.
D1, D2, D3—10 V zener diode
Q1—2N170 transistor
T1—transistor interstage trans. (Argonne AR-153 or equiv.)
M1—500 μA meter

Fig. 2. The rate meter is transformer-coupled to the stethoscope and accepts pulses which are read out on the meter.

Fig. 3. Schematic and parts list for the electronic stethoscope. This amplifier is similar to the Lafayette 99-R-9037.



R1—500 ohm potentiometer
R2, R5—100,000 ohm resistor
R3—220,000 ohm resistor
R4, R8—10,000 ohm resistor
R6—560,000 ohm resistor
R7—1000 ohm resistor
R9—27,000 ohm resistor
R10—270,000 ohm res.
R11, R14—330 ohm res.
R12—3300 ohm resistor
R13—6800 ohm resistor
R15—10 ohm resistor
R16—200 ohm pot.
(All resistors ½ watt.)
C1, C11—5 μF, 10 V capacitor
C2 through C7—10 μF, 10 V cap.
C8—50 μF, 10 V capacitor
C9—5 μF, 10 V capacitor
C10—0.05 μF, 25 V capacitor
T1—transistor input trans.
T2—transistor output trans.
Q1, Q2, Q3—2SB113 or equiv.
Q4, Q5—2SB165 or equiv.
RT—Lafayette 32S thermistor

Solid-State Circuit Breaker Operates Within Microseconds

By STANLEY W. THOMAS/Lawrence Radiation Laboratory, Univ. of Calif.*

This electronic circuit breaker operates within microseconds of initial appearance of a possible damaging short circuit.

FUSES may be too slow for adequate short-circuit or overload protection for expensive hi-fi power output stages and power supplies in the event of accidental shorting of the speaker leads. The solid-state circuit breaker to be described is a 2.4-ampere device that opens in 2.5 microseconds under a 4.8-ampere load (100% overload). A simple change in a resistive shunt permits any desired trip from 10 mA to more than 10 amperes. The addition of a capacitor will provide a "slow-blow" characteristic.

The basic circuit is shown in Fig. 1. *R*1, the sensing shunt, is made from #20 Manganin or Nichrome wire and must be formed in a non-inductive manner to prevent current surges from accidentally firing the circuit. A parallel combination of carbon resistors may be used in place of the wire. Although the circuit was designed for 28-volt operation, it can be modified for any supply voltage.

Operation is as follows. Resistor *R*3 is selected to provide current to saturate *Q*2 for a collector current equal to the trip current. When an overload occurs on the output side, the voltage drop across *R*1 cuts off diode *D*1 and allows the current through *R*2 to flow into the gate of *Q*1. This fires the SCR which now shunts the base drive current for *Q*2, turning *Q*2 off. This removes the voltage from the output. Simultaneously, the "Overload" lamp glows. The SCR (*Q*1) is held in conductance by the current through *R*3 and the lamp current. Removing the supply voltage (operating the "Reset" switch) extinguishes *Q*1 and resets the circuit.

If the lamp indicator is not needed, it may be removed and *D*2 and *D*3 replaced by a conductor.

Diode *D*1 protects the gate of *Q*1 from high surge current, temperature-compensates the circuit, and permits the use of a capacitor (*C*1) to form a firing delay. Fig. 2 shows the effect of *C*1 on trip time when the load current exceeds the trip current by 10%. Diode *D*2 compensates for the *D*3 voltage drop and permits the use of the indicator lamp. Diodes *D*4 and *D*5 permit positive shutoff of *Q*2 by providing a barrier voltage greater than the "on" voltage of *Q*1. Fig. 3 illustrates the effect on trip time of excessive currents.

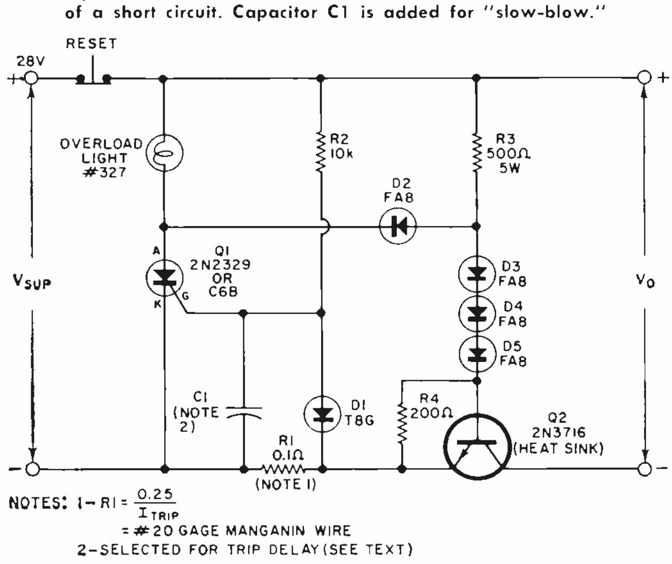
A 2N3055 can be substituted for the 2N3716 (*Q*2). This will slightly increase the trip time. For trip currents of three amperes or less, a 2N3054 may be used. A 2N3053 can be used if the trip current is less than 0.5 ampere. In all cases, *Q*2 should be heat-sinked.

Any silicon diode, such as the 1N4001, can be used for *D*3, *D*4, and *D*5. Any not-too-leaky small germanium diode (1N270, for example) can be used for *D*1. Diode *D*2 should be silicon and have a reverse voltage rating greater than the supply voltage. A 1N4001 can be used to 50 volts, while a 1N4002 can be used to 100 volts.

SCR *Q*1 may be any low-current device (about 0.5 to 2 amperes) having a breakdown voltage greater than the supply voltage. The 2N2329 costs about $21, while the C6B (*G-E*) costs about $2 and has a 200-volt rating. For 100-volt circuits, a C6A ($1.87) may be used. ▲

*Work performed under auspices of U.S. Atomic Energy Comm.

Fig. 1. The solid-state "fuse" operates within microseconds of a short circuit. Capacitor C1 is added for "slow-blow."



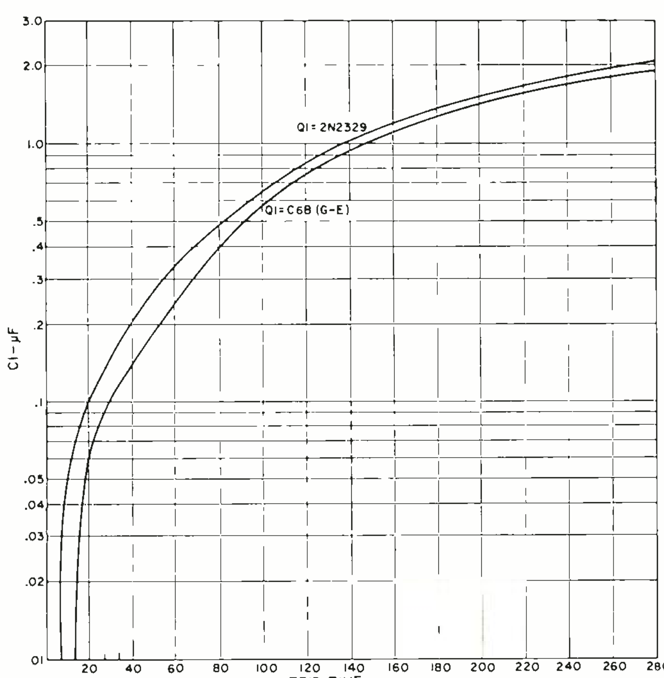
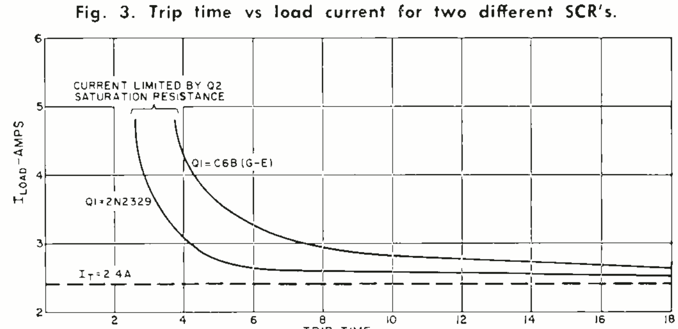


Fig. 2. The effect of C1 on trip time when the load current exceeds trip current by 10%. This is extra feature.

Fig. 3. Trip time vs load current for two different SCR's.



INDEPENDENCE HALL RECONSTRUCTION SOUND SYSTEM

By J. PETER NELSON / Ampex Corporation

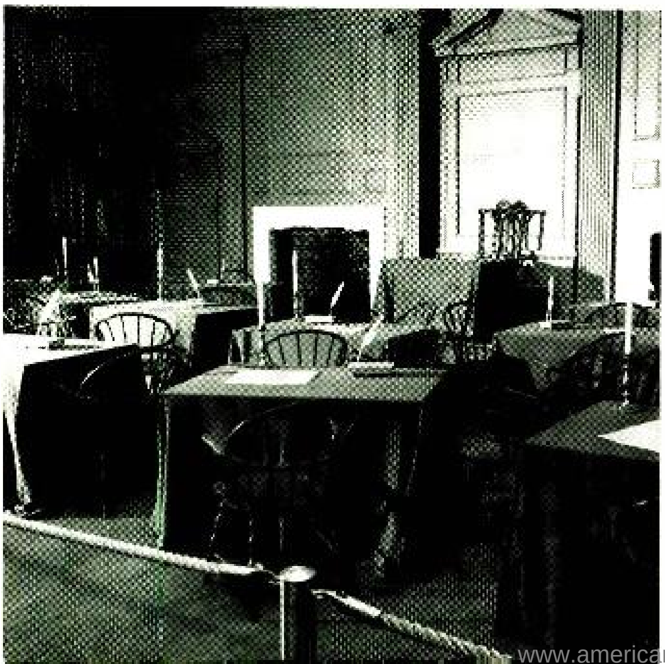
Description of 14-channel tape system that carries dialogue, sound effects, and switching signals to recreate a historical setting.

A BRICK-BY-BRICK reconstruction of the original Independence Hall in Philadelphia was dedicated on July 4 last year and opened to the public. Located at Knott's Berry Farm, some 40 miles southeast of Los Angeles, this building houses a unique electronic exhibit that dramatizes the important events surrounding the signing of the Declaration of Independence.

The exhibit, set in a reconstruction of the assembly hall where the historic document was signed, relies primarily on the power of sound to recreate the historic aura of the spirited discussions and conversations that attended the original event. Tables, chairs, candles (electric), ink stands, and other memorabilia of the period serve as visual focal points for the program and set the mood for the audio presentation.

Spectators in tour groups sit along one side of the 40-foot-square room, roped off from the exhibit area. A pretty girl in colonial dress, the tour guide, turns a key in a door casing, and the show begins.

The house lights dim and the electric candles on the delegates' tables flicker to life. The audience is transported in imagination to the 1770's as the 56 delegates to the Second Continental Congress are heard entering the room and walking through the audience and on to their tables. Chairs scrape, men talk and laugh, and papers rustle. John Hancock, President of the Continental Congress, raps his gavel for order and recognizes Richard Henry Lee as the first speaker.



Reconstruction of 40' by 40' room where Declaration of Independence was signed. The chair in the right background beneath the ornamental arch is a replica of the "rising sun" chair used by John Hancock, president of the Continental Congress. Speakers are installed under tables, in wall panels, window casements, and fireplaces for effective stereo illusion.

During the presentation, a battle rages outside the building, a marching band tramps past playing "The White Cockade," the town crier proclaims the surrender of Yorktown, and the Liberty Bell tolls. As John Adams delivers an impassioned speech, the audience hears him stand and walk in ghostly fashion from one side of the room to the other.

This histrionic wizardry is accomplished with an elaborate audio system called "Stereo-Rama Fourteen" by its creator, Philip Stuart, Hollywood producer of documentary films and exhibits. Stuart has placed 56 (coincidentally, the number of delegates) *James B. Lansing* speaker systems throughout the exhibit room to give depth and presence to his special effects. They are located under delegates' tables, in walls, and in window casings and fireplaces.

The Tape System

The heart of the system is a pair of *Ampex* AG-300 solid-state professional audio recorders modified to handle one-inch-wide, 1.5-mil magnetic tape and to provide 14 channels of signals. The machines run at either 7½ or 15 inches per second. Ten of the channels carry dialogue, three are used for special sound effects, and the final track controls the room lights, candles, and audio special effects switching from speaker to speaker.

The program was recorded in the room where it is presented. Stuart gathered more than twenty famous voices from radio, motion pictures, and the Broadway stage to portray the voices of history. These well-known voices add a dimension of familiarity to the stereo program.

All of the actors gathered in the assembly hall for ten live recording sessions over a period of six weeks. Acoustical flats on their tables cut down on bothersome crossfeed. Footsteps, rustles, and chair-scrapings were recorded as they took place. The final effect is a blend of these sessions, with the special effects, outside noises, and control track added later.

The tape equipment is rack-mounted in the spacious projection room of the building's second-floor movie theatre. In the original building, the space was rarely used until toward the beginning of the 20th century, when a museum was installed complete with stuffed birds.

To provide duplicating and standby capacity, one unit is a record/reproduce machine and the other is a reproduce only. The recorders are used on alternate days, leaving the extra unit for standby. This combination allows operators to make their own play copies of tapes from masters and enables them to change and upgrade the program at any time.

Each 14-track tape machine uses seven two-track professional audio-recorder electronic units, modified to include a muting relay to short line outputs in every mode but "Play." These units have been transferred to deeper chassis for more effective cooling (the units run for 11 hours a day).

The equipment is set up for virtually automatic operation of the entertainment cycle so that a tour leader need do no more than insert a key in a tamper-proof lock in a door casement to start the show.

To accomplish this, engineers installed photocell assemblies and memory systems in the control boxes of the tape recorders. Lights and photocells are mounted in the tape path. As the tape runs between the cells, they sense transparent leaders spliced at the beginning and end of the program.

At the end of the program, the machine goes into rewind (approximately one minute is required to rewind the entire program). When the beginning of the program is sensed, a forward relay cues the show up automatically.

Building the Recorders

Building 14-track recorders posed special problems. The recorders were modified to take the wider tape by installing takeup and wind motors with double the normal torque. Locking-type holddowns were permanently attached to the assemblies. Wider capstan and reel idlers were added and longer shafts were made for the capstan assemblies. Heavier solenoids were used for the capstan idlers and heavy-duty silicon rectifiers were installed in the transport power supply.

Staggered, optically aligned, fixed azimuth audio heads with low impedance, 200-micro-inch gaps were designed to give adequate signal-to-noise ratios from the narrow tracks and retain good tracking and frequency response. This design also gives minimum crosstalk between channels and good separation.

Two patch panels (one for each recorder)) were installed and interconnected so that the output, which normally comes from the reproducer, may be jumpered to lead from the recorder, and the recorder input, which normally is connected to an external source, may be jumpered to lead to the reproducer.

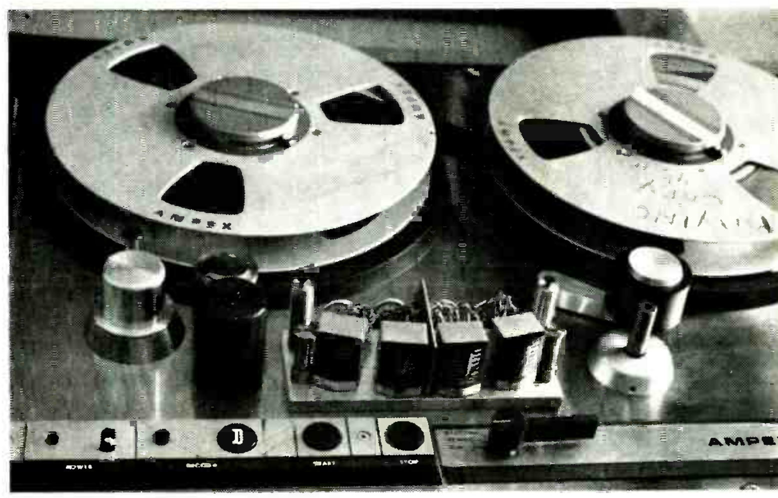
The automatic control circuit for the visual effects and audio special effects employs frequency-sensitive circuits with solid-state SCR switching to control the house lights and candles and to switch the three audio special-effects channels to any or all of ten surrounding speakers.

Eight *JBL* S-4000 solid-state power amplifiers are built into one rack to handle the fourteen channels at 40 watts per channel. The fourth rack in the system carries a 14-channel monitor system.

In the assembly hall, 38 speakers are built into the window casings. Six unique speakers are mounted in the wall paneling, using balsa-wood panels as voice-cone resonators. Two standard studio monitor speakers are mounted in the fireplace casements and ten modified systems are located under tables, concealed by tablecloths. These systems use theater drivers for middle and upper ranges and woofers to give the desired bass quality.

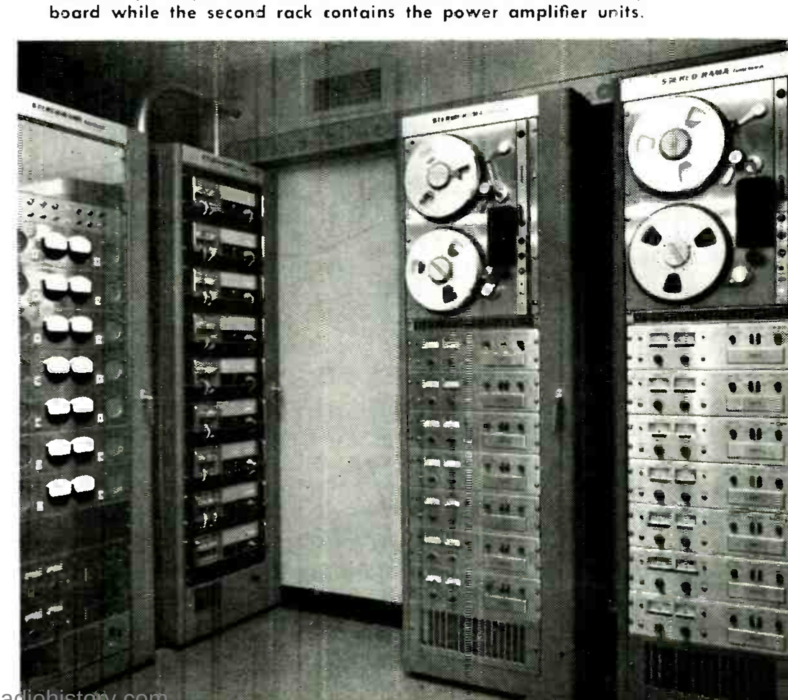
Stuart plans to add additional special effects to the program, such as candles that flicker when the man at that table speaks and electric fire in the fireplaces. These effects will also be acuated by the tape-control tracks. ▲

One of modified speaker systems located under ten tables in the Assembly Hall. Theater drivers are used for the middle and upper frequency ranges along with woofer for desired bass.



Close-up view of the modified tape recorder with its 14-track head stacks, lengthened capstan and idlers, and locking holddowns.

The special sound system consists of two modified 14-track professional stereo audio tape recorders along with their rack mounted preamps. The rack at the extreme left is a monitoring board while the second rack contains the power amplifier units.



Editor's Note: Recently we have seen integrated circuits in TV sets, radios, phonographs, and hi-fi receivers. Almost every day more and more IC's are finding their way into consumer electronic equipment. As a matter of fact, we expect that many color-TV sets will go directly from tubes to integrated circuits, bypassing the transistorized stage altogether. To the purchaser of such equipment, this will mean smaller, cooler, better, more reliable, and ultimately, less expensive products (or else products with a greater number of features). But what will this revolution mean to the service technician? In the first place, the days of the tube puller and v.o.m. prober are definitely numbered. The technician will have to learn and use a different approach to his servicing and he will have to employ different techniques. To help orient his thinking along these lines, and to inform the consumer as well, we are running this important 2-part article. Part 1 covers the new functional approach that must be taken, while Part 2 (next month) will go into the specific test-equipment techniques.

TROUBLESHOOTING INTEGRATED CIRCUITS

PART 1. THE FUNCTIONAL APPROACH

By WALTER H. BUCHSBAUM and WILLIAM D. HENN

New consumer products are being revolutionized by the use of IC's. The service technician will have to upgrade his knowledge and change his test methods in order to meet the challenge that the new circuits will present.

INTEGRATED circuits first appeared in black-and-white TV sets last year and have since found their way into color-TV receivers, radios, phonographs, and high-fidelity equipment. Within the next few years IC's will be used in all consumer electronic products where high power is not required. *RCA*, one of the leading manufacturers of IC's for consumer products, has set up a special engineering task force to develop a color-TV set using only IC's and a few power transistors. The idea is to eliminate the stage of designing a fully transistorized color set and concentrate on new circuits and special IC's for all low-power circuit functions. It may be possible, for example, to provide all color sync and demodulation functions with only three IC's

The integrated circuits used in consumer products generally fall into the category of *linear* or *analog* circuits, as opposed to the *digital* circuits used in computers. Analog circuits use many more semiconductors but because of the very small size of the integrated circuit itself, there is usually no difference in packaging. These IC's invariably work with conventional discrete components, such as resistors, capacitors, and inductors, which are connected to the IC by the printed-circuit board.

When troubleshooting equipment using vacuum tubes, the first step is usually to check that the filament of each tube is on. The second step is to substitute known good tubes for the suspected ones. These two steps eliminate the majority of defects without test equipment and without requiring much technical know-how. Where series filaments are involved, or when the defect is not due to a tube, basic voltage and resistance measurements can usually locate another large category of possible defects. Sophisticated test equipment, such as signal generators and scopes, is usually needed only for alignment, which is rarely done.

In troubleshooting transistorized equipment, however, this first step—checking filaments and substituting tubes—cannot be used and some form of test equipment is needed immediately to locate the defect. Voltage and resistance measurements help to isolate the defect to a particular circuit function but then individual components, including the transistors, must be tested. This is usually done with the power off and often requires quite a bit of unsoldering of leads. In many instances new transistors are temporarily connected into the circuit. For complete dynamic tests of a transistor a good transistor tester is needed and even this check is not always conclusive because the temperature effects in the equipment are not duplicated by the transistor tester. As a last resort, test equipment, such as signal generators and oscilloscopes, is required to trace the defect down to the responsible components.

When it comes to troubleshooting equipment using integrated circuits, voltage and resistance measurements are often inconclusive and difficult to perform. It is not practical to unsolder the 10 to 14 leads of the suspected IC and then solder another IC in place. The d.c. voltages alone often do not pinpoint the defect and ohmmeter measurements can damage the IC by applying wrong voltages across semiconductor terminals. The only remaining troubleshooting procedure is signal-tracing but this, too, is often limited. As will be shown later, many IC's contain more than the basic amplification function and this means that the output signal frequency may be different from that of the input. Even if signal tracing pinpoints the defect to a particular stage, it is not easy to determine whether the IC itself or one of the external components is defective. If the external component defect has caused the IC to be damaged, troubleshooting can be extremely difficult.

In order to troubleshoot IC's efficiently, the technician will need two basic aids. The first is good-quality test equipment capable of dynamic, in-circuit testing over a wide range of frequencies, modulations, and waveforms. The second is a detailed knowledge of the circuit functions and signals in each part of the equipment, and how they can be examined under dynamic conditions. The test equipment problem will be covered in depth in a subsequent article while the functional aspects of integrated circuits will be discussed here.

"In order to troubleshoot IC's the technician will need two basic aids. The first is good-quality test equipment capable of dynamic in-circuit testing. The second is detailed knowledge of circuit functions and signals."

How Can IC's Become Defective?

Solid-state devices, and integrated circuits in particular,

"The ideal approach would be one in which test signals are injected and measured by inductive or capacitive coupling probes."

are inherently more reliable than vacuum tubes. They do not contain a cathode which can wear out, they do not contain the relatively large mechanical structure of the electrodes, nor do they depend on the vacuum. Nevertheless, any integrated circuit can fail. Most of the reliability and life studies performed on IC's for military applications have concentrated on digital circuits, but the results are equally applicable to analog circuits.

IC defects are classified as those due to manufacturing faults, those due to electrical circuit abuse, those due to mechanical abuse, and those due to undetermined causes. Fortunately, this last group accounts for a very small percentage of failures. Manufacturing faults may only become apparent after a few months. For example, internal short circuits may develop due to very slow chemical reaction or because of inadequate passivation. Contamination is another manufacturing defect which may not show up for months.

Probably the most frequent cause is mechanical abuse in the equipment assembly process. When individual leads are stretched tight it may only take a few cycles of heating and cooling until the internal connection breaks and such breaks often result in a high-resistance connection rather than a clear open circuit. Mechanical vibration or shock can, over a period of time, loosen internal connections until the IC becomes defective. The electrical circuit abuse is usually the result of some external component failure which produces excessive voltages or insufficient bias which then damages the IC.

Technicians cannot spend the time and effort required to disassemble and microscopically examine the IC to find the damage. This would be fruitless, in any event, since the IC cannot be repaired. The technician's aim is to determine positively that the IC itself is defective and that this defect is not caused by failure of some other component.

The Pin-Connection Problem

The great advantage of IC's is their small size. At the same time, however, analog IC's provide a wide range of functions and therefore have quite a few external connections. The dimensional outline of Fig. 1 shows a typical low-power, wide-band amplifier with 12 separate pins. A small tab opposite the number-12 pin serves as key. The leads are usually spread out, sometimes by special standoff pads, which separate the IC from the printed-circuit board. Even the spread-out leads are still too close together to permit attachment of even the smallest alligator clip to one lead without touching its neighbor. It is almost impossible to unsolder a single lead without damage to the rest of the circuit. Even the use of a miniature soldering iron, with a tip diameter of 1/16" is not much help because it is difficult to pull an individual lead out through the printed-circuit board.

Fortunately, most of the IC leads are connected to the external components or to wires and these can be unsoldered, leaving the printed-circuit board connection as an isolated terminal of the IC itself. When several components are connected to the printed-circuit terminal, all of them have to be unsoldered in order to isolate one IC lead. For this reason tests which require connections to several IC terminals are very cumbersome and technicians should try to avoid them if possible.

To eliminate the messy unsoldering usually associated with getting at the IC pins, techniques are needed which depend on in-circuit tests and need only a minimum of test connections. Even these few connections should be made to the external component rather than the IC itself. The ideal approach would be one in which test signals are injected and measured by inductive or capacitive coupling probes. Such an approach will be described in further detail in Part 2.

Understand the Function

In troubleshooting tube and transistor equipment, the technician has become accustomed to analyzing the circuit in terms of each resistor, capacitor, and inductor so that he can trace the defects to individual components. If this same technique were used in troubleshooting IC's, considerable difficulty would be encountered. To illustrate, let us consider the *RCA* CA-3000 d.c. amplifier, the circuit of which is shown in Fig. 2. As seen here, the amplifier really consists of two amplifiers with two inputs and two outputs and control circuitry that permits a variety of connections. Q3 and diodes *D1*, *D2* and their associated circuitry permit a variety of controls for one or both of the amplifiers.

The manufacturer's data describes four modes of operation for this circuit with different terminals shorted, different conditions of the diodes, and different values of emitter resistance for the control transistor. Without going into the various modes in which this IC can be used, let us consider a very practical application, that of a 10-MHz amplifier, as illustrated in Fig. 3. This amplifier, typical of the i.f. stages in an FM receiver, uses a tuned-input and tuned-output circuit and provides a gain of approximately 29 dB.

To test the operation of this amplifier, it is only necessary to inject a signal, V_{IN}, and then measure the output, V_{OUT}. V_{IN} should be a 10-MHz sine wave of approximately 10 mV peak-to-peak amplitude and V_{OUT} should then be about 30 times that amplitude. This measurement requires a well-

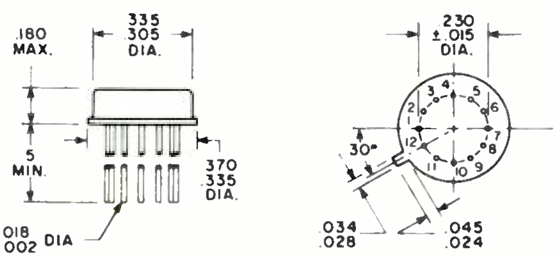
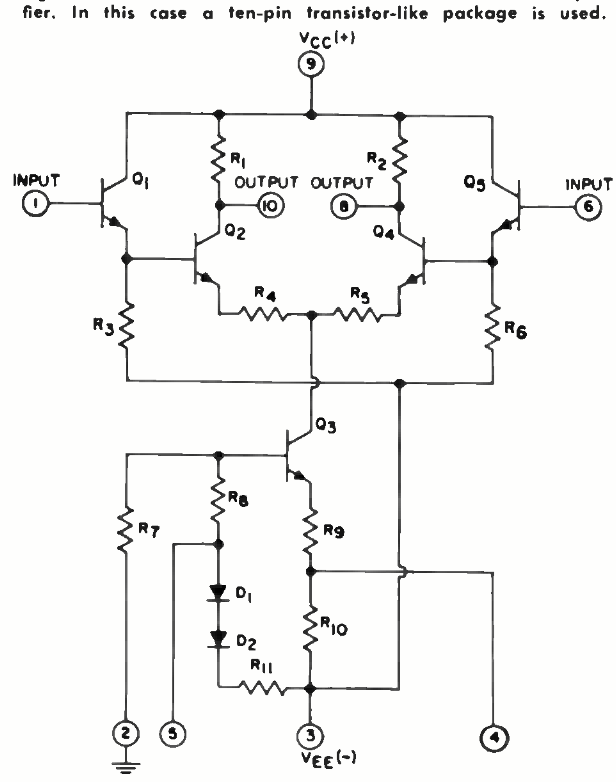


Fig. 1. Dimensions (in inches) of typical integrated circuit. Another commonly used package is the plastic flat-pack, a rectangular case with a number of leads coming out of the sides.

Fig. 2. Schematic and terminal connections for IC d.c. amplifier. In this case a ten-pin transistor-like package is used.



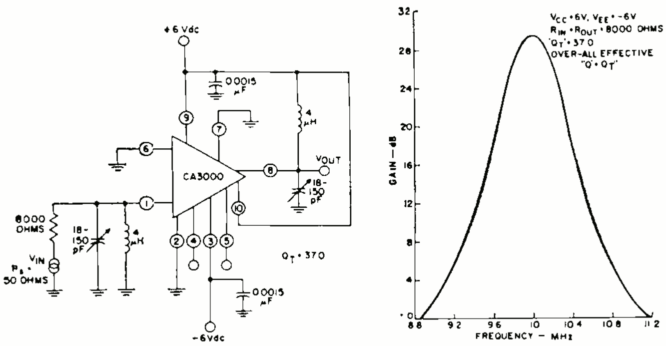


Fig. 3. Schematic and response curve of 10-MHz tuned-input, tuned-output, narrow-band amplifier using IC shown in Fig. 2.

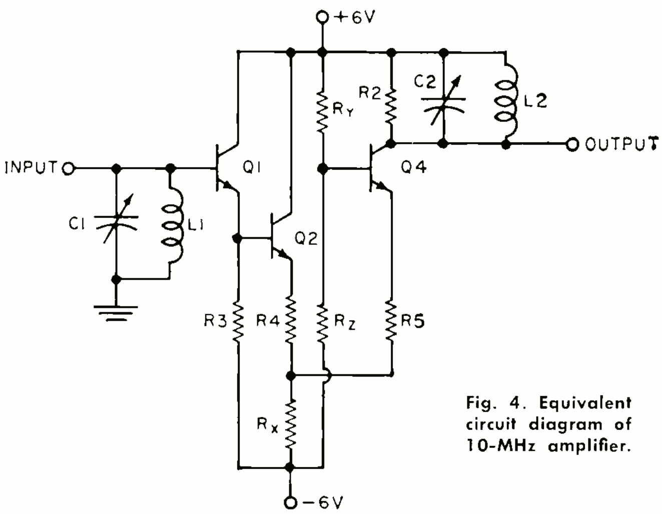


Fig. 4. Equivalent circuit diagram of 10-MHz amplifier.

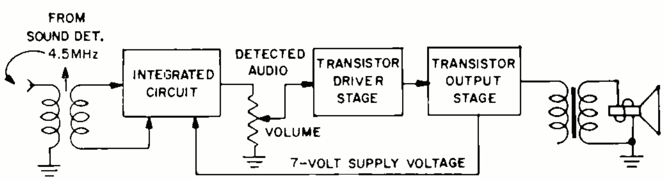


Fig. 5. Block diagram showing use of IC in television receiver.

calibrated sweep generator and an oscilloscope capable of 10 mV/cm sensitivity with a detector probe.

If something appears wrong, the technician would then check to make sure that the correct positive voltage is applied at pin 9 and a negative voltage at pin 3. Pin 10 must also be connected to the "B+" and pins 2, 6, and 7 must be at ground. To analyze the circuit takes quite a bit of doing. We must translate the schematic diagram of Fig. 2 and the connection diagram of Fig. 3 into the actual equivalent circuit of Fig. 4. To simplify the circuit of Fig. 2 only the important elements are shown.

The control circuit composed of Q3 and its diodes and resistors has been lumped together as resistor R_X. The functions provided by Q5 and R6 have been lumped together into R_Y and R_Z. With these simplifications we now recognize a two-stage, emitter-follower (Q1 and Q2) driving the emitter of Q4. The signal output is at the collector of Q4. For the sake of simplicity we have omitted the r.f. bypass capacitors and we have connected the output capacitor C2 directly across L2, which is equivalent to the connection shown in Fig. 3. We can now analyze the circuit of Fig. 4 in terms of each of the transistors and individual resistors but since we cannot test them individually or measure their values, very little has been gained. A defect in any of these components will still prevent the entire unit from operating correctly.

"It becomes obvious that an analysis of the internal circuit itself is of no particular value in troubleshooting. The function of the IC and functions of each lead are the really essential parts."

Evaluation of the circuit of Fig. 4 and its relation to Fig. 2 does tell us, however, that if pin 4, for example, were grounded, this would alter the effective value of R_X. If pin 4 were shorted to pin 3, a typical defect in an IC assembly, the value of R_X would be similarly affected and the over-all gain would change. If pins 4 and 5 were shorted together, R_X would again be affected. Pin 6, the input lead to Q5 in Fig. 2, is grounded for this particular application and if it were shorted to the ground of pin 7, this would have no effect at all. If pins 8 and 9 were shorted together, however, this would be equivalent to shorting out the tuned circuit load and there would be no output from the amplifier. The same thing applies if pins 1 and 2 were shorted together, as this would effectively short out the input tuned circuit.

It becomes apparent that the condition of the ten pins of the CA-3000 integrated circuit is of much more significance in troubleshooting than the individual components which make up the IC. It also becomes obvious that an analysis of the internal circuit itself is of no particular value in troubleshooting. The function of the IC, in this case an amplifier of 10 MHz, and the functions of each of the leads are the really essential parts for troubleshooting.

Troubleshooting directions for the 10-MHz amplifier circuit can simply direct the technician to make sure that pins 6 and 7 are grounded and that none of the other pins is grounded, that pins 9 and 10 are at +6 volts, and that pin 3 is at −6 volts. The amplitude of V_{IN} and the expected amplitudes of V_{OUT} must be given, together with the impedances. The technician would then check the voltages, measure the input 10-MHz signal and compare it with the output.

IC pins are quite thin and it can happen that the connection from the printed-board terminal to the IC itself is intermittent or open. The voltage check will not reveal this since the test leads cannot be attached to the point where the IC pin enters the IC case. Connecting a signal generator or scope probe to the tuned circuits without loading or detuning them requires some care. These points will be discussed in Part 2 of this article.

Troubleshooting the TV Sound IC

To demonstrate how the IC in a typical consumer product modifies the established troubleshooting procedures, let us consider the integrated circuit which is used in an intercarrier-sound TV receiver. Fig. 5 is a block diagram of the RCA Model CTC-21 sound section. From the second detector the 4.5-MHz intercarrier sound i.f. goes through a transformer to the integrated circuit. The +7 volts are supplied to the integrated circuit and the audio-output signal goes from the IC to the volume control. The transistor driver stage and the transistor output stage are conventional and will not be discussed.

Judging by the block diagram of Fig. 5, only four connections must be made to the integrated circuit. In actual practice, however, the interconnections are much more complex. Fig. 6 shows the detailed interconnection diagram of the single IC which serves as an amplifier, FM detector, and audio preamplifier.

It is interesting to compare the functional diagram of Fig. 6 with the actual circuit of the IC itself as shown in Fig. 7. The IC consists of eight transistors, Q1 through Q8, which perform the i.f. amplification and limiting, and two transistors, Q9 and Q10, which provide suitable bias voltages, and two diode assemblies, D1 and D2, which act as voltage dividers. This section amplifies the 4.5-MHz intercarrier i.f. signal to drive the discriminator transformer. The FM detector and audio amplifier section consist of the remainder of the IC. Two diodes, D3 and D4, together (*Continued on page 75*)

The author received his BS Magna Cum Laude from Yale in 1937 and his PhD in physics from Yale in 1940. He joined Bell Labs in 1940 doing research in microwave circuits, switching to microwave tube development in 1944. Since 1948, he has been concerned with transistor and diode research and development, including varactor diodes and high-speed switching diodes, microwave protectors, amplifiers, and power sources. He is currently in charge of microwave transistor development and their fabrication techniques.

Selection of Transistors

By R.M. RYDER
Bell Telephone Laboratories

The various types of transistors covered in this special section are compared with a view toward making the best selection.

TRANSISTOR selection is a complicated matter. There are literally thousands of type numbers belonging to several different kinds of construction and operation. In order to understand how their properties interrelate, some generic properties of different classes of transistors are discussed in this introduction.

1. The original **point-contact transistor** was of great theoretical importance in establishing the possibility of bipolar (electrons moving in one direction, holes in the opposite direction) transistor action, namely, the injection and collection of minority carriers. Such minority carriers are holes in n-type material and electrons in p-type material. However, from a practical point of view, its properties never were under very good control; and this transistor has been relegated to the museum by later types.

2. **Grown-junction transistors** are also important from the theoretical point of view since they establish the quantitative accuracy of Shockley's theory of bipolar transistor action. From the practical point of view, they have been replaced by alloy junctions.

3. The **alloying** technique, using germanium, led to the first successful large-area junction transistors. Their performance is good up to several megahertz in frequency, and also suffices for power units of respectable size—scores of watts. The alloy-junction transistor is still in extensive manufacture.

4. **Filamentary transistors** (sometimes known as "double-base diodes"), and four-layer p-n-p-n stepping transistors ("controlled rectifiers") have some interesting special properties but will not be discussed further here.

5. The **diffused-base technique** (1956) raised the frequency capability of transistors by orders of magnitude. With increasingly fine control of electrode sizes as well as diffusion profiles and epitaxial material, bipolar transistor performance has moved up to several thousand megahertz. The diffusion technique also facilitated the use of silicon rather than germanium, which helps power capability; and with the development of passivating insulating coatings a very high degree of reliability can be achieved. With diffusion and photolithography as techniques and with silicon as a material, the bipolar transistor has developed today's very wide performance capabilities.

6. **Field-effect transistors** were proposed even before the bipolar transistor was discovered, but their operation in a practical sense has depended upon techniques developed for bipolar transistors. The interplay between these two types of transistors is very interesting and will be described in some detail.

Up to a few years ago, FET's were not available for the following reasons. First, FET's would not work at all until semiconductor surfaces were available which had reasonably low populations of surface states. Second, even after reasonably good surfaces were available, the performance gain-band product, f_{max}, was lower than bipolar transistors by an order of magnitude. Third, the reliability of FET's was highly questionable. With small input currents, a small change in leakage current means a fairly large drift in biasing point.

In the course of the past several years, this situation has changed drastically, again for three reasons. First, surface coatings with much better and more stable surface characteristics have been developed. Second, the insulated-gate FET has been invented. This device, variously known as the IGFET, MOSFET (metal-oxide silicon field-effect transistor), or MOS transistor, has the gate electrode deposited on top of the insulating coating, thereby exerting field-effect action on the carrier flow in the semiconductor beneath, without at the same time drawing appreciable d.c. current. This feature is believed likely to lead to flexibility in applications to monolithic integrated circuits, since the electrodes can be deposited with protean shapes and sizes. Third, photosensitive methods have been developed for making very fine scale, closely controlled electrodes on semiconductor devices. These are the same techniques which have enabled bipolar transistors to operate successfully well into the microwave region. Even though it is still true that bipolar transistors are faster than FET's, the latter are capable of useful operation up to several hundred megahertz. So we have the curious situation that the FET transistor, which is historically older than the bipolar, has become practical more recently, and in fact is dependent on bipolar techniques for its practicality.

At present the broad situation can be outlined as follows. 1. It is expected that with proper fabrication methods all these types of transistors will be stable for long-term operation even without external protective cans. 2. The bipolar transistor is greatly superior for gain-band product in broadband applications or for maximum frequency response such as microwave applications. Bipolar transistors are also higher in power capability than FET's. 3. FET's have some special advantages, too. For one thing, the input impedance is high, at least at low frequencies, permitting high-impedance amplifiers resembling vacuum tubes in behavior. This property is often convenient in such applications as bridging amplifiers or in working from high-impedance sources. Then, too, the fact that gain-band product is lower is advantageous to the FET in some applications. For example, in narrow-band applications such as radio receivers, for equal gain the selectivity of an FET is better, so that the receiver can utilize the narrower band to help discriminate against interfering signals. For the same reason, distortion products may be lower when signals become large.

Noise performance is remarkably good for the best transistors of either type. However, at low frequencies where 1/f noise is important, the usual operating points of bipolar transistors tend to be noisy because high current is drawn. Special designs for low noise at low frequencies should have very low currents and voltages, and special care should be taken with these surfaces to keep 1/f noise low, although bandwidth or frequency response may be sacrificed.

7. **Integrated circuits.** In the future it is expected that to an increasing extent the entire circuit, rather than the transistor alone, will be built as a unit. This introduces still other considerations into the choice of transistors, since fabrication compatibility with the rest of the circuit enters the picture and there are many possibilities to be intercompared (monolithic, thin-film circuits, multichips, and many subvariations). While a discussion of IC's is outside the scope of these articles, it will be found that a discussion of the properties of transistors is still germane to their performance even when they are used in integrated circuits.

To sum up, bipolar transistors may be designed to have higher bandwidth, high-frequency response, and higher power. Field-effect transistors may be more selective, have higher input impedance especially at low frequencies, and perhaps have some fabrication advantages which may reduce cost, especially in integrated circuits. ▲

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Small-Signal High-Frequency Transistors

By T. J. ROBE
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Valuable tips are offered below for selecting radio-frequency transistors. Included is description of scattering parameters.

SMALL-signal high-frequency transistors are designed to provide high gain and low noise at high frequencies. To attain this, high-frequency transistors have a very narrow base and small base-spreading resistance r_b'. Low-frequency (audio) transistors generally require a very high d.c. *beta*, higher breakdown-voltage ratings, and low low-frequency noise. Small-signal switching transistors, which are also required to have high-frequency capabilities, must be designed to minimize carrier storage in the base and collector regions. In general, the requirements for switching low- and high-frequency transistors are incompatible and compromises must be made to achieve the optimum characteristics for an intended application.

Today's high-frequency transistors have unity-power-gain frequencies, f_{max}, in the range from 500 MHz to 6 GHz. Most transistors which are suitable for small-signal high-frequency amplification can be classified as one of the following general types:

Table 1. Significant parameters for high-frequency transistors.

C_c	Collector-barrier capacitance
C_{CB}	Collector-base feedback capacitance
f_{max}	Unity-power-gain frequency (figure of merit)
f_T	Gain-bandwidth product (the frequency where $h_{fe} = 1$)
G_{MA}	Maximum available transducer power gain
G_{MS}	Maximum stable power gain
G_{TU}	Transducer power gain (unilateral)
h_{fe}	Forward current gain with output a.c. short-circuited
k	Stability factor
NF	Ratio of total transistor noise power delivered to a load to the noise power delivered to the same load by the source
r_b'	Base-spreading resistance
r_e	Emitter-base dynamic resistance
S_{11}	Input reflection coefficient
S_{12}	Reverse voltage transfer ratio
S_{21}	Forward voltage transfer ratio
S_{22}	Output reflection coefficient
y_{11}	Input admittance } with output a.c. short-circuited
y_{21}	Forward current-voltage ratio } with output a.c. short-circuited
y_{12}	Reverse current-voltage ratio } with input a.c. short-circuited
y_{22}	Output admittance } with input a.c. short-circuited

1. Silicon planar epitaxial transistors (examples: 2N2857, 2N3932, and 2N4259).
2. Insulated-gate field-effect transistors which are also called MOSFET's (examples: 3N128 and *RCA* Dev. Nos. TA7010, TA2644).
3. Junction gate FET's (examples: 2N4416, 2N3823).

Important Parameters

The significant parameters for high-frequency transistors are summarized in Table 1. An examination of the internal transistor parameters which relate to the unity-power-gain frequency, f_{max}, and to low noise at high frequency is facilitated by use of an approximate high-frequency equivalent circuit for a transistor (Fig. 1A). The circuit describes the diffused transistor chip, exclusive of its package, which is applicable at frequencies very near f_{max}. It is assumed that internal feedback is negligible; this assumption permits the calculation of the frequency at which the unilateral power gain is unity. From Fig. 1A, the following expression for the tranducer power gain, G_{TU}, under conditions of matched load and matched source impedances, can be derived:

$$G_{TU} = \frac{\textit{power delivered to matched load}}{\textit{power available from the source}} = \frac{f_T}{8\pi\, r_b'\, C_c\, f^2} \quad (1)$$

If the unilateral power gain is assumed to be unity, Eq. 1 can be rewritten to express the frequency at which this occurs:

$$f = f_{max} = \sqrt{\frac{f_T}{25\, r_b'\, C_c}} \quad (2)$$

Eq. 2 indicates that if a high f_{max} is required, the transistor should have a high gain-bandwidth product f_T, a low base-spreading resistance, r_b', and a low collector-barrier capacitance, C_c.

At high frequencies, a high f_T and a low r_b' are required for low noise figure NF, as well as for high power gain (Fig. 1B). The manufacturer's data on low-noise, high-frequency transistors normally specifies a minimum value for small-signal h_{fe} measured at a frequency, f, above which the reduction in h_{fe} with frequency is given by the following relation:

$$h_{fe} = f_T/f \quad (3)$$

The gain-bandwidth product, f_T, can be easily calculated from Eq. 3.

Although it is difficult to measure r_b' directly, it is relatively easy to measure the $r_b' \, C_c$ product. The parameters f_T and $r_b' \, C_c$ together with the power gain and noise figure, serve as a good initial guide to transistor selection. Another important parameter in the selection process is the total collector-to-base feedback capacitance C_{cb} which provides some indication of transistor stability. This feedback capacitance includes the collector-barrier capacitance C_c, the internal base-contact-to-collector capacitance, and the stray interlead capacitance of the header.

High-frequency figure-of-merit parameters comparable to f_T and r_b' are not generally available for field-effect transistors. However, power gain and noise figure in a functional circuit are normally given for FET's which are intended for high-frequency operation. As will be discussed later, if the two-port parameters are given they can also be used in the selection.

The figure-of-merit parameters f_T and $r_b' \, C_c$ are related to the transistor chip only and do not include the effects of the package stray reactances, such as series lead inductance and interlead capacitance. The two-port parameters, on the other hand, characterize the total transistor at the single frequency at which they are measured. From this standpoint, these parameters paint a better over-all picture of the transistor performance at high frequency, especially for operation at frequencies above approximately 100 MHz.

In the earlier transistors which had an upper-frequency limit of about 100 MHz, it was common to find the *h*- or hybrid-*pi* parameters in the manufacturer's data because these parameters are relatively easy to measure on these particular transistors. As the frequency capabilities of transistors increase to the higher v.h.f. and the lower u.h.f. ranges, it becomes more difficult to measure these parameters, because the "hotter" transistors tend to oscillate with open-circuit terminations. The short-circuit *y*-parameters have replaced the *h*-parameters in the manufacturer's data and are today the most prominent two-port parameters given for small-signal high-frequency transistors. The short-circuit admittance parameters are very useful in determining the maximum stable power gain that can be realized at a given frequency.

Scattering Parameters

High-frequency transistors which are capable of operation at frequencies on the order of 1 GHz and higher are available. At these microwave frequencies, the scattering (*S*) parameters may be easier to measure than either the *h*- or *y*-parameters. Neither an open-circuit nor a short-circuit termination, both of which are difficult to achieve in the microwave region, is required for the measurements. Instead, the transistor is terminated by a reference impedance, typically 50 ohms, which consists of a transmission line operated into a matched termination. An accurate termination of this type is much easier to achieve than the short-circuit termination required for the admittance parameter measurements.

The scattering parameters of a two-port network are defined in terms of reflection coefficients and voltage-transfer ratios rather than by ratios of the terminal voltages and currents. For the network of Fig. 2, the scattering parameters are defined as follows:

$S_{11} = S_{ie} = \frac{E_{R1}}{E_{I1}}\Big|E_{I2} = 0$ = input reflection coefficient with the output terminated in Z_o.

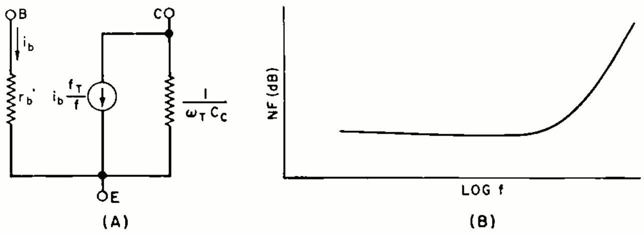

Fig. 1. (A) Approximate high-frequency equivalent circuit for conventional (bipolar) transistor. (B) Frequency at which noise figure begins to rise depends on f_T and r_b'.

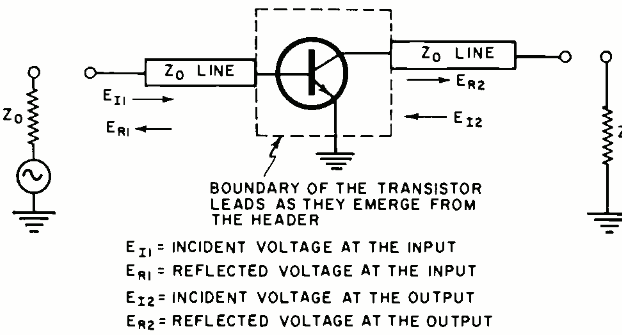

Fig. 2. Circuit for defining scattering (S) parameters.

$S_{21} = S_{fe} = \frac{E_{R2}}{E_{I1}}\Big|E_{I2} = 0$ = forward voltage transfer ratio with the output terminated in Z_o.

$S_{22} = S_{oe} = \frac{E_{R2}}{E_{I2}}\Big|E_{I1} = 0$ = output reflection coefficient with the input terminated in Z_o.

$S_{12} = S_{re} = \frac{E_{R1}}{E_{I2}}\Big|E_{I1} = 0$ = reverse voltage transfer ratio with the input terminated in Z_o.

Transistor Selection

Military and aerospace applications normally require guaranteed reliability and environmental capability, with cost somewhat subordinate. Entertainment applications tend to emphasize low cost. The reliability of the transistor must also be considered, however, because field failures in auto radios and TV sets will soon cut into the set manufacturer's profit. In industrial applications, cost, reliability, and environmental factors are just about evenly weighted.

The differences in transistor cost are primarily based on two factors: volume and guarantees in terms of reliability and electrical performance. Low-cost entertainment transistors are available because of the high volumes in which they are produced. High-reliability transistors for military and aerospace applications are produced in relatively small quantities with extensive inspections, burn-ins, and life tests to guarantee and document their reliability. As a result their costs are relatively high. In terms of cost *versus* reliability, a transistor from a high-volume production line should be selected if guaranteed reliability is not required (the word *guaranteed* should be emphasized because reliable performance is also required of the high-volume transistor). Of course, when transistors which represent the limit of state-of-the-art are required in the application, the cost of these particular devices will be relatively high.

The choice between silicon and germanium has all but vanished in the small-signal high-frequency area. The planar process has allowed the environmentally superior silicon transistor to equal or exceed the high-frequency electrical performance of its germanium competitor while at the same time its cost is low if produced in large volumes.

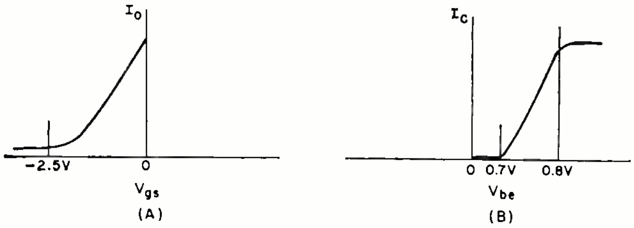

Fig. 3. Transfer characteristics of (A) FET, (B) bipolar transistor.

Another fundamental choice that must be made is whether to use a bipolar transistor or a field-effect transistor. If cost is critical, the FET is an unlikely choice because at present these transistors are produced in much smaller volumes and, therefore, are more costly than many high-performance bipolar transistors. Generally, bipolar transistors also provide somewhat better noise figures and power gain. The high-frequency FET, however, provides a superior dynamic range and greater freedom from cross-modulation distortion.

Fig. 3 shows typical transfer characteristics of an FET and a bipolar (conventional) transistor. The curves show that the input voltage change from cut-off to saturation for the bipolar transistor is only about 0.1 volt as compared to several volts for the FET. Although it is not obvious from the curves, the FET approximates a square-law characteristic, which is ideal for the reduction of third-order nonlinearities that result in cross-modulation and in-band intermodulation distortion products. The FET might then be the choice for applications in which low distortion is very important.

(Editor's Note: For further details on the field-effect transistor, refer to the article on that subject in this special section.)

Automatic gain control is an important factor in the selection of a high-frequency transistor for a stage in which gain control is required. A dual-gate MOSFET (*e.g.*, *RCA* Dev. Nos. TA7010, TA2644) provides both excellent a.g.c. capability and outstanding cross-modulation performance. Bipolar transistors can also be gain-controlled. Some types provide reverse a.g.c. (gain reduced by decreasing emitter current) while others are designed to provide forward a.g.c. (gain reduced by increasing emitter current). The f_T of transistors that have forward a.g.c. characteristics decreases rapidly when the emitter current rises above about 3 mA. If the gain-controlled stage is located in the receiver at a point where cross-modulation is important, it is preferable to choose a forward a.g.c. type because cross-modulation distortion in bipolar transistors decreases with increasing emitter current.

The final item to consider is the amount of stable power gain required. The two-port parameters provide an insight into this capability at a single frequency. The transistor will be unconditionally stable (*i.e.*, no combination of source and load terminations can be found which will cause oscillation) at a given frequency if the stability factor k, defined by Eq. 4, is equal to or greater than unity:

$$k = \frac{2 g_{11} g_{22} - R_e (y_{12} y_{21})}{|y_{12} y_{21}|} \geq 1 \qquad (4)$$

where the g's are conductances and the y's admittances. For common-emitter operation, $g_{11} = g_{ie}$; $g_{22} = g_{oe}$; R_e $(y_{12} y_{21})$ = real part of the $(y_{re} y_{fe})$ product; and $|y_{12} y_{21}|$ = magnitude of the $(y_{re} y_{fe})$ product.

Under the condition $k \geq 1$, the transistor can be conjugately matched at the input and output terminals, and the maximum available transducer power gain, G_{MA}, is then expressed as follows:

$$G_{MA} = \left| \frac{y_{21}}{y_{12}} \right| \frac{1}{k + (k^2 - 1)^{1/2}} \qquad (5)$$

If the transistor is not unconditionally stable, lossy terminations g_S and g_L (source and load conductances, respectively), can be placed at the input and output terminals so that $k = 1$. For this condition, the maximum stable power gain, G_{MS}, is given by Eq. 6:

$$G_{MS} = \left| \frac{y_{21}}{y_{12}} \right| \qquad (6)$$

These power-gain expressions are useful for comparisons of high-frequency transistors. The practical transistor amplifier will probably provide somewhat less gain than the maximum stable value because a safety margin must be allowed for transistor interchangeability and temperature changes. In addition, losses associated with the transformation networks will subtract from the amount of gain that is realizable.

Practical Circuit Considerations

Calculation of the stability factor k shows that the common-emitter (CE) configuration is unconditionally stable over a much wider range of frequencies than the common-base (CB) connection. The CE circuit, therefore, is recommended in most applications because it is much easier to stabilize. It is for this reason that the manufacturer's data on high-frequency transistors gives CE rather than CB y-parameters. When the operating frequency is sufficiently high so that CE operation does not provide adequate gain, the CB configuration should be used in order to take advantage of its positive feedback. This situation, however, does not normally occur until the operating frequency is higher than approximately 70% of f_T.

When a high-frequency transistor stage is designed for low-noise operation, such as in the first r.f. amplifier of a radio receiver or the first i.f. amplifier when no r.f. amplifier precedes the converter, particular attention should be given to the design of the input circuit. Noise figure is a function of the source resistance R_S at the transistor input terminals. At a given frequency and emitter current, there is an optimum value of R_S for low-noise operation; this value decreases with increasing frequency and increasing emitter current.

For the transistor in the CE configuration, the optimum R_S is normally not much different from the power-matched source resistance. There is an optimum emitter current for low-noise operation because the emitter-to-base dynamic resistance, r_e, is an inverse function of the emitter current, I_E. For most high-frequency transistors, the optimum emitter current is in the range from 1 to 2 mA. The input circuit is required to provide the optimum value of source resistance R_S, but must not be lossy because any attenuation at the input adds directly to the over-all noise figure, *i.e.*, an input loss of 1 dB will increase the noise by 1 dB.

The preceding discussion of stability accounts for the transistor internal feedback only. In order to realize the stable gain capabilities of the transistor as outlined, the external circuit feedback should be reduced to a minimum. Therefore, it is necessary to shield the input from the output circuit, to provide a low-impedance path to ground for the common transistor lead, and to assure adequate a.c. decoupling of the power supply. If sockets are used, they must have low feedback capacitances and permit electrical contact to be made very close to the transistor header.

At high frequencies, lead length becomes quite important and it is necessary to determine the maximum lengths that can be tolerated at a particular frequency with lumped constants. Generally, the lead lengths should be short in comparison to a wavelength. A rough rule of thumb is to limit the lengths to less than 0.02 wavelength. In the higher v.h.f. and u.h.f. ranges, this restriction becomes impractical and the inductance of the lead must be taken into account. ▲

The author, inventor of annular semiconductor devices, has been active in semiconductor development since college. As manager of Motorola Device Development, he was both an active participant and section manager. He received his BS and MS degrees in electrical engineering from MIT and is presently manager of the company's Thyristor Operations.

Diffused Transistors

By JACK HAENICHEN/Manager, Thyristor Operations
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Annular, mesa, epitaxial, interdigitated—what do all these terms mean? When should a diffused transistor be selected? The answers are supplied in the article.

THE manner in which impurities are added to a crystal of germanium or silicon not only determines what the transistor is called but also its electrical and thermal behavior. In the "grown" process, the required junctions are formed while the crystal is being grown. As the crystal is being pulled or grown from a vessel containing molten silicon or germanium, the impuritiy content of the melt is changed with time and contiguous *n*- and *p*-type regions are formed. Because of its low yield, high cost, and other limitations, the grown transistor has been supplanted by the superior diffused device.

When certain metals are alloyed with semiconductors in the alloy process, a small regrowth region is formed in the semiconductor near the interface of the two materials. If the metal being alloyed contains *p*- or *n*-type impurities, the regrowth region will retain a certain amount of these impurities, making it either a *p*- or an *n*-type, respectively. Alloy transistors are being gradually replaced by diffused transistors but still find use in high-power applications.

In epitaxial growth, silicon deposits itself and grows upon the original substrate, forming a mechanical extension of it. If a small quantity of *p*- or *n*-type dopant is added, the latter will grow *p*- or *n*-type, respectively. The epitaxial transistor offers a high BV_{CBO} with good frequency response and high switching speeds.

In the diffusion process, while the semiconductor wafers are hot, a source containing the desired impurities is presented to their surfaces and the impurities distribute themselves within the crystal. The final impurity concentration is maximum at the surface and falls off exponentially in the wafer. Because of this exponential impurity profile, a built-in field is established in the base. This aids in transporting charges from the emitter to collector and, as a result, the frequency response of the transistor is improved. Today base widths have shrunk from several mils to less than one micron, making the electric field provided by a diffused base region of little importance. However, the great degree of control afforded by diffusion, as opposed to other techniques, makes this process most attractive and economical. In addition, reliability of the diffused devices is usually claimed to be greater than those made by other processes.

Diffused Transistor Structures

In the mesa diffused transistor (Fig. 1A), the emitter regions are formed selectively either by an alloy or a masked diffusion technique. A series of "mesas" are etched away to interrupt the continuous base region. This restricts the size of the base and reduces the base-collector capacitance. If the emitter-base and collector-base junctions are brought to the surface, a planar diffused transistor results (Fig. 1B).

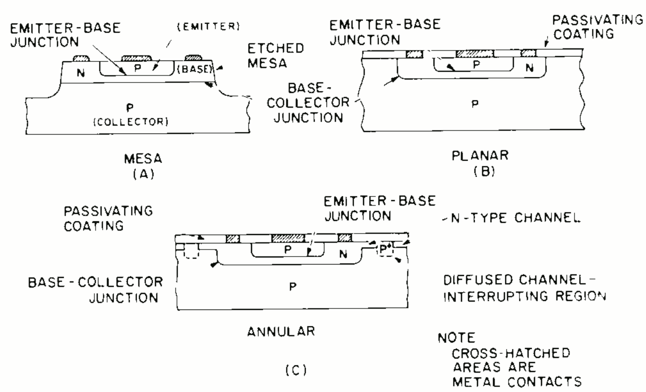
The silicon dioxide coating used for masking is often left on the wafer or a new coating is applied after all diffusions are completed. A permanent coating inhibits foreign material from reaching the junctions and other critical regions near the surface where it might interact with the normal action of the transistor. Such coatings have been referred to as passivating coatings.

It was found that such a coating could aggravate, rather than help, the situation because of impurities within the coating itself. One of the most serious effects is channeling, wherein the presence of the oxide coating actually disrupts the charge distribution near the surface of the wafer in such a way as to cause an inversion of conductivity type. For example, in an *n-p-n* transistor where the collector is normally *n*-type, a *p*-type inversion layer or channel forms under the coating. Such a channel constitutes an extension of the base region and not only increases the effective size of this region, but also causes erratic behavior of the reverse current. In the annular transistor these channels are interrupted and terminated by a positive annular band, as illustrated in Fig. 1C.

Since the basic starting material in the structures just described is the collector, it is most common to find the collector connected to the case of diffused transistors.

In order to obtain maximum current rating with minimum device capacitance, the structures shown in Fig. 2 were developed. Fig. 2 (left) shows a star transistor where the emitter region consists of four tapered "fingers" radiating from a center point which serves as an emitter bonding island. Tapering of the fingers is consistent with the fact

Fig. 1. Three main types of diffused transistor structures.



that current is continually leaving the finger toward its end. In Fig. 2 (center), one sees an interdigitated geometry where a large number of slender fingers are interconnected to form multiple interlaced base and emitter regions, tightly packed into a small area. Such structures provide a high emitter perimeter-to-area ratio which has large current-carrying capability and low capacitance. An extended version of such structures is used in many silicon power transistors (Fig. 2, right). This all-diffused device can carry 50 amps of current in a chip measuring 120 x 150 mils.

Materials: Only germanium and silicon are used in production units, despite the better theoretical suitability of such materials as gallium arsenide (*GaAs*). It has been found that III-IV compounds (*e.g., GaAs*) possess such untenable chemical and metallurgical properties that ordinary processes of diffusion, etc. become extremely difficult for transistors.

Silicon is dominant in most of the new designs because of its processing flexibility and high temperature capability. Development of new germanium devices continues to be important, especially in the microwave field and in certain parts of the power-transistor field.

Cost: Fig. 3 compares pricing trends of transistors and tubes over the past 12 years. On a function-for-function basis, transistors today are less expensive to fabricate than are vacuum tubes.

Selecting Transistors

When a device is designed for optimum performance in one or more parameters, compromises are often required in the other parameters. Circuit designers should be aware of these interactions so that certain parameters are not over-specified to the detriment of the others.

Breakdown voltages and junction capacitances: The breakdown voltage of a diffused junction can be twice that of an alloy junction. All things being equal, silicon junctions provide higher voltage breakdown than germanium junctions. The circuit designer should not specify much higher breakdown voltage ratings than required because he might have to pay for this voltage safety margin with a degradation in other key parameters. In alloy types, these trade-offs are less severe.

Further, devices designed for extremely high-voltage breakdown are likely to have more surface problems than lower-voltage units. The depletion region at high voltage is wide and the electric field associated with high-reverse bias on such a junction will fringe into a volume outside the chip, where possible interaction with its environment can occur.

For low junction capacitance, a high collector resistivity is used and the junction is kept small. A transistor having a low collector capacitance, C_{ob}, generally has a high BV_{CBO}; conversely, a high C_{ob} implies a low BV_{CBO}. The circuit designer should be cautioned about transistors with very small values of emitter and collector capacitances since they may oscillate spuriously in certain low-frequency circuits.

Current gain, β: The behavior of β with collector current for a typical diffused transistor is shown in Fig. 4. The curves represent the performance of two silicon annular transistors which are identical in all respects except for breakdown voltage, BV_{CBO}. It should be noted that in the high-breakdown transistors, β peaks at a lower current and falls off much more rapidly with current than in the low-breakdown case. This effect is often referred to as a forward a.g.c. characteristic, because the gain decreases with increasing current.

Not shown are curves of gain-bandwidth product, f_T, *vs* collector current since they are similar to those of β.

In general, diffused transistors have extremely low values of inverse current gain (the current gain of the transistor when the emitter and collector leads are interchanged in a circuit) because the collector is more lightly doped than the base. Typically, inverse β is less than unity. Alloy transistors generally have a high reverse *beta*.

Saturation voltage, $V_{CE(SAT)}$: This is usually specified at some current and under a "forced β" condition. Its value is related to the forward and reverse current gains and the series resistances in the collector and emitter. In general,

Table 1. Selection guide for popular germanium and silicon diffused transistors for various currents and voltages.

	OPTIMUM COLLECTOR CURRENT RANGE									
BV_{CEO} min V d.c.	10 µA-10 mA d.c. p-n-p	10 µA-10 mA d.c. n-p-n	10-100 mA d.c. p-n-p	10-100 mA d.c. n-p-n	100-400 mA d.c. p-n-p	100-400 mA d.c. n-p-n	400-800 mA d.c. p-n-p	400-800 mA d.c. n-p-n	800-3000 mA d.c. d-u-d	800-3000 mA d.c. n-p-n
19 ↓ 5	2N4411 †MM5000	2N708 2N3493	†AF239 2N499 †2N559 2N869A †2N960-967 †2N968-974	2N2369 *2N4264 *2N4265	†2N1142 †2N1195 †2N2929		†2N1561 †2N1692			
20 ↓ 29		2N916	†2N700 †2N2415 †2N3127 †2N3279 †2N3283 †2N3783 †2N3784	2N3227	†MM380 2N1991	2N697	†2N1204 †2N1495 †2N2381			
30 ↓ 39			*2N4125		2N1132 †2N2273 †2N2955 †2N3323	2N2218-19	2N3252			
40 ↓ 59		2N915	2N3251 *2N3905 *2N3906	*2N3903 *2N3904 *2N4409	†2N502 2N2904-07 *2N4402 *2N4403	2N2218A-19A *2N4400 *2N4401	2N3468	2N3444	2N3719	2N3507
60 ↓ 79			2N3251A		2N2904A-07A				2N3720	
80 ↓ 119			2N3496	*2N4410		2N3499				
120 ↓ Up			2N3637 2N3743	2N3742		2N3501				

†Germanium devices; * Silicon plastic, all others are silicon metal

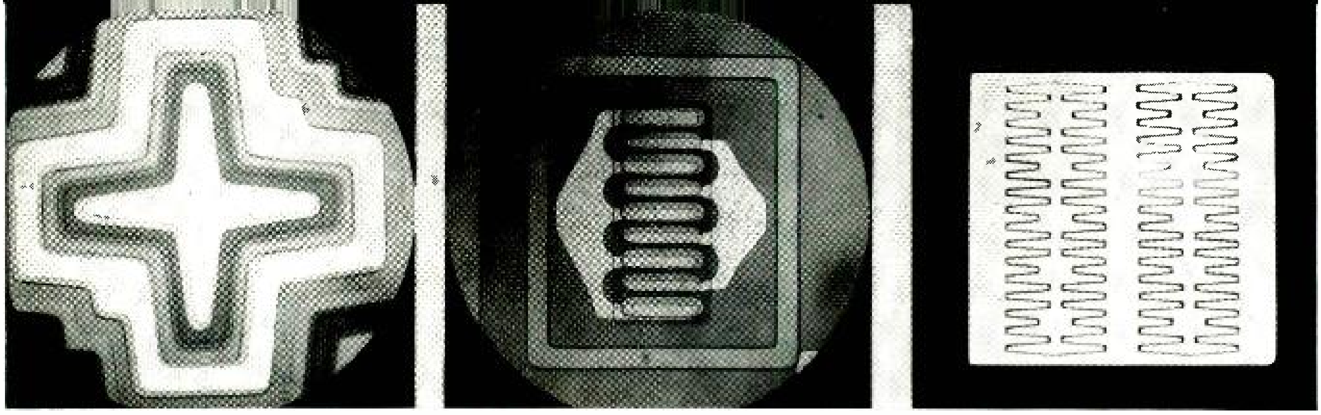


Fig. 2. Photomicrographs of transistor geometries. (Left) star, (center) interdigitated and (right) power.

at high current, such as found in power applications, alloy transistors have a lower value of this parameter than diffused transistors because the collector and emitter series resistances of an alloy device are negligible. Further, germanium transistors generally have an edge over silicon in this particular parameter and *n-p-n*'s (*Ge* or *Si*) are superior to *p-n-p*'s.

Voltage $V_{CE(SAT)}$ is important with respect to power dissipation and loss of useful linear operating range in the transistor. Diffused epitaxial transistors provide lower $V_{CE(SAT)}$ than non-epitaxial versions.

Base resistance, r_b'. This is a distributed parameter, and since the base impurity concentration is not uniform (exponential) is a diffused transistor, calculating r_b' is extremely difficult. For this reason, it is normally determined by a high-frequency measurement.

Low r_b' designs have a low noise figure since a large portion of r.f. noise in diffused transistors is generated in the base resistance. However, a low r_b' generally means greater emitter capacitance.

Input impedance, h_{ie}: Input impedance decreases with increasing emitter current. A typical value at an emitter current of 1 mA is 1000 ohms, in contrast to an FET which has an input impedance in the megohm range. Clearly, where high input impedance is required, an FET should be selected.

Replacing non-diffused transistors: In most instances direct replacement of a non-diffused transistor (*e.g.*, alloy) by a diffused type will not work well without circuit changes. Saturation voltage, current gain *versus* current, etc. are quite different than in non-diffused types. In general, the family of diffused transistors is a much higher frequency breed of device. Values of f_T of 500 MHz are common and amplifier circuits with poor layout will often oscillate when a high-frequency diffused transistor is used in place of an alloy or grown device.

Nevertheless, there are times when such changes can be made, especially if some circuit modifications are possible. Often a diffused device will be available in a plastic package at considerably lower cost than an older type. Also, silicon devices can often be used to replace germanium, resulting in improved high-temperature performance. Such replacements must take into account silicon's higher saturation resistance. With the passage of time, diffused types will be more readily available as suppliers phase out production of non-diffused transistors.

Device packaging: Diffused transistors come in a variety of packages, including the TO-5, 18, 46, 52, 72, and the TO-92, a molded plastic package. Today's plastic-encapsulated passivated silicon transistor represents the minimum-cost transistor configuration which the industry has been seeking.

Table 1 is a selection guide for popular germanium and silicon diffused transistors in terms of current and voltage ratings.

Of the presently available types of diffused transistors, it is likely that the passivated silicon device in a plastic package will continue to be produced for the longest time. Such transistors, as well as specialty devices including the FET and UJT, will be available in plastic packages for various applications.

Passivated germanium transistors might become important since government- and industry-sponsored research continues in this area. In addition, considerable research is under way with germanium as u.h.f. power sources. In this work, diffused semiconductor chips are being incorporated in strip-line and coaxial packages.

Compound semiconductors continue to frustrate the in-

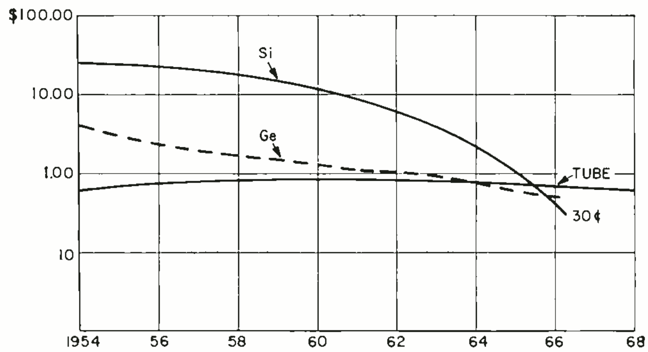


Fig. 3. Selling price of tubes and transistors over the years.

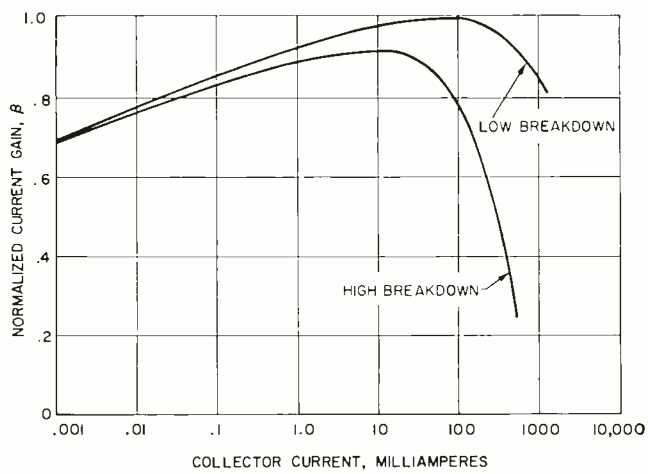


Fig. 4. Beta vs collector current for diffused transistors.

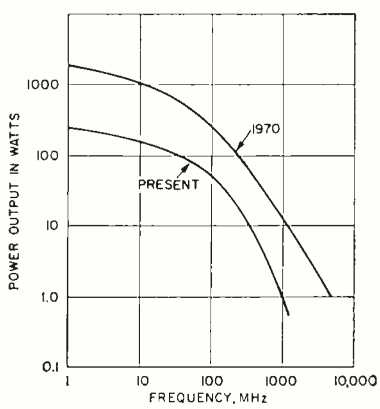


Fig. 5. The r.f. power transistor trends. In just a few years it is expected that substantial increases in output power and higher operating frequencies will be readily obtainable.

dustry. Diffused transistors have been fabricated in gallium arsenide and other materials, but their performance has been disappointing since it has been well below theoretically predicted values. The possibility of a breakthrough in this area still exists, however, and work continues.

Extension of existing diffused techniques will lead to devices capable of many watts output at hundreds of megahertz (Fig. 5). Low-frequency silicon power transistors capable of handling perhaps 100 amperes will be developed, but the author feels that the very-high-current, high-voltage field will continue to be dominated by thyristors. Photolithographic techniques will continue to improve and allow even smaller devices. Today's 2N3493 which operates at 10 μA will be complemented by devices operating at currents orders of magnitude lower.

Devices such as the FET, UJT, and microwave bipolar diffused transistors are continuing to acquire a share of the market now enjoyed by other active devices. In many instances, UJT's or FET's can do a job easier, cheaper, and better than conventional transistors. ▲

ALLOY TRANSISTORS

THE alloy transistor, one of the first produced bipolar junction transistors, has been superseded by diffused-junction devices such as the mesa, planar, and epitaxial types for the majority of applications. The diffusion process yields low-cost high-quality transistors with excellent electrical characteristics and reliability. Today, alloy devices are used primarily for replacement or when they can be purchased cheaper than comparable diffused transistors. In general, a fairly constant *beta vs* collector current and a low collector saturation voltage are characteristics of alloy devices. Table 1 is a random sampling of alloy transistors and some of their characteristics.

It should be pointed out that many germanium power transistors are fabricated by the alloy process with either homogeneous or graded bases. (For further details on this subject, see "Power Transistors" in this special section.)

Most alloy transistors are *p-n-p* germanium and this will be assumed in the following discussion. For the basic alloy process, two small "dots" of a *p*-type impurity like indium are placed on opposite sides of a thin wafer of *n*-type material (germanium) which serves as the base (Fig. 1). After sufficient heating, the two dots alloy with the *n*-type wafer to form the regions for the emitter and collector junctions, and a *p-n-p* transistor is formed. The base connection in this structure is made to the original semiconductor wafer. Because the collector has to dissipate greater power than the emitter, and the current from the emitter diverges as it flows toward the collector, the collector "dot" is larger than the emitter "dot."

In the drift transistor, a modification of the alloy junction device, the concentration of *n*-type impurity in the base is non-uniform, *i.e.*, graded. Advantages of the drift device over the basic alloy transistor are improved transit time, higher collector breakdown voltage, reduced collector junction capacitance, and greater power gain. These advantages lead to a substantial extension of the frequency performance.

Another important variation of the alloy transistor is the micro-alloy diffused transistor (MADT). In this process, pits are electrochemically etched away from the *n*-type wafer until a very thin effective base width is achieved. The *p*-type impurities are then plated on each side of the wafer and a *p-n-p* transistor is produced. These transistors have very fast switching speeds and low saturation voltages, making them ideal for direct-coupled transistor logic.

The future for new types of alloy transistors is dim since most current research is directed toward the improvement of the diffused and field-effect transistors.

Among the advantages of these latter two transistor types are: the use of a relatively light impurity concentration in the collector region of a diffused transistor resulting in high collector breakdown voltages and low collector junction capacitance; and in the case of the field-effect transistor, its very high input impedance.

These two types are also the basic ingredients of the integrated circuit and this type of semiconductor circuit is rapidly becoming more important in all areas of switching and linear applications. ▲

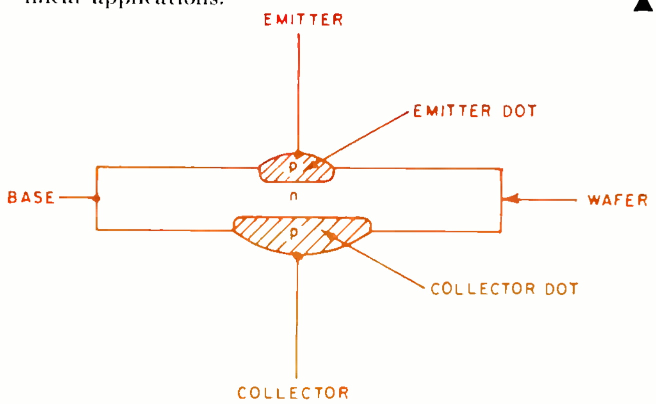


Fig. 1. In an alloy transistor, two "dots" of impurity element are placed on opposite sides of the base wafer.

Table 1. A random sampling of some alloy transistors, divided into areas of interest, and their characteristics.

Example	Type	P_C (mW)*	BV_{CBO} (V)	h_{FE}	f_T (kHz)*	$V_{CE(SAT)}$ (V)	t_{on} (μsec)	t_{off} (μsec)	Package (TO–)
Small-signal audio									
2N591	p-n-p Ge	50	40	70	700	–	–	–	1
2N1310	n-p-n Ge	120	90	20	1000	–	–	–	5
High frequency									
2N1090	n-p-n Ge	120	25	20	5 MHz	–	–	–	5
2N1397	p-n-p Ge	120	40	90	120	–	–	–	33
Switching									
2N388	n-p-n Ge	150	25	150	–	0.2	0.5	1.4	5
2N404A	p-n-p Ge	150	25	100	–	0.1	0.36	0.57	5
Power									
2N173	p-n-p Ge	150 W	45	37	10	–	–	–	36
2N1905	p-n-p Ge	50 W	60	90	7.5 MHz	–	–	–	3

*unless otherwise stated

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Power Transistors

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Practical guidelines are offered for selecting the right transistor for a power application. Various tables and graphs are provided to simplify the selection process.

POWER transistors are required where operation at large signal swings and appreciable power levels (1 watt or more) is of prime concern. Applications, in general, involve driving transducers, high-level power switching, and linear amplifications. Due to the requirements of these applications, power transistors are normally utilized in ranges where small-signal concepts and models cannot be effectively used. However, where low-level amplification is desired, many of the small-signal concepts and models are valid if the base spreading resistance and emitter resistance are accounted for. Some typical values are 10 ohms for the former and 0.04 ohm for the latter. For high-power applications, graphical solutions are still required. With the advent of computerized design, more complex power transistor models may be developed which will replace the graphic approach.

A prime concern in power-transistor design is power-handling capability. For this reason, power transistor elements are first mounted to a good thermal base (usually copper) with provisions to transfer heat from this base to the surrounding environment. To minimize hot spots within the transistor junction, uniform current flow is necessary. This then dictates junction size, collector size, and base width. These factors dictate performance with frequency response dependent upon base width and collector size. Thus, incompatibility exists between high power handling and high-gain, high-frequency performance.

Both germanium and silicon power transistors are available. Most germanium transistors are made by the alloy process with either a homogeneous or diffused base. Silicon power transistors are of double- or triple-diffused construction with a few selected types having the diffused emitter and collector separated by a homogeneous base. The latter devices are limited to relatively low-frequency power applications, whereas double- and triple- diffused power transistors are available in a wide range of voltage, current, and frequency ratings.

Table 1 lists representative germanium and silicon power transistors and includes the high current, low voltage and low current, high voltage ends of the operating spectrum.

For most applications, power transistors can be adequately defined by only a few of the many available parameters. Table 2 lists the significant parameters in terms of two general application areas for power transistors—amplification and switching. In establishing the transistor parameters for a given application, breakdown voltage, current gain, frequency response, and leakage must be specified.

Breakdown voltage: When the transistor is biased at a high current operating point, V_{CEO} or $V_{CE(SUS)}$ should be specified as the maximum voltage. For the transistor operating in the "off" or nonconducting state, then V_{CEX}, V_{CBO}, V_{CER}, or V_{CES} ratings are satisfactory. These ratings, which are based on zero or extremely low collector current, should *never* be used when the transistor is to

Table 1. A number of representative examples of popular power transistors and their operating ranges.

TRANSISTOR CONSTRUCTION	OPERATING RANGE I_C	V_{CEO}	f_T	$P_{C(max)}$ (25°C)	APPLICATION AREA	EXAMPLES	V_{CEX}
Germanium, homogeneous base	7 A	60 V	300 kHz	100 W	Audio amplifier, solenoid driver	DTG-110 2N392 & 2N301	---
Germanium, high-current homogeneous base	50 A	60 V	200 kHz	150 W	Regulators and converters	2N1523	---
Silicon, homogeneous base	15 A	60 V	500 kHz	85 W	Amplifiers and switching	2N3055	100 V
Silicon, high-frequency diffused base	1 A	18 V	100 MHz	2 W	High-frequency power amplifier	2N3925	---
Silicon, diffused base	15 A	60 V	6 MHz	100 W	Amplifier & switching	DTS-100	100 V
	3 A	325 V	4 MHz	100 W	H.V. switching & TV deflection	DTS-402	700 V
Germanium, diffused base	25 A	60 V	1 MHz	100 W	Low-distortion, high-frequency audio amp.	DTG-110B	100 V
	25 A	120 V	500 kHz	100 W	Inductive high-current switching	DTG-2400 2N1653 & 2N2834	300 V

POWER-AMPLIFIER PARAMETERS	SWITCHING-CIRCUIT PARAMETERS	HIGH-FREQ. AMP. PARAMETERS	RELIABILITY PARAMETERS
h_{FE}	$V_{CE(SAT)}$	V_{CEO}	V_{fl}
V_{CEO} or V_{CES}	$V_{EB(SAT)}$	I_{CBO}	PET
$V_{CE(SUS)}$	t_{on}	Power gain	
V_{CBO} or V_{CEX}	t_{off}	f_T	
V_{EB}	$V_{CE(SUS)}$		
f_T	$I_{CBO}, I_{CER}, I_{CES}$, or I_{CEX}		
Θ_R			
$V_{CE(SAT)}$			

Table 2. Important parameters for various power applications.

PARAMETER	MATERIAL	CHANGE WITH CURRENT	CHANGE WITH TEMP.
V_{EB}	Ge	Insignificant over normal range	Decreases 2.2 mV per °C increase
V_{EB}	Si	Insignificant over normal range	Decreases 2.0 mV per °C increase
I_{CBO} (2 V)	Ge & Si	Not applicable	Doubles approximately 11° C temperature increase
V_{CEO}	Ge	Resistance positive at low current then becomes negative with increasing current	Increases with increasing temperature
V_{CEO}	Si		Increases with increasing temperature
h_{FE}	Ge & Si	See Fig. 2	See Fig. 3

Table 3. Parameter variations with current and temperature.

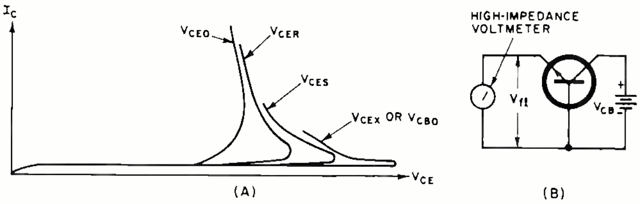


Fig. 1. (A) Breakdown voltage dependence on the amount of collector current (B) Test circuit used to measure value of V_{fl}.

conduct any appreciable amount of collector current.

The collector voltage-current dependence for the various breakdown conditions is shown in Fig. 1A. It is important to note that whenever appreciable collector current flows, the breakdown curve, irrespective of condition, approaches the V_{CEO} curve.

In order to evaluate transistor voltage capabilities at high current levels, the sustaining voltage ($V_{CE(SUS)}$) test was developed. The transistor under test is subjected to a specified peak current and voltage condition simultaneously. The maximum collector-emitter voltage the transistor sees should never exceed $V_{CE(SUS)}$ when conducting large collector currents.

Gain and frequency: In specifying h_{FE}, the ratio of required collector-to-base current should be multiplied by 1.5. This ensures reliable operation even with possible transistor aging and gain degradation.

High-frequency gain is a linear parameter and is used in amplifier applications. Here the gain requirement, normally specified in terms of f_T, is determined by multiplying h_{FE} by the upper cut-off frequency. For example, if an amplifier requires an h_{FE} of 30 and the desired frequency response of the system is 10 kHz, then an f_T = 300 kHz would be required without feedback.

Leakage: Transistor leakage is normally considered with respect to thermal stability and consequently must be evaluated in terms of the maximum temperature and voltage the transistor will see. Since leakage parameters are closely related to the circuit design, it is not practical to include all possible contingencies of temperature and voltage on a data sheet.

For germanium, I_{CBO} at room temperature (25° C) is provided on the data sheet and, generally, the lower the specified I_{CBO} rating, the lower the transistor leakage. (For silicon, I_{CBO} can be ignored up to about 150° C.) Since in many circuits the transistor is not turned off in an I_{CBO} mode, the designer can often reduce costs by evaluating available transistors in terms of actual leakage, such as I_{CER} or I_{CES}, instead of I_{CBO}.

Reliability and Parameter Variation

The preceding parameters will, in most cases, adequately define the transistor requirements for a given power application. However, two other specifications—floating potential (V_{fl}) and pulse energy test (*PET*)—should be added for reasons of device reliability.

One of the easiest of all power transistor parameters to measure, and one of the most important, is V_{fl}. This test (Fig. 1B) consists of measuring the potential developed across the emitter-base junction (V_{fl}) at a specified collector-base voltage (e.g., V_{CBO}). Mechanical defects or major manufacturing errors will show up as a significant emitter-base voltage. If this potential exceeds 0.5 volt, the unit should be considered a reliability hazard. Life test data has shown that units with a high V_{fl} fail five times faster than those with low V_{fl} potentials.

A second reliability test, which subjects the transistor to a power pulse for a specified length of time, is the pulse energy test. The ability of a transistor to withstand this power pulse is a measure of the transistor's durability. Because of the destructive nature of the test, its primary importance is to establish and insure product capability. It is well suited to comparing the energy capabilities of various transistor types intended for the same application. Since it is potentially destructive, *PET* is not suitable for 100% production testing, but this does not limit its usefulness as a Quality Assurance Test.

Transistor parameters appear on most data sheets at a specific operating point and temperature. Some of the parameter variations encountered are inherent in the bulk material used for the transistor and others depend strictly upon device design. A summary of these variations with current and temperature are provided in Table 3 and Figs. 2 and 3.

Selecting and Specifying the Transistor

In selecting a transistor for a given application, the important criteria are performance, reliability, and cost. Obviously, the highest reliability transistor is unsatisfactory if it will not perform in its intended application. Conversely, a very low-cost device may, in reality, be quite expensive if its reliability or performance is unsatisfactory. Performance criteria should be established first, closely followed by reliability standards. The most economical one should be selected from transistors meeting these requirements.

Table 4 lists some specific application areas and expressions for computing required transistor characteristics. For maximum reliability, a $V_{CE(SUS)}$ (and V_{fl} for germanium transistors) should appear on every specification for the maximum voltage and current expected under worst-case conditions. The use of Table 4 in selecting a transistor is demonstrated in the following example.

Example: Consider a 25-watt, class-AB amplifier, with a transformerless output and 8-ohm load, using two power supplies of 22 volts each. Determine the transistor specification.

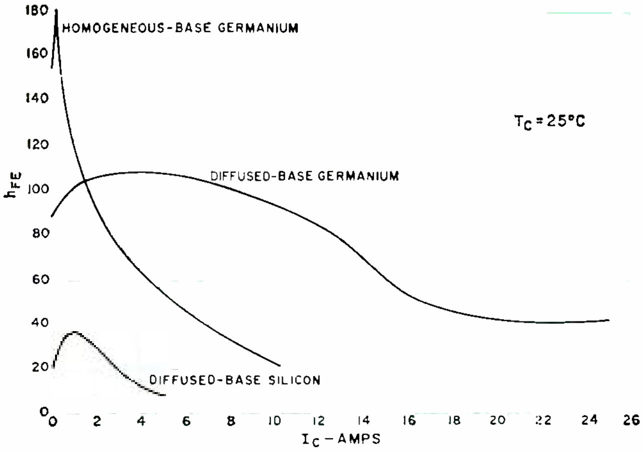


Fig. 2. Typical h_{FE} variation with different collector currents.

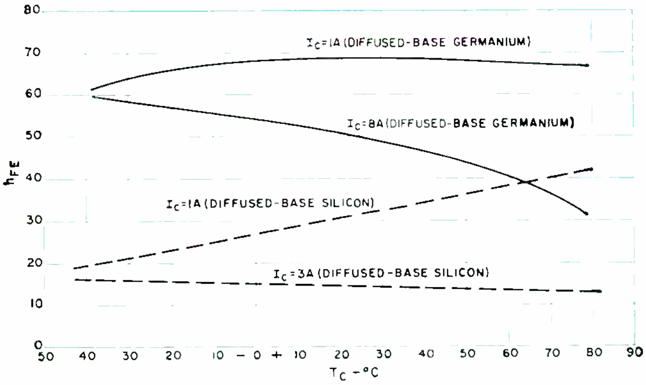


Fig. 3. Typical h_{FE} variation with different temperatures.

1. From Table 4, the maximum voltage for the transistor in the "off" condition is 2.3 V_{cc} = 2.3 × 22 ≅ 51 volts; this corresponds to V_{CEX}. Further, assume the "off" current will not exceed 25 mA.

2. The maximum-voltage, maximum-current condition occurs under shorted load conditions and the voltage is equal to V_{cc}; consequently, specify $V_{CE(SUS)}$ = 22 volts.

3. Normal peak operating current, from Table 4, is V_{cc}/R_L = 22/8 ≅ 3 A. The base drive provided to the amplifier is 100 mA peak; therefore an h_{FE} of 30 at 3 amperes is required. An h_{FE} = 1.5 × 30 = 45 at 3 A should be specified. Assume V_{CE} = 2 volts at the peak current.

4. Since 15-kHz operation is desired, with a feedback factor of .707 an f_T of 30 × 15 × .707 or 318 kHz is needed.

5. Since V_{CEX} = 51 volts, a V_{fl} = 0.5 volt is specified at 51 volts.

6. Pulse energy requirements, under shorted load at 100 Hz, have been determined to be 4 amperes at 18 volts for 10 milliseconds. Therefore, $PET = 4 \times 18 \times 10 \times 10^{-3}$ = 720 millijoules is specified.

The specifications for the output transistor would be as follows:

h_{FE} @ I_C = 3 A, V_{CE} = 2 V	45 min.
f_T	450 kHz
$V_{CE(SUS)}$ @ 3 A	22 V min.
PET @ I_C = 4 A, V_{CE} = 18 V	720 mj
V_{fl} @ V_{CB} = 51 V	0.5 V max.
V_{CEX} @ 25 mA	51 V min.

Transistor construction and polarities: The operating capabilities of germanium and silicon devices are shown in Fig. 4 for ambient temperatures below 100° C. For ambient temperatures greater than 100° C, only silicon transistors should be used.

Choice of transistor polarities depends on the basic transistor material. When silicon is chosen, an *n-p-n* polarity should generally be used; for germanium, a *p-n-p* polarity

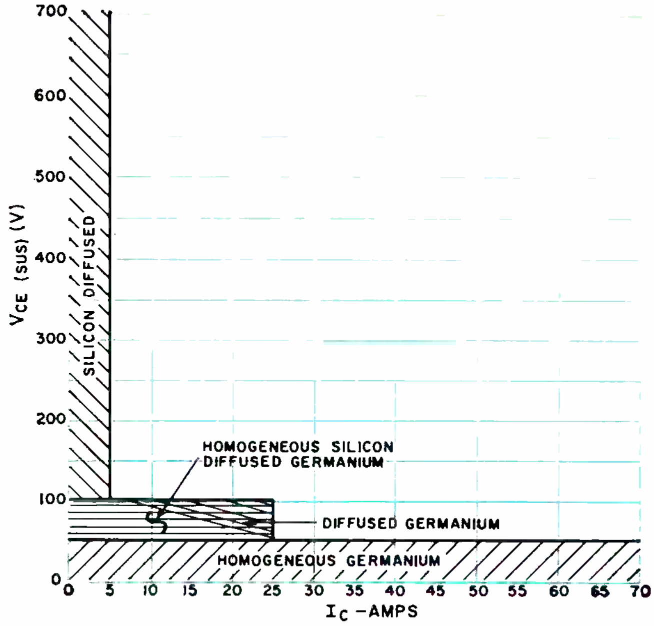


Fig. 4. Voltage and current capabilities of power transistors.

is desirable. These polarities are optimum for their respective materials and lend themselves to the most reliable units at the lowest cost.

Thermal Considerations

The d.c. derating curves, as supplied on most data sheets, are indicative of transistor junction-to-case thermal resistance and, for the most part, do not represent the true limitations of the transistor described. In addition to the junction-to-case thermal resistance, heat-sink thermal resistance, mounting interface thermal resistances, and safe operating area parameters must be considered when determining true maximum power dissipation for a given transistor.

Most heat sinks are specified with a still-air thermal resistance and decreasing thermal resistance with increasing air flow.

Interface thermal resistance, that is, the effective heat loss between the mounting base of the transistor and the heat sink, must be accounted for. For a TO-3 package, this value is usually 0.25°C/W, and drops to 0.1°C/W with the addition of silicone oil to reduce the effect of surface irregularities. If transistor isolation from the heat sink is required, then the use of a mica washer insulator will increase the interface thermal resistance to 0.5°C/W. For maximum heat flow, the heat sink should be isolated from the circuit rather than the transistor isolated from the heat sink.

Consider a TO-3 package with a thermal resistance of 0.8°C/W and 20 watts power dissipation mounted on a *Delco* 7270725 heat sink. With silicone oil the thermal resistance of the assembly would be 3.2°C/W (0.8°C/W junction-to-case + 0.1°C/W case-to-heat sink + 2.3°C/W heat sink-to-air). In order to keep the transistor junction below 110°C with an ambient of 25°C, the maximum power is 26.5 watts (the temperature differential is 110–25 = 85°C; 85°C /3.2°C/W = 26.5 W). This figure reduces to 10.9 watts with an ambient of 75°C. If a mica insulator is used in place of silicone oil, then the allowable power dissipation would be reduced to 23.6 and 9.7 watts, respectively.

These power ratings, based on a maximum allowable junction temperature and thermal resistance, cannot be used for a specification but only as an approximate guide. To determine the actual power rating specification, it is necessary to make a careful analysis of the safe (maximum reliability) operating area. In addition, further de-

APPLICATION	I_C	V_{CEX} or V_{CES}	POWER OUT	DEVICE DISSIPATION	V_{CEO} or $V_{CE(SUS)}$	f_T
Amplifier—class-A transformer coupled	$\frac{2\,V_{cc}}{R_L'}$	2.3 V_{cc}	$\frac{V_{cc}^2}{2\,R_L'}$	$\frac{V_{cc}^2}{2\,R_L'}$	---	30 times max. required frequency response.
Amplifier—class-B transformer coupled	$\frac{V_{cc}}{R_L'}$	2.3 V_{cc}	$\frac{V_{cc}^2}{2\,R_L'}$	$\frac{V_{cc}^2}{\pi^2\,R_L'}$	1.15 V_{cc}	30 times max. required frequency response.
Amplifier—class-AB transformerless (2 power supplies)	$\frac{V_{cc}}{R_L}$	2.3 V_{cc}	$\frac{V_{cc}^2}{2\,R_L}$	$\frac{V_{cc}^2}{\pi^2\,R_L}$	1.15 V_{cc}	30 times max. required frequency response.
Amplifier—class-B transformerless (single power supply)	$\frac{V_{cc}}{2\,R_L}$	1.15 V_{cc}	$\frac{V_{cc}^2}{8\,R_L}$	$\frac{V_{cc}^2}{4\pi^2\,R_L}$	$\frac{1.15\,V_{cc}}{2}$	30 times max. required frequency response.
Inverter (up to 5 kHz)	$\frac{5\,P_o}{4\,V_{cc}}$	---	---	---	$\frac{5.7\,V_{cc}}{2}$	200 kHz
Inverter (5 kHz-10 kHz)	$\frac{5\,P_o}{4\,V_{cc}}$	---	---	---	$\frac{5.7\,V_{cc}}{2}$	400 kHz

where: R_L' = reflected impedance seen by the output transistor; R_L = load impedance; V_{cc} = collector supply voltage; P_o = output power.

Table 4. Specific application areas for power transistors and expressions for computing required characteristics.

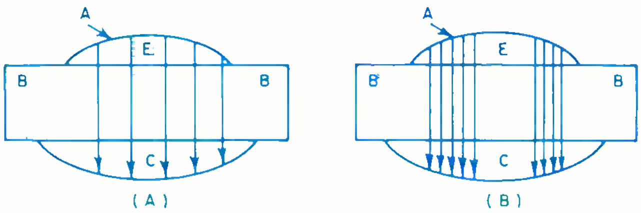


Fig. 5. (A) Uniform and (B) non-uniform current flow in power transistor. Latter condition may lead to second breakdown.

rating is required for higher ambient temperatures and different emitter-bias conditions.

Safe operating area: Consider the transistor structure shown in Fig. 5. At low voltages (about 0.1 V_{CEO}) and moderate currents (0.5 $I_{C(max)}$), uniform current flow exists between emitter and collector as shown in Fig. 5A. When either the voltage or current exceeds these figures, current flow will tend to localize, as shown in Fig. 5B. This can lead to the destruction of the transistor, a condition referred to as *second breakdown*.

Obviously, the temperature at point A of Fig. 5B will be much greater than the corresponding point in Fig. 5A, even though the temperature across the junction is identical. Because of this effect, the power capabilities of the transistor decrease with increasing collector voltage.

To return to the previous example, where it was found that 26.5 watts could be dissipated with the heat sink using silicone oil mounting, at voltages below 24 volts, this figure is satisfactory, as shown by the safe operating curve of Fig. 6. At 40-volt operation, the maximum allowable power dissipation is reduced to 20 watts (from Fig. 6). Although the average junction temperature is below the maximum allowable 100°C, some portion of the junction will be close to a critical temperature because of current concentration caused by high voltages.

Therefore, reliable performance depends on maintaining transistor operation within the bounds not only of average thermal resistance characteristics, but also within limitations dictated by a maximum reliability d.c. operating area curve (Fig 6). Total reliance only on thermal resistance calculations may lead to unreliable designs.

Future Outlook

Advances in power transistor technology will be in the areas of new packaging concepts and higher voltage and current ratings in both germanium and silicon devices. Plastic-encapsulated transistors are already on the market but in the 10-watt and under range. Higher power designs, exceeding 50 watts, are expected to be available soon in the plastic package.

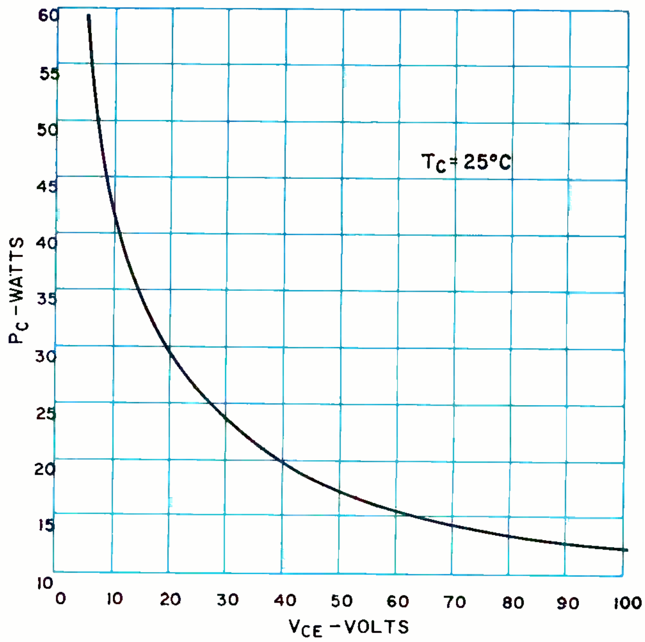


Fig. 6. Safe operating curve for a power transistor (DTG-2400).

The primary advantage of this package is lower cost, although significant secondary advantages of smaller size and lower weight are not to be overlooked. Wider lead spacing in the plastic package simplifies the introduction of very-high-voltage (1000 volts) transistors. Disadvantages of this package are its higher thermal resistance and lower storage temperature ratings compared to the standard TO-3 package. It is apparent that the advantages outweigh the disadvantages.

Voltage ratings of V_{CEX} = 700 volts and $V_{CE(SUS)}$ = 500 volts are now available. The 1000-volt V_{CEX} and 700 volt $V_{CE(SUS)}$ ratings are in pilot production.

Higher current transistors will be available in both germanium and silicon structures. However, high-gain, high-current devices will continue to be germanium. Silicon power transistors will be more readily available with current ratings of 25-50 amperes. These devices, however, will normally have lower voltage ratings.

Much research has been done in the area of second breakdown and although some success has been achieved, no major breakthroughs are foreseen in the near future.

In the pricing of germanium power transistors, moderate price reductions will continue as manufacturing improvements occur. Silicon power transistors will probably continue to show significant price reductions. ▲

The author received his BS(EE) from Southern Methodist in 1950 and took postgraduate work in solid-state physics at the University of Illinois. He joined Siliconix as Manager of Applications in April 1962, shortly after the company was formed. Prior to his present association, he spent 12 years at Texas Instruments where he was active in the design and development of semiconductor production and test equipment, germanium transistors, IC's, silicon FET's, and silicon diodes. He holds several FET patents.

Field-Effect Transistors

By ARTHUR D. EVANS
Vice-President and Engineering Manager, Siliconix, Inc.

What to look for in using JFET's and MOSFET's is considered. Temperature effects as well as reliability are also covered.

ALTHOUGH quite old in concept, the field-effect transistor (FET) is fairly new in availability. Two basic types on the market today are the junction FET (JFET) and the metal-oxide semiconductor FET (MOSFET). The latter is also referred to as the insulated-gate FET (IGFET). Figs. 1 and 2 show sectional views of these two devices, both of which may have either a *p*- or *n*-channel. Parameter symbols and definitions are provided in Table 1, while the important parameters to be considered in selecting an FET are listed in Table 2.

FET's have entered the consumer product price range. For example, FET's have been used in FM tuners for more than a year. As with bipolar transistors, FET prices cover a wide range. Units packaged in epoxy are available at less than 50 cents each in production quantities. High-quality, military-grade, hermetically sealed units cost much more. The average price of FET's sold in 1966 was about $3.90, down from a 1965 average of $7.00.

Device Characteristics

The JFET is a normally "on" device, *i.e.*, a conducting channel connects the source to the drain even in the absence of a gate-to-source voltage, V_{GS}. The channel will conduct current in either direction, source-to-drain or drain-to-source, its conduction being a function of V_{GS}. For the *n*-channel FET, a negative gate voltage depletes the channel of carriers and thus lowers channel conduction. A positive gate voltage has a similar effect on the *p*-channel device. The magnitude of voltage required to reduce the channel conduction to zero is called the pinch-off voltage, V_p. Beyond V_p, the only d.c. drain or source current that flows is the reverse saturation current of the drain-gate or source-gate *p-n* junctions (I_{DGO} and I_{SGO}, respectively).

If the gate is forward-biased with respect to the source, the channel conductance, g_{ds}, will increase (Fig. 3). However, beyond a few tenths of a volt, the gate-to-channel current begins to rise exponentially, hence forward-gate bias is usually avoided for the JFET. The JFET has top and bottom gates. In most devices, these two gates are connected internally and function as a single gate. However, the gates can be separated and provide independent control of channel conduction (*e.g.*, the 3N89 tetrode).

A very important characteristic of the MOSFET is that the top gate is insulated from the channel by an oxide dielectric. In contrast to the JFET, the top gate can therefore be forward-biased to enhance the channel as well as reverse-biased to deplete it. The back gate or body is brought out to a separate terminal or is connected to the source. It is seldom used as a means of controlling channel conduction.

The insulated top gate makes feasible the normally "off"

Table 1. Important FET parameters and their meanings.

PARAMETER	MEANING
BV_{GSS} or BV_{GDS}	Breakdown voltage from gate-to-channel with gate junction reverse-biased
BV_{DGO} and BV_{SGO}	Similar to the above except that either source (BV_{DGO}) or drain (BV_{SGO}) is open-circuited
BV_{DSS} or BV_{DGS}	Breakdown voltage from drain to source with $V_{GS} = 0$
BV_{DSX}	Breakdown voltage from drain to source with $V_{GS} \neq 0$. Normally specified for depletion-type MOS when $V_{GS} > V_P$
I_{GSS}	Gate-leakage current. This current is gate-to-channel in junction FET's, gate-to-body in MOS
I_{DGO} and I_{SGO}	Leakage current from drain (I_{DGO}) or source (I_{SGO})
I_{DSS}	Drain-to-source current when $V_{GS} = 0$
I_{DSS1}/I_{DSS2}	Match in I_{DSS} for differential pairs
I_D	Drain current under specified conditions
I_{DZ}	Sometimes used for drain current under zero temperature coefficient conditions
$I_{D(OFF)}$ and $I_{S(OFF)}$	Drain or source current with channel current cut off. $V_{GS} > V_P$
V_{GS}	Gate-to-source voltage under specified conditions
V_P or $V_{GS(OFF)}$	Gate pinch-off or cut-off voltage
$V_{GS(th)}$	Gate threshold voltage
$V_{GS1} - V_{GS2}$	Gate-to-gate differential offset voltage in matched FET pairs
$\frac{\Delta \lvert V_{GS1} - V_{GS2} \rvert}{\Delta T}$	Incremental $\lvert V_{GS1} - V_{GS2} \rvert$ drift over temperature range
g_{fs} or $\lvert y_{fs} \rvert$ g_m or g_{mo}	Magnitude of small-signal, common-source, short-circuit forward transfer conductance (admittance, transconductance or transadmittance)
g_{fs1} / g_{fs2}	Match in g_{fs} for differential pairs
g_{ds}	Dynamic drain-source (channel) conductance; $r_{ds} = 1/g_{ds}$
r_{DS}	Static drain-source resistance
$r_{ds(on)}$, $r_{DS(ON)}$	r_{ds} and r_{DS} when $V_{GS} = 0$ in junction FET's and when gate biased "on" in MOS
g_{iss}, g_{is} or $R\lvert y_{iss} \rvert, R\lvert y_{is} \rvert$	Small-signal, common-source, short-circuit, input conductance
g_{oss}, g_{os} or $Re\lvert y_{oss} \rvert, R\lvert y_{os} \rvert$	Small-signal, common-source, short-circuit output conductance
C_{iss}, C_{gss}	Small-signal, common-source, short-circuit input capacitance
$C_{rss}, C_{dg}, C_{dgs}, C_{rs}$	Small-signal, common-source, short-circuit reverse transfer capacitance
C_{oss}	Small-signal, common-source, short-circuit output capacitance. Approximately equal to C_{rss}
C_{sgs}	Small signal source-to-gate capacitance, gate shorted to drain. Approximately equal to C_{rss} in symmetrical units
C_{dgo} and C_{sgo}	Small signal drain-to-gate (or source-to-gate) capacitance with source (or drain) open. Approximately equal to C_{rss}

Analog Switch	Digital Switch	High-Freq. Amplifier	Low-Freq. Amplifier	Low-Noise Amplifier	Differential Amplifier	Low d.c. drift Single-Ended Amplifier	Electrometer Amplifier
$r_{ds(on)}$ $I_{D(OFF)}$ C_{dgs}/C_{sgs} $V_{GS(OFF)}$	$r_{DS(ON)}$ $V_{GS(th)}$ or $V_{GS(OFF)}$ $t_{on} + t_{off}$ or C_{iss} and C_{rss}	g_{fs} g_{iss} NF C_{rss} I_{DSS} $V_{GS(OFF)}$	g_{fs} I_{DSS} $V_{GS(OFF)}$ C_{iss} C_{rss}	$\bar{e}_n$ and $\bar{i}_n$ or NF g_{fs} I_{DSS} $V_{GS(OFF)}$	$\lvert V_{GS1}-V_{GS2}\rvert$ $\frac{\Delta\lvert V_{GS1}-V_{GS2}\rvert}{\Delta T}$ $\lvert I_{G1}-I_{G2}\rvert$ g_{fs} g_{fs1}/g_{fs2}	I_{DZ}($I_{D\ ZERO}$ TC) g_{fs} at I_{DZ} V_{GS} at I_{DZ} I_G at I_{DZ}	I_{GSS} g_{fs} I_{DZ}
2N3386 2N3970 M103 M106 G116F	2N3970 2N3386	2N3823 2N4223 U183	2N4339 2N4340 2N3458	2N4868 2N4340 2N3578	U205 U231 2N3921	2N2843 2N4117	2N3631 2N4119A

Table 2. Pertinent parameters for a number of important FET applications, along with some device examples.

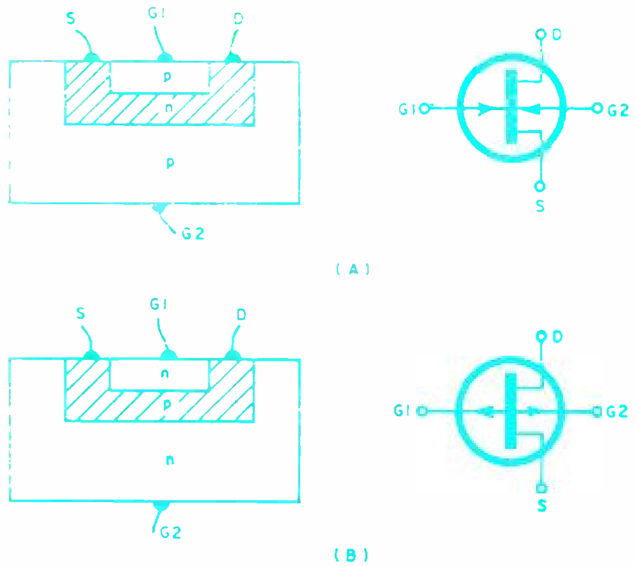
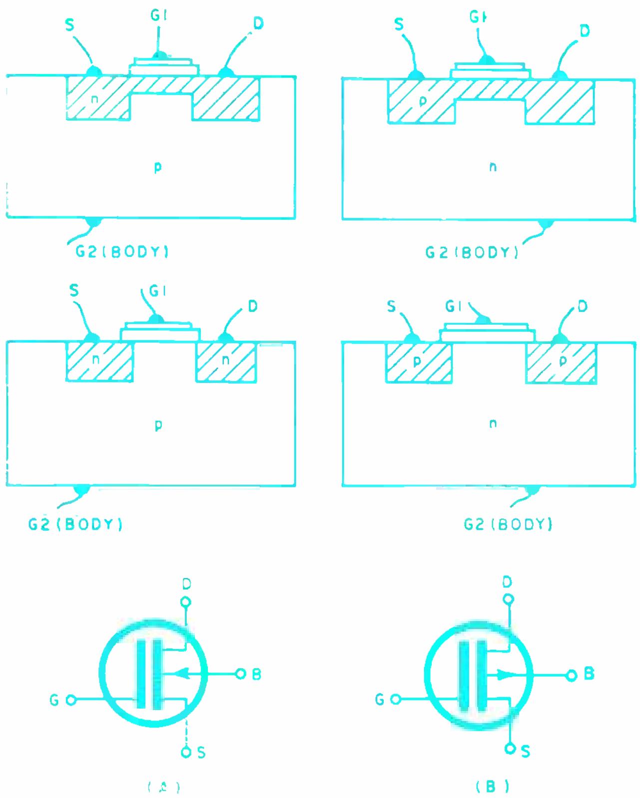


Fig. 1. (A) N-channel and (B) p-channel junction FET's.



← Fig. 2. MOSFET types. Top to bottom: depletion, enhancement, symbol for the (A) n-channel and (B) p-channel types.

(enhancement-mode) devices in Fig. 2. As indicated in Fig. 4A, a forward gate bias is required to enhance a channel from source-to-drain and turn these units "on". For the normally "on" MOSFET (depletion-mode type) of Fig. 2, channel conductance *vs* gate voltage characteristics are similar to junction units. An important difference, however, is that the channel can be further enhanced by a forward bias on the gate, as shown in Fig. 4B. The input resistance of the MOSFET gate is extremely high due to the good insulating properties of the silicon-oxide dielectric. Values in the range of 10^{15} ohms are common (*e.g.*, the 2N3631). Usually, the leakage of the device package is the limiting factor.

The JFET gate has the characteristics of an *n-p* diode. Normally, it is reverse-biased and gate input leakage current I_{GSS}, at 25°C ranges from less than one picoampere (2N4117A) to a few nanoamperes, depending upon device geometry and manufacture. As with junction diodes, I_{GSS} approximately doubles for each 10°C temperature rise.

The gate voltage of the JFET is limited in the reverse direction by avalanche breakdown of the gate-to-source and gate-to-drain diodes. For the MOSFET, the gate voltage limitation is the destructive breakdown of the oxide dielectric under the gate. This breakdown must be avoided, otherwise permanent damage to the oxide results. Gate protection can be included within the device in the form of a breakdown (zener) diode between the gate and body. If the application requires very high input impedance, the diode is not usually included. However, for most switching applications it is provided.

Package types. The majority of FET's are mounted in the common 3- or 4-lead TO-18 type transistor package. Most *p*-channel JFET's use terminal 2 for the gate. For *n*-channel JFET's, terminal 3 is commonly used. The gate may be electrically connected to the case or, if the unit is isolated, the case may be connected separately to pin 4. When the gate is connected to the case, care must be taken to insulate it from ground when mounting the device in a circuit.

MOSFET's usually require four active terminals because of the body connection. Most available devices have the case and body connected to a common pin. Typically, their terminal connections follow neither of the junction FET connections.

Temperature effects. Mobility of majority carriers in the FET channel has a negative temperature coefficient. Therefore, except under certain bias conditions, drain current, transconductance, and channel conductance have negative temperature coefficients. If the JFET is biased for constant drain current I_D, the major temperature effect is on the gate leakage current I_{GSS}, which approximately doubles for each 10°C increase in temperature. The room-temperature value of gate current for today's n-channel JFET is so low that even at 125°C it may still be less than 50×10^{-9} A in a typical amplifier circuit. For even lower input leakage current at high temperatures, an n-channel MOSFET such as the 2N3631 may be used.

FET performance in general improves as temperature decreases; operation is good below −200°C. The low-temperature limit occurs when an inadequate number of impurities in the channel are ionized to provide carriers. Sufficient carriers are available at −250°C for channel conduction of about one half the room-temperature value.

Reliability. The mechanical structure and packaging of FET devices are similar enough to the bipolar transistor to make their mechanical failure mechanisms comparable. The parameters ($g_{fs}, I_{DSS}, V_P, g_{oss}$) associated with the buried part of the device, that is, away from the surface of the silicon oxide interface, are extremely stable with time. Stability of surface-dependent parameters, like leakage current and breakdown voltage, is a function of device geometry and processing. An inverted surface which may result in high leakage or low breakdown, cannot be seen by visual inspection. It can, however, be detected by an analysis of electrical measurements, and is thus subject to quality control.

For the MOSFET, good quality control is extremely important since, by design, its channel parameters ($r_{ds}, g_{fs}, V_{GS(th)}$) are dependent upon the existence of an inversion layer. The stability of these parameters depends on the stability of the inversion layer. Under normal operating conditions, *i.e.*, less than 125°C, V_{GS} shifts in the g_{ds} *vs* V_{GS} characteristic are small. In most switching applications where V_{GS} may swing from 0 to 30 volts, the shift is negligible.

A special handling problem for MOSFET's is the prevention of static charge build-up on an open gate lead. Because of the low leakage of the MOS gate (less than 10^{-15} A/V) sufficient static charge may accumulate on the gate and result in a voltage-induced breakdown of the gate oxide. One common means of avoiding this problem is to build into the device a breakdown diode between the gate and the body, as mentioned earlier. For units without built-in protection, care should be taken to ensure that a short circuit or leakage path exists from the gate to another terminal until the unit is in a test socket or circuit. A gate-to-channel voltage in excess of about 100 volts may cause permanent damage to the device.

Some manufacturers solder the tips of the leads together prior to shipping; other ship in a special container lined with conductive foil which shorts the leads together. When handling the device, it is a good idea to provide a leakage path from the gate lead to another lead by holding a finger against both. If common good engineering practices are observed, little handling trouble will be experienced in working with these MOSFET's.

Making the Selection

The output and transfer characteristics of a typical n-channel channel FET (2N4340) are shown in Fig. 5. Similarity to the characteristics of a pentode vacuum tube is obvious and suggests direct FET substitution in many tube circuits. Indeed, FET performance is superior in many applications ranging from low-drift d.c. amplifiers, through low-noise audio, video, and r.f. up to several hundred MHz.

A low-frequency small-signal equivalent model for the FET is given in Fig. 6A. The parameter values g_{fs} *and* g_{oss} are a function of the operating point (point "Q" in Fig. 5A). Typically, for amplifiers, a drain-to-gate voltage greater than the value of pinch-off voltage is used to minimize the value of the output conductance, g_{oss}. This region of operation is to the right of the dotted line in Fig. 5A where g_{oss} is low and the transconductance g_{fs} is fairly independent of drain voltage. This maximizes the voltage amplification factor, g_{fs}/g_{oss}.

At high frequencies, capacitance becomes important and more complex equivalent circuits are required (Fig. 6B). As the operating frequency is increased, input conductance

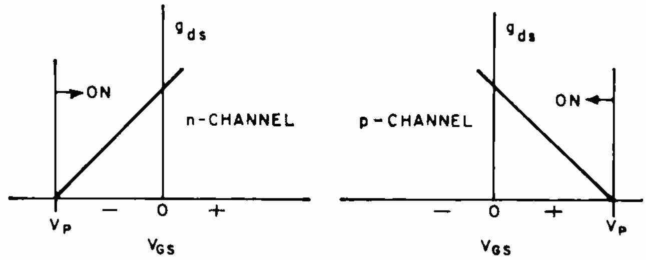


Fig. 3. Dynamic conductance curves vs voltage for JFET's.

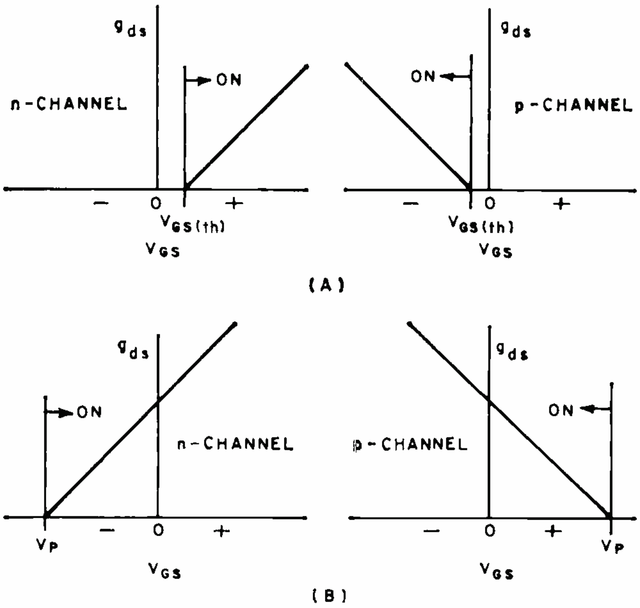


Fig. 4. Dynamic conductance curves vs voltage for MOSFET's of the (A) enhancement mode and (B) depletion mode types.

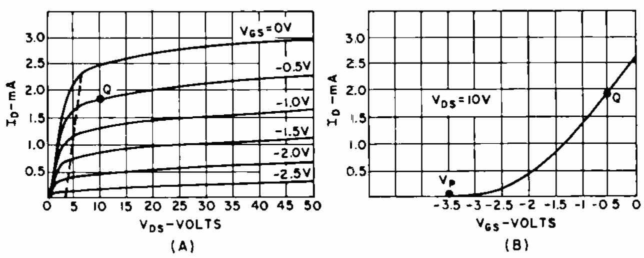
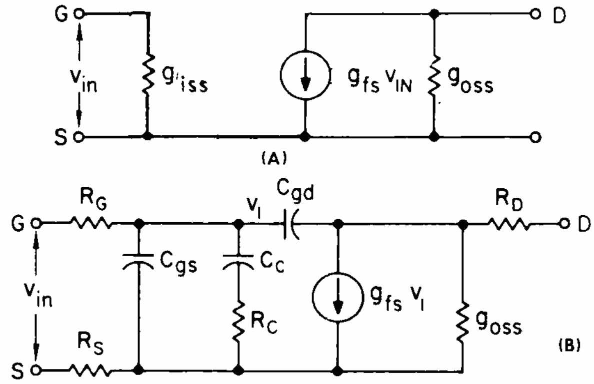


Fig. 5. (A) Output, (B) transfer characteristics of typical FET.

Fig. 6. Small-signal equivalent circuits for the field-effect transistor operating at (A) low frequency, (B) high frequency.



g_{iss} and output conductance g_{oss} increase, while transconductance g_{fs} decreases. The maximum available gain (MAG) drops to unity when $g_{iss}g_{oss} = g_{fs}^2/4$. The frequency at which this occurs is the maximum frequency of oscillation for the device.

An important characteristic of the FET in r.f. circuitry is its almost perfect square-law transfer characteristic (Fig. 5B). This results in amplifier cross-modulation distortion figures of at least one order of magnitude better than those of bipolar transistor designs.

In a low-noise amplifier the equivalent input noise voltage $\overline{e_n}$ and current $\overline{i_n}$ are most important. Since these are frequency dependent, care must be taken in comparing device types to note the frequency at which these parameters are specified. Some device types have a specified noise figure, *NF*, for a given operating condition with a given generator resistance. Usually a high value of generator resistance is specified to make the device "look good". If the value of *NF* is 3 dB, then the specified value of generator resistance is equal to the equivalent noise resistance of the FET.

For a differential amplifier, the incremental input drift over a specified temperature range is probably the most important parameter. An often overlooked parameter in this application is the differential output conductance, $|g_{oss1}-g_{oss2}|$. If g_{oss} is large or not well matched, the common-mode rejection will be poor. If the input signal source resistance is high, then the differential gate leakage current $I_{GSS1}-I_{GSS2}$ is also important.

When the FET is used as a switch for analog signals, the series switch resistance r_{ds} and the drain leakage current $I_{D(OFF)}$ are probably the most important parameters. Gate-drain and gate-source capacitances are important because they determine how much of a "spike" is rejected into the analog signal path in turning the switch "on" and "off". V_p or $V_{GS(th)}$ will determine how much gate drive voltage is needed to control the switch.

FET's are less susceptible to damage by high-energy radiation than bipolar transistors. Type 2N3631 MOSFET's perform well even after exposure to fast neutron radiation of 10^{16} nvt. Major effect is increase in g_{fs}, I_{DSS}, and V_p.

Power FET's

Several companies have reported work on the development of power FET's that approach operation in the 1 GHz region. One method uses a gate structure embedded below the silicon surface. Electrons flow down from the source contact at the surface, through a grid of gate elements, then to the silicon substrate which is the drain. Called a "Gridistor", this device is reportedly being worked on by Dr. Stanislaw Teszner of France and is expected to be capable of 5 watts at 500 MHz.

A similar multi-channel FET has been reported by R. Zuleeg of *Hughes Aircraft Solid State Research Center*. For five devices operating parallel, 2 watts of power was obtained at 100 MHz with an efficiency of 66%. A different approach was explored by Mitchell of *RCA*. Using a MOS tetrode made by integrating two triodes on a single chip, a cascode circuit achieved 12 dB gain at 800 MHz. It will not be too long until power FET's become available to compete with bipolar transistors in many areas of application. ▲

THE UNIJUNCTION TRANSISTOR

EVEN though the unijunction transistor was developed in 1954, the electronics industry is just beginning to utilize the potentialities of this remarkable, single **p-n** junction semiconductor device.

The unijunction transistor finds application in many different areas; including timing circuits, multivibrators, pulse generators, SCR firing circuits, saw-tooth generators, time-relay circuits, ring counters, and voltage-sensing circuits. Maximum frequency of oscillation is approximately 1 MHz and, although low in price, the unijunction has excellent linearity, stability, and requires very simple circuits which are stable over a wide range of temperature variations.

As will be shown, the output from a unijunction oscillator can be either a positive- or negative-going pulse accurately occurring at the flyback of a saw-tooth waveform, which can also be used as the output.

Fig. 1A shows the symbol for a unijunction, while Fig. 1B shows a cross-sectional view of a typical unit. The **n**-type silicon bar has an aluminum wire (emitter) alloyed to it to form the only junction within the device. The two base contacts, one at each end of the silicon bar, are ohmic contacts only and are not rectifying junctions.

The resistance between base 1 and base 2 will vary (with various types of unijunctions) from 4500 to approximately 12,000 ohms. In conventional operation, base 2 is connected to a source of positive voltage while base 1 is connected to the negative end (usually ground). The base bar acts as a conventional resistance and has a voltage gradient within it ranging from a maximum at base 2 to zero at base 1. As the emitter is connected at some point above zero, some fraction of the voltage applied between the two bases also appears between the emitter and base 1. This fraction, or proportional part of the voltage between the bases, is the most important parameter of the device and is called "intrinsic stand-off ratio" or η.

As shown in Fig. 1C, $\mathbf{R}_{B1}$ and $\mathbf{R}_{B2}$ represent the ohmic resistance of the silicon base bar, while diode **D1** represents the p-n junction formed by the alloying of the aluminum emitter wire and the silicon bar.

If an external voltage (V_E) is applied to the anode of the diode, and if this voltage is less positive than the voltage on the diode cathode as a result of the voltage division of the silicon bar (ηV_{BB}), then the diode will be reverse biased and no current will flow through it. Voltage ηV_{BB} is referred to as the peak, or firing, point.

However, when $\mathbf{V}_E$ rises above ηV_{BB}, the emitter junction will then be forward biased and current will flow through the diode to base 1. This increase in current flow consists primarily of minority current carriers injected into the silicon bar. As a result of this rise in current flow, the effective resistance of $\mathbf{R}_{B1}$ is decreased, allowing still more emitter current to flow, further reducing the effective resistance of $\mathbf{R}_{B1}$, thus producing a negative-resistance characteristic.

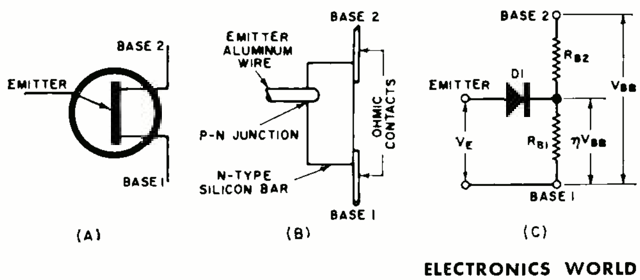
There is a different peak point for each value of $\mathbf{V}_{BB}$ due to a different proportional voltage being applied at the emitter-bar junction, thus reverse biasing the junction diode at different levels of voltage.

In most practical cases, a capacitor (**C**) is connected between the emitter and ground, and a resistor ($\mathbf{R}_2$) is connected between this capacitor and the positive voltage source. A resistor ($\mathbf{R}_3$) is connected between the positive voltage source and base 2 with another resistor ($\mathbf{R}_1$) between base 1 and ground. When power is applied, capacitor **C** starts to charge exponentially via $\mathbf{R}_2$ towards the positive level. When the voltage across the capacitor reaches $\mathbf{V}_E$ (firing point), emitter current starts to flow and the resultant negative resistance action causes a very rapid discharge of the capacitor. The action then restarts to form an unbroken saw-tooth train available at the emitter junction. At the trailing (capacitor discharge) edge of the saw-tooth, a sharp negative-going pulse will appear across $\mathbf{R}_3$, while a similar but positive-going pulse will appear across $\mathbf{R}_1$. The frequency of oscillation can be approximated by: $f = 1/(\mathbf{R}_2\mathbf{C})$.

Resistor $\mathbf{R}_3$ is used primarily as temperature compensation and usual values lie between 200 and 600 ohms. Resistor $\mathbf{R}_1$ is determined by the circuit signal levels required for a desired pulse output.

Recently, **G-E** introduced its D5K unijunction transistor whose characteristics are like those of conventional types, except that the currents and voltages applied to it are reversed. That is, the positive voltage is applied to base 1, and the p-n junction formed by the emitter and bar is reversed. The intrinsic stand-off ratio is .58 to .63, or ±3%. The unit has a low base 1 to emitter voltage drop at high current, permitting high output pulses with low base-to-base voltages. ▲

Fig. 1. Symbol, construction, and equivalent circuit of device.



The author is an engineer/physicist. During his training at the University of Toronto he studied such unrelated subjects as x-rays and spectroscopy, numerical analysis and ultrasonic propagation in liquid helium. He holds a BA Sc degree in engineering physics and MA and PhD degrees in physics. Since joining General Electric's Semiconductor Applications Engineering Section (a section he now heads), his responsibilities have included digital and pulse applications of unijunction transistors and silicon controlled switches as well as conventional transistors.

Small-Signal Low-Frequency Transistors

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Semiconductor Products, Electronic Components Div., General Electric Co.

Transistor differences, parameter variations, and reliability are considered. A checklist is given to help select transistors for audio applications.

As a transistor amplifies higher frequency signals, a point is reached where gain begins to decrease. At frequencies below this point the transistor is said to be operating in its low-frequency region. There are several constructional factors which control the frequency at which gain decreases; these include the transistor's base width, its junction capacitances, and the built-in resistances which work with the capacitances to reduce gain. The newer planar silicon transistors generally extend their low-frequency range beyond 1 MHz. For the purposes of this article, we will consider low frequencies as synonymous with audio frequencies.

If a "large" signal is applied to the transistor, in effect the signal will vary the operating point over a considerable range causing significant changes in the transistor characteristics. By contrast, a small signal is one that hardly changes the operating point so that the transistor's input, output, and gain characteristics can be considered constant. It is important to note that this definition does not depend on power output, but rather on the constancy or linearity of the transistor parameters. Therefore, a class-B audio output amplifier delivering 50 mW is an example of a large-signal application; a power transistor class-A stage supplying the same power represents a small-signal application. Amplifier transistors rated at less than 1-watt dissipation are generally classed as "small-signal" devices.

All transistors generate appreciable noise at very low frequencies. As frequency is increased, the noise decreases to a lower constant level; audio transistors are designed to minimize this noise. Because of the low small-signal power levels, small, low-cost transistor structures can be used. For example, for coupling into microphones, or low-output tape recording heads, audio transistors need to combine low noise with high current gain at low collector current.

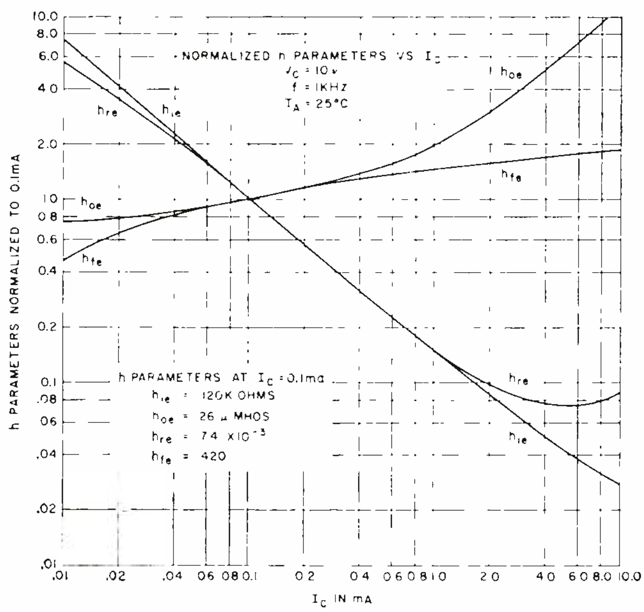
High-frequency transistors, on the other hand, sacrifice high gain and low noise in order to achieve narrow base widths and low junction capacitances. In power transistors, the more important factors are the thermal characteristics of the case and the voltage ratings.

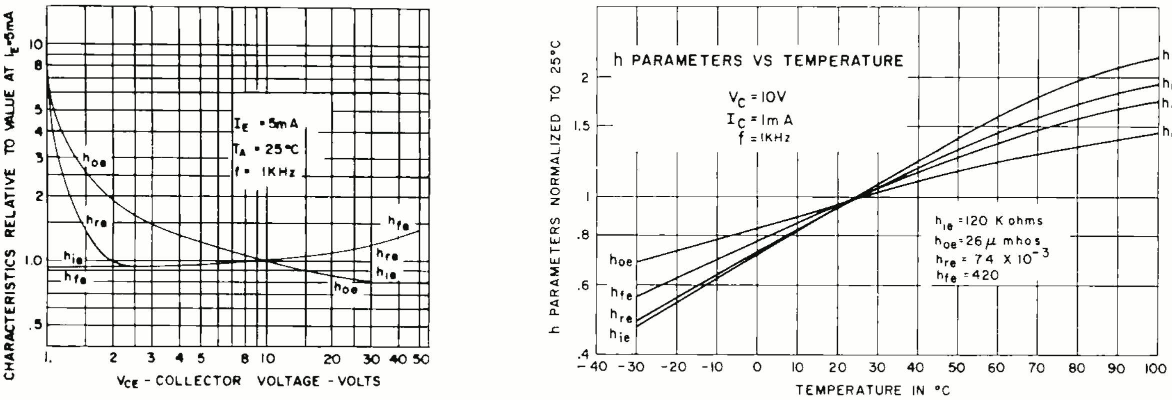
Switching transistors are designed to be an effective short-circuit when turned "on"; when "off", the leakage current must be low. Since the speed with which a transistor responds to an input is important, its design incorporates a narrow base width and a low collector capacitance. For rapid turn-off, gold is introduced into the base of the transistor to neutralize the carriers stored there during the "on" state. Gold reduces the transistor's gain and increases its noise, making it less suitable for audio applications.

Examples of high-performance audio transistors include the 2N3391, 2N3394, 2N3415, 2N3403, and the 2N508 series. The 2N3391 is characterized by low noise; where low noise is not mandatory, the 2N3394 is a low-cost transistor with a narrow current-gain range that simplifies circuit design. The 2N3415 has good linearity at higher currents, while the 2N3403 offers the same electrical performance as the 2N3415 but at higher dissipation due to its integral heat sink. The 2N508A is a *p-n-p* alloy germanium transistor with broad applications in audio circuits.

Areas of application for small-signal low-frequency transistors include FM-stereo multiplex decoders, electronic organ oscillators, electrocardiogram amplifiers, servo amplifiers, and other similar circuitry.

Fig. 1. Normalized h-parameters vs collector current for 2N3391.





(A) (B)

Fig. 2. Family of normalized h-parameter curves shown as a function of (A) collector voltage and (B) temperature.

Important Device Parameters

The most useful and practical parameters for audio-frequency applications are the small-signal parameters h_{ie} and h_{fe}, and the upper -3 dB cut-off frequency, f_β (see Table 1). When "current gain" is meant, the term *beta* (β) is often used rather than h_{fe} (or h_{FE}). For an effective load impedance of 10,000 ohms or less, $h_{ie} \cong$ input impedance of the amplifier; $h_{fe} \cong$ current gain of the amplifier; and $f_\beta \cong$ the upper -3 db cut-off frequency for the amplifier.

The h-parameters, with capital subscripts (h_{IE}, h_{FE}, h_{RE}, and h_{OE}) refer to average or d.c. parameters and are useful for biasing the transistor. For example, if $I_C = 10$ mA and $I_B = 0.5$ mA (as measured on a v.o.m.), $h_{FE} = 10/0.5 = 20$.

While the h-parameters are easier to measure at low frequencies, the y-parameters of Table 1 are more convenient for mathematical analysis and are more readily measured at high frequencies. It is for this reason that transistors such as the 2N3854 are characterized at 100, 45, 10.7, 4.5, and 1 MHz in y-parameters and at 1 kHz in h-parameters.

It is noteworthy that the h-parameters are measured at only one operating point and normalized curves are supplied to permit calculation at other operating points. For any given transistor manufacturing process, all the transistors tend to vary in the same manner with operating point, irrespective of the actual value of the parameter, that is, a high *beta* unit will have its *beta* peak at the same collector current as does a low *beta* unit. Similarly, the percentage change of *beta* with temperature will also be relatively independent of the actual *beta*. For operating points other than the one at which the parameters were measured, the measured value is multiplied by the factor shown on the vertical scale. Some examples of normalized curves are illustrated in Figs. 1 and 2.

Table 1. Small-signal parameters (common-emitter) for audio.

f_β	Upper -3 dB cut-off frequency where h_{fe} is 0.707 its value at 1 kHz	
h_{fe}	Forward current gain	with output a.c. short-circuited
h_{ie}	Input impedance	
h_{oe}	Output admittance	with input a.c. open-circuited
h_{re}	Reverse voltage transfer ratio	
NF	Ratio of total transistor noise power delivered to a load to the noise power delivered to the same load by the source	
y_{11}	Input admittance	with output a.c. short-circuited
y_{21}	Forward current-voltage ratio	
y_{12}	Reverse current-voltage ratio	with input a.c. short-circuited
y_{22}	Output admittance	

The relationship between h_{fe} and h_{FE} is illustrated by the curves of Fig. 3. Either one may be greater, depending on the operating point at which they are compared. The graph also shows that h_{fe} decreases at higher frequencies. Since there is a reasonable correlation between h_{fe} and h_{FE}, frequently only one is measured for specification purposes and the other estimated. However, current gain applies only to the point of measurement and the gain may be different if the intended operating point is far removed.

The curves of Fig. 1 indicate typical variations of h parameters with collector current. For a 1000 to 1 range in collector current, h_{fe} varies by less than 4 to 1; therefore, *beta* can be considered a constant once an approximate operating point is chosen. Parameter h_{ie}, on the other hand, changes

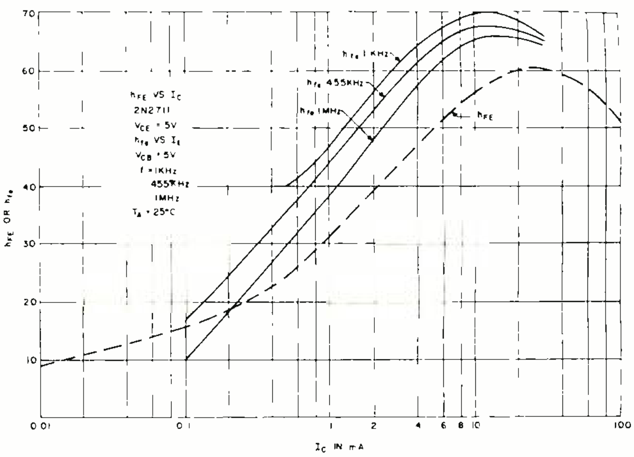


Fig. 3. Variation of h_{fe} and h_{FE} with collector current.

approximately 200 times in the same current range. Since h_{ie} is very nearly equal to the input impedance of the transistor, we see that the input impedance is approximately 1 megohm at 10 µA of collector current and 3600 ohms at 10 mA. While h_{re}, the feedback factor, varies drastically, its absolute value is so low that it may be ignored. The variation of h_{oe} can also be neglected when, as is generally the case, the output of a transistor is coupled into the base of another transistor.

Typical variations in the h-parameters with V_{CE} for small-signal audio transistors are given in Fig. 2A. Parameters h_{ie} and h_{fe} are fairly constant over a wide range of collector voltages. The variations in h_{oe} and h_{re} can usually be ignored.

Variations in h-parameters with temperature are indicated in Fig. 2B. The most important variation is in h_{fe}; of lesser importance is h_{ie}. (The upper cut-off frequency f_β behaves approximately as parameter h_{ie}.) Changes in h_{re} and h_{oe} with temperature can usually be disregarded.

Noise seen at the collector of an amplifying transistor depends on the signal-source impedance as well as the collector current. Typical curves of constant noise figure (NF) as a function of collector current and source resistance are shown in Fig. 4. From the graph it can be seen that the best noise figure is obtained for source impedances between 3000 and 10,000 ohms at a collector current of approximately 40 μA.

Selection Guidelines

First of the many factors to consider in selecting a transistor is the circuit and environmental performance requirements. There are the obvious constraints imposed by the available supply voltage, humidity, shock, and temperature environment that add to the electrical requirements of gain, low noise, and manufacturability. An experimenter buying one transistor need not concern himself with the last factor. However, any equipment manufacturer must go beyond the obvious circuit requirements and consider available safety margins on the voltage ratings and package dissipation, the uniformity of device characteristics from shipment to shipment, the versatility of the transistor for other potential applications, amount of available design data, and packaging.

It is well to understand the more important factors that influence cost. Planar transistor technology, which permits batch fabrication of hundreds of transistors simultaneously, yields excellent low-cost small-signal transistors. Another factor affecting cost is the transistor case. A hermetically sealed can is significantly more expensive than a plastic encapsulation. Assembling the planar transistor pellet on the header and welding leads to it are also expensive. Cost is also influenced by electrical specifications. Generally high-voltage and high-current-gain specifications raise cost by leaving residue for the manufacturer after he selects to specifications. In other cases, special tests involving nonstandard temperatures or noise figures are expensive to perform.

Reliability depends on the ability of the transistor to perform in its intended application. This requires that one consider the reliability of the circuit as a whole rather than that of the transistor itself. For example, germanium and silicon transistors and FET's will, in general, all meet the demands of the consumer market. Germanium is currently used in most foreign portable radios. It offers acceptable radio performance, even after the battery voltage has dropped to half its initial value, with simpler circuitry than silicon devices permit. On the other hand, silicon transistors are used in domestic radios because years of American research in silicon have frequently brought silicon transistor prices below those of germanium. Car radios

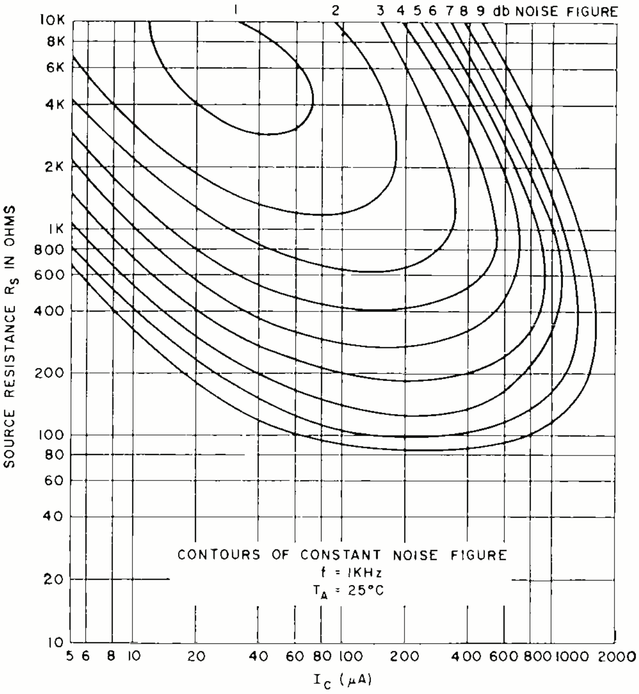


Fig. 4. Noise figure vs source resistance, collector current (2N3391).

utilize silicon transistors to cope with high temperature ambients. The field-effect transistor is slowly making inroads, but its price and little if any improvement in electrical performance in most circuit functions has not made it too attractive.

The major potential problem with plastic encapsulated transistors is penetration by humidity. This need not be a problem if appropriate quality-control measures are implemented. Current life tests indicate that properly encapsulated plastic transistors rival the stability of hermetically sealed units.

A checklist for selecting low-frequency small-signal transistors is given in Table 2. This list will help avoid overlooking some important factors in making the selection. Cost was not explicitly identified because all factors contain cost implications. The user must decide how much value each factor has in his application. In addition, questions to ask the manufacturer or his representative if you are designing a piece of equipment for production purposes include the following:

1. Are you recommending my choice of transistor for new designs?

Table 2. Here is a useful checklist to be employed in selecting small-signal audio transistors.

Voltage ratings	V_{CEO} should exceed maximum voltage the transistor will see. V_{EBO} is of no importance in a conventional amplifier.
Current ratings	$I_{C(max)}$ is generally no problem.
Dissipation	P_C is very low for small-signal applications.
Current gain	h_{fe} and h_{FE} should be large.
Noise figure	For very low source impedance, a type such as the 2N508A germanium allow "p-n-p" is excellent. For 2000 to 50,000-ohm source impedance, a type such as the 2N3390A is recommended. For 1-megohm source impedance, the FET gives best performance.
Case or packaging	Note whether case is electrically isolated from transistor. Small plastic transistors are available.
Versatility	Specifications can be extensive enough to permit use in most low-frequency applications without undue cost penalty.
Data	Curves showing transistor performance allow extrapolation of specifications with greater confidence.
Power-supply voltage range	Operating point easier to stabilize with germanium than silicon transistors if power-supply voltage varies significantly.
Temperature	Germanium difficult to use in ambients exceeding 70°C; silicon may be used to 125°C. Silicon transistors have negligible leakage current and more h-parameters than germanium.
Shock	Plastic encapsulation provides most rugged construction.
Humidity	Most detrimental ambient is 40°C and 95% relative humidity. Plastic transistors satisfactory for practical application.
Electrical transients	Transistors should be protected against lightning or power-switching-induced transients. FET's are most vulnerable to damage.

2. For what market is this transistor intended?
3. Under what other numbers are transistors of this same process sold?
4. What cost advantage is there in relaxing some non-critical specifications?
5. What would it cost to tighten up on a critical parameter?

What Lies Ahead?

With the increased use of computers, more tightly controlled processing, resulting in less variation between transistors and less residue and thus lower cost, will be possible. The computer should also permit faster and more sophisticated testing for better assurance of electrical performance. For the circuit designer, computer-aided design will allow more accurate compensation for transistor variability, lower safety factors on specifications, and higher performance from each transistor stage.

With all the current effort being directed to the development of integrated circuits (analog and switching), there is little doubt but that discrete transistors will eventually become obsolete for most uses. The important questions are: when?, in what applications?, and by what kind of integrated circuit? In retrospect, we see that after 18 years of transistor progress, some electronic functions are still handled best by tubes. Similarly, today, low-noise transistors, high-resistance values, and coupling and bypass capacitors are a problem for integrated-circuit techniques.

While integrated circuits are improving, so are transistors. Also, new higher performance devices are constantly being introduced, such as the new Darlington amplifier, which is really two transistors integrated into a transistor-like structure. So while integrated circuits will continue to supplant discrete transistors in the simpler applications, we can expect to have discrete transistors with us for a number of years to come. ▲

RESONANT-GATE TRANSISTOR

ALTHOUGH the introduction of the semiconductor permitted circuits to get physically smaller, there has always been one function that has been difficult to miniaturize. That is the frequency selective network usually consisting of inductance and capacitance. In an effort to do away with *LC* combinations, particularly at audio frequencies where the values of these components would be inordinately large, circuit designers have resorted to relatively complex semiconductor circuits that perform the frequency selection process.

The experimental field-effect transistor shown in Fig. 1 represents a new generation of semiconductors in that it is a combination of frequency selective device and amplifier. Like all field-effect devices, it also has the advantage of a very high input impedance.

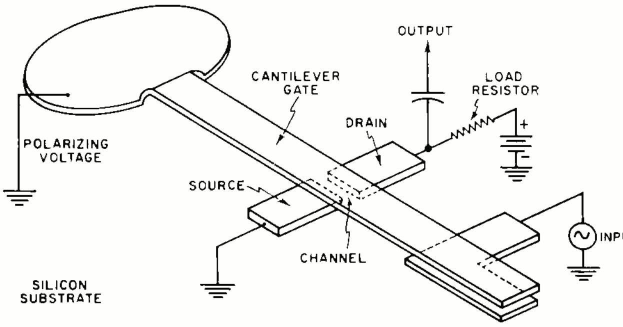
As shown in Fig. 1, the gate electrode is cantilevered over the other electrodes. The cantilever can be made to mechanically vibrate at its resonant frequency by the application of an a.c. electrostatic field applied to the input electrode.

One end of the gate electrode is fixed to the silicon substrate while the free end is positioned over the input electrode. Both these electrodes are insulated from the silicon substrate by a silicon oxide (glass) layer.

If an alternating voltage, of a frequency matching the mechanical resonant frequency of the cantilever, is applied to the input electrode, the cantilever will vibrate at its resonant frequency. The resultant field between the cantilever and the channel affects the conductivity between the source and drain electrodes. The output is taken from the drain in a conventional manner.

The polarizing voltage applied to the stationary section of the cantilever reduces the second harmonic output which arises, since, without this voltage, the electrostatic force between cantilever and input electrode is proportional to the square of the input voltage.

Fig. 1. The fundamental frequency is a function of the mechanical resonance of the cantilevered gate electrode.



Such a device, having a gold cantilever 0.04-inch long, has been made to resonate at 3 kHz with a bandwidth of 20 Hz and a "*Q*" of about 150. Some other experimental devices have been produced with fundamental resonances from 1 to 7 kHz, with "*Q*'s" up to 400. The devices can operate in the overtone mode, with the overtones not being related to the fundamental. The first and second overtones occur at 6.27 and 17.55 times the fundamental frequency, thus enabling operation up to the lower i.f. frequencies.

Devices with resonant frequencies up to 1 MHz are feasible, and gains of up to 6 dB have been reported.

The beam resonance theory has been tested for use in IC's as demonstrated by *IBM* not too long ago. Called a resonistor, the device is essentially a cantilevered chip of silicon measuring 0.0350-inch long, 0.090-inch wide, and 0.008-inch thick, mounted on a substrate.

An excitation electrode is connected near the stationary end of the silicon device, and a strain sensor (piezoresistor) is mounted farther out along the cantilever.

When an input signal is applied to the excitation electrode, it supplies heat to the slender silicon chip setting up strains which cause the silicon to vibrate at its mechanical resonant frequency. The unsupported end vibrates up and down approximately 50-millionths of an inch.

The vibration causes the output strain sensor to change its resistance proportional to the vibrating frequency. When d.c. is applied across the piezoresistor, a.c.-like output voltage is produced. The basic resonant frequency can be controlled by weighting the unsupported end of the cantilever.

Although the bulk of the output signal occurs at the cantilever resonant frequency, a smaller signal appears at half the resonant frequency. Several resonistors operating at different frequencies have been built.

Frequency selection by application of mechanical forces applied to a semiconductor have also been carried out in the audio field. Here, the surface in the emitter region of a planar transistor is mechanically stressed by a stylus. The stress changes the emitter-base characteristics, and hence changes in the stress level create changes in the transistor parameters. If the stylus is mechanically connected to a diaphragm, the transistor acts as a microphone.

Stressed transistors have also been used in multivibrator circuits where stress level determines frequency. ▲

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Switching Transistors

By STEVE FIERRO
Fairchild Semiconductor

Important factors in choosing a transistor for computer and high-level switching applications are considered. Also included is a graphical method for predicting storage time.

A TRANSISTOR functioning as a switch differs from one used as a linear amplifier in one important respect: the operating point. As a switch, the transistor has two stable states—it is either "on" (conducting) or "off" (non-conducting). Ideally, when in the "on" state, the transistor collector-emitter voltage drop is zero; when "off", the collector current is zero. Junction transistors designed for switching can be made to approximate these ideal states to a remarkable degree. In linear amplifiers, like a transistor biased in class A, collector current always flows and an important objective is distortionless operation.

The two basic switching modes are *saturated* and *non-saturated*. In saturated switching, when the transistor is in the "on" state, the collector-base junction becomes forward biased and the collector-emitter voltage, $V_{CE(SAT)}$, is typically less than 0.2 volt. In non-saturated switching, when the transistor is "on", the collector-emitter voltage is greater than $V_{CE(SAT)}$ and the collector-base junction remains reverse-biased. Non-saturated switching does not exhibit any storage time. Although the saturated switch suffers from storage time (see Fig. 1), the average power dissipation is less and the circuitry is simpler than for non-saturated operation.

The transistor sold as a switch is different, for example, from one which is marketed for linear operation at high frequencies. In addition to low internal capacitances along with a low-gain-bandwidth product, a switching transistor must also have very low storage time.

To minimize storage time, gold is added to the semiconductor material during the fabrication process. Gold diffused into silicon or germanium has the effect of introducing recombination centers which reduce the lifetime of minority carriers in the collector of the transistor. It is these minority carriers which give rise to storage time.

Table 1 lists representative transistors designed for switching applications while the important device parameters are summarized in Table 2. Today, the diffused planar epitaxial transistor type is preferred in most applications. Its reliability is high and the price, in the plastic package, is quite low. The diffused transistor is available in standard (TO-5, 18, 39, 46, 52, etc.) and in non-standard packages. Devices like FET's and SCR's are also of importance in certain types of application and will be considered later in the article.

Switching Parameters

The input waveform of Fig. 1 is typical of what is applied to the base of a switching transistor in the common-emitter (CE) configuration. The CE connection is used predominantly in digital computer and other switching circuits because of its gain and phase inverting (*not*) properties. The output waveform is distorted and one can define four delay times which limit the switching speed of the transistor. Referring again to Fig. 1:

1. Delay time, t_d: measured from the 10% point on the input leading edge to the 10% point on the output leading edge. Delay time varies with C_{TE}, C_{ob}, $V_{BE(0)}$, and inversely with the turn-on base current, I_{B1}.

Table 1. A selection of some typical "n-p-n" and "p-n-p" switching transistors along with their characteristics.

	N-P-N SWITCHING TRANSISTORS						P-N-P SWITCHING TRANSISTORS				
TYPE	FT-709	2N2369A	2N3014	2N3724	2N3725	FK-1213	FT-1902	2N5057	2N5022	2N5023	FK-1711
BV_{CEO}(volts)	6	15	20	30	50	6	6	15	30	50	6
h_{FE}	30-120	40-120	30-120	60-150	60-150	50-125	30-120	30-100	40-100	25-100	50-125
Optimum I_C(mA)	1-20	10-100	30-300	100-1000	100-500	1-20	1-50	10-100	100-1000	100-500	1-20
τ_s(nsec)	4	9	12	37	37	*	10	15	40	40	*
F_T(MHz)	800	675	550	450	450	1200	1200	1200	230	280	1200

*Designed for non-saturated switching.

C_{ob}	Open-circuit common-base output capacitance
C_{TE}	Open-circuit common-base input capacitance
f_T	Gain-bandwidth product (frequency where $h_{FE} = 1$)
h_{FE}	Average value of common-emitter current gain
BV_{CEO}	Collector-emitter breakdown voltage with base open
BV_{CER}	Collector-emitter breakdown voltage with a specified resistance in base circuit
I_{CBO}	Collector current with emitter open
t_d	Delay time
t_f	Fall time
t_r	Rise time
t_s	Storage time
t_{on}	Turn-on time = $t_d + t_r$
t_{off}	Turn-off time = $t_s + t_f$
$V_{BE(0)}$	Reverse bias voltage on base-emitter junction
$V_{BE(SAT)}$	Forward bias voltage on base-emitter junction with transistor in saturation
$V_{CE(SAT)}$	Collector-emitter voltage with transistor in saturation
τ_s	Storage time constant

Table 2. Important parameters for switching transistors.

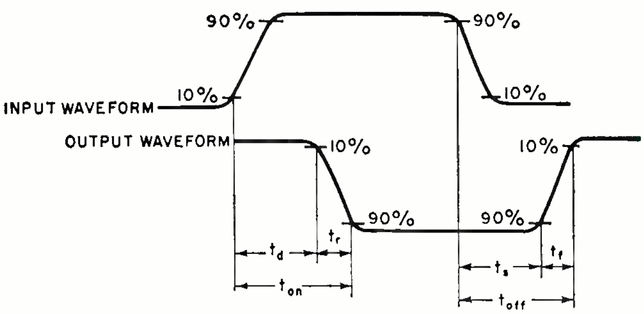


Fig. 1. Typical input and output waveforms produced in circuit that uses a saturated transistor switching element.

2. Rise time, t_r: measured from the 10% point on the output leading edge to the 90% point on the output leading edge. Rise time varies inversely with h_{FE} and with f_T.

3. Storage time, t_s: measured from the 90% point on input trailing edge to the 90% point on the output trailing edge. Storage time varies with τ_s, the storage time constant, and the ratio of the base turn-on/turn-off (I_{B1}/I_{B2}) currents (see Fig. 2).

4. Fall time, t_f: measured between the 90% and 10% points of the output trailing edge. Fall time varies with C_{ob} and inversely with f_T and I_{B2}.

In addition, one can define turn-on time (t_{on}) as the sum $t_d + t_r$ and turn-off time (t_{off}) as the sum $t_s + t_f$.

The storage time delay, t_s, occurs only in saturated switching. For this mode of operation, excess minority carriers are stored in the base and collector during the time the transistor is in the "on" state. When the transistor is turned "off", it takes time for the excess charges to recombine; this is the storage time.

The storage time constant parameter, τ_s, is measured with the collector current I_c and the turn-on and turn-off currents I_{B1} and I_{B2}, respectively, equal. Because it is widely used, τ_s serves as a useful yardstick for comparing different switching transistors with respect to storage time. The curves of Fig. 3 are examples of τ_s as a function of collector current for typical switching transistors. Knowing the τ_s of a transistor at a specified collector current, the storage time t_s can be predicted from Fig. 2. For example, if $\tau_s = 10$ ns and $I_{B1}/I_{B2} = 2$, it is found from Fig. 2 that $t_s = 15$ ns.

Another important parameter is the reverse leakage current, I_{CBO}. This current almost doubles for every 10°C rise in temperature. The lower the value of I_{CBO}, the better the transistor approximates an ideal switch when the transistor is in the "off" state. With the high quality diffused-type transistors available, the reverse leakage current does not usually provide any problems except at very elevated temperatures.

Variation in transistor delays with collector current are shown in Fig. 4A. Over a wide range of collector current, the delays t_d, t_r, and t_f fall with increasing current and t_s rises somewhat with increasing current. In characterizing a device for switching performance, it must also be recognized that rise, fall, and storage times are functions of h_{FE} and BV_{CEO}. In general, as h_{FE} and BV_{CEO} increase, the storage time increases too. Further, high *beta*, high voltage, and fast switching speeds tend to be mutually exclusive. High *beta*, low voltage and low *beta*, high voltage come naturally.

For example, referring to Table 1, types such as the FT-709 and FT-1902 have few peers if speed is the sole criterion. However, both are 6-volt units and perform best in the 1-20 mA range. A more appropriate choice might be a type such as the 2N2369A or its *p-n-p* counterpart, the 2N5057. These devices perform best in the 10-100 mA

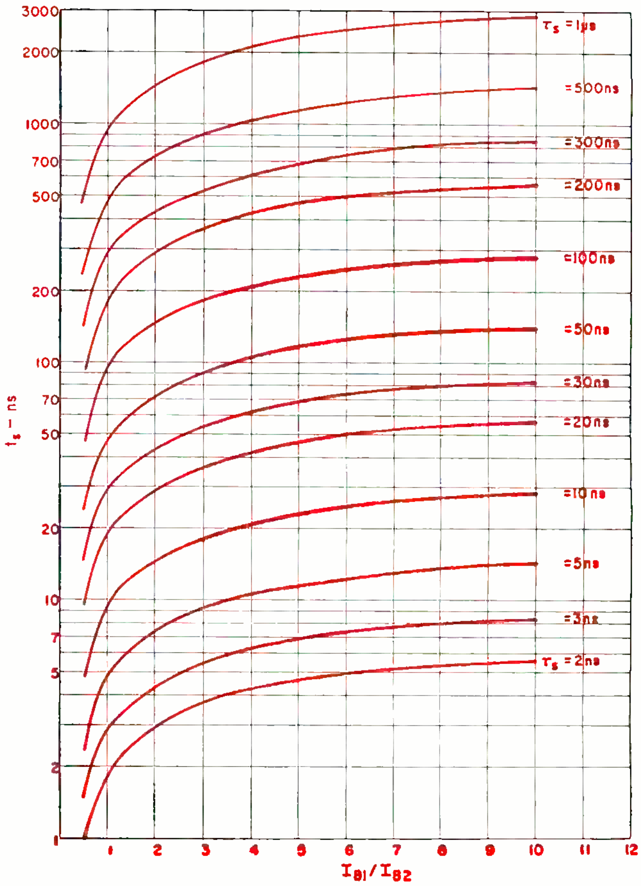
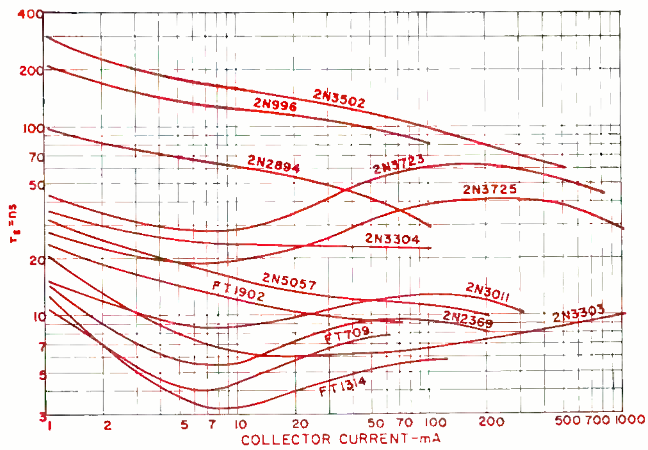


Fig. 2. Curves for predicting storage times of transistors.

Fig. 3. Variation of storage time constant as a function of collector current for a number of switching transistors.



range and have higher breakdown voltage ratings, but, of necessity, are somewhat slower, especially at low currents.

The important message to the user is not to insist on superlatives in all parameters. Devices that have such attributes are either non-existent or such a small part of the normal distribution that their price would be high and reproducibility in large quantities difficult. Part of the confusion is caused by the device manufacturers themselves. Two or three data sheets are often written for one basic product type. They usually represent different parts of the distribution, the most exotic device being the most expensive. What is often not visible to the user is that the price is high, not because the parameter limits are necessarily superior, but because the yield is low.

Making the Selection

The diffused transistor in its many forms is the transistor most commonly used for switching. These devices are fast and can be produced in large quantities at low cost. Where fast switching speeds are not important, alloy-type transistors can be used if they are cheaper than the diffused device. With some alloy switching transistors, —the saturation voltage $V_{CE(SAT)}$ is less than 50 mV, making them well suited for direct-coupled transistor logic.

In some high-speed switching circuits, germanium rather than silicon devices are employed. However, for conservative operation, the junction temperature of a germanium transistor cannot exceed 80°C; for silicon, the upper limit is 125°C.

The popularity of saturated switches stems largely from the fact that their average power dissipation is low and their design is fairly straightforward and predictable. However, everything is not in favor of the saturated switch. Storage time is a serious problem and in the saturation region, C_{ob} and f_T degrade quite severely.

The non-saturated switch avoids this degradation and storage time by keeping the operating point away from the saturation region. The net result is that devices such as the FK-1213 and FT-1711, especially designed for this operating mode, can have total switching (turn-on plus turn-off) times of less than 2 nsec. One of the prices paid is increased dissipation, a feature that tends to preclude use of non-saturated operation in integrated circuits. Current mode logic, which uses non-saturated switching, requires voltage level translators in the form of emitter-followers. Types like the FK-1213 and FT-1711 are used in this logic. These transistors are mirror-image devices and, when used together, level translation is not required.

Another mode of operation is avalanche mode switching. As the reverse collector-emitter voltage of a transistor is increased, a point is reached where the transistor begins to operate in the avalanche mode (Fig. 4B). This is similar in operation to a reverse-biased diode, such as a zener or reference diode. From Fig. 4B it is noted that after breakdown, a negative region exists, *i.e.*, as the collector voltage falls below BV_{CER}, the collector current rises. If a load resistance, R_L, is chosen so its load line intersects the negative-resistance region between points X and Y, the transistor is operating as an avalanche mode switch. The output voltage swing is $V_X - V_Y$ volts and extremely fast switching speeds (turn-on plus turn-off) of less than 1 nsec can be realized. However, the average device dissipation is greater than for conventional saturated and non-saturated modes of operation.

The FET and its kin, the MOSFET and IGFET, can also be used to advantage in some discrete switching applications. Chief among these is their use in choppers where their low offset makes them superior to junction transistors. In general, the field-effect transistor has not displaced the bipolar transistor primarily because of its relatively high "on" state dissipation and poorer switching speed.

DCTL	RTL	DTL	CML
Low $V_{CE(SAT)}$	High BV_{CEO}	Medium BV_{CEO}	High operating current
High $V_{BE(SAT)}$ with tight spread	High h_{FE}	Low C_{ob}	High collector dissipation
		Low τ_s	
Moderate h_{FE}	Low C_{ob}	Lower operating current than for RTL	Low C_{ob}
Low τ_s	Low τ_s		Low C_{TE}

Table 3. Important device requirements for transistor logic.

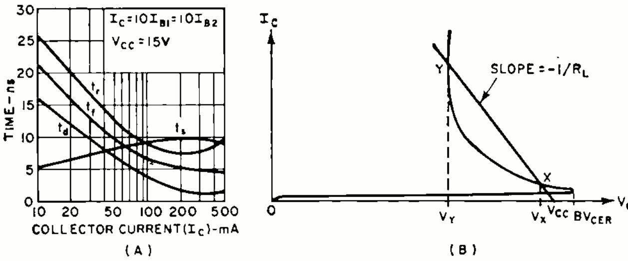


Fig. 4. (A) Dependence of transistor delays on collector current. (B) Operating region for avalanche mode switching.

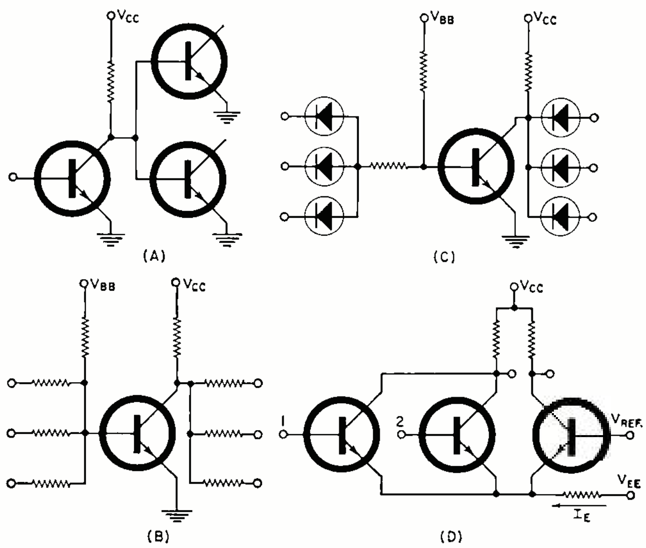


Fig. 5. Examples of transistor logic circuits shown here include (A) DCTL, (B) RTL, (C) DTL, (D) CML.

At high-power or high-voltage levels, the SCR starts to look attractive for power conversion applications. At lower levels, however, the commutation problems and poorer switching speeds give transistors a decided edge.

Transistor Logic Requirements

Different types of transistor logic circuits are realized by changing the coupling element between transistors. These coupling elements are either direct connections, resistors, diodes, or resistor-capacitor combinations. The four most popular logic forms used with discrete components are: DCTL (direct-coupled transistor logic), RTL (resistor-transistor logic), DTL (diode-transistor logic), and CML (current mode logic). Table 3 lists the important device requirements for these four forms of logic.

The breach between integrated and discrete logic circuits is widening. Passive elements with tight tolerances and dissimilar device characteristics are no problem for discrete components. These constitute formidable obstacles in integrated form and this has led to modification of these logic forms and to the evolution of completely different classes of logic.

In DCTL, the collector of one device couples directly to the base of another, as shown in Fig. 5A. Its advantages are: simplicity, minimum of components required, low cost, and the fact that only a single supply voltage is required. Its disadvantages include: low signal levels and therefore sensitivity to noise, strong dependence on uniform device characteristics, and switching speed limited by storage time.

Resistors perform the logic while the transistor serves as the inverter in RTL (Fig. 5B). For cascading purposes, the output is designed to be the same as the input side. This logic is relatively simple, low cost, less sensitive to variations in $V_{CE(SAT)}$ and $V_{BE(SAT)}$, and good noise immunity. On the minus side, RTL has low fan-in and fan-out capabilities, slow speed, and requires high signal voltage levels. A variation of RTL, RCTL uses a capacitor across the coupling resistors. This results in faster operation than RTL because the base sees a low impedance both during turn-on and turn-off and the delays are considerably reduced. However, noise immunity is poor and transient loading can be severe.

In DTL, the resistors used in RTL are replaced by diodes (Fig. 5C). This logic provides optimum use of available base drive by avoiding the current-shunting paths existing in DCTL and RTL. Also it has good noise immunity, fan-in capability, and is faster than RTL and DCTL. One disadvantage is that, in saturation, the bases of the following stages see a voltage equal to $V_{CE(SAT)}$ plus the diode voltage drop. This means that a larger turn-off current is required. What is more, it is also costlier than RTL.

The salient feature of CML is that it is the only logic of the four listed that is non-saturating. Referring to Fig. 5D, the emitter current, I_E, is relatively constant and is switched from one transistor to another as the signal to input 1, or 2, is varied. The variation in the input signal is with respect to the reference voltage, V_{REF}. CML is a very fast logic because it has no storage time, very good noise immunity, and a high fan-in. The price paid for this superior performance is high power dissipation and a requirement for level translation. In addition, many transistors are required, making the cost high.

Future Possibilities

Regarding performance, no major breakthroughs are anticipated in the near future. The market incentive is not there for low-level discrete applications; logic functions have been taken over by integrated circuits. Integrated semiconductor technology is particularly suited for producing large numbers of identical circuits with unprecedented reliability, making them naturally compatible with computer circuits.

In power applications, the discrete switch will remain on the scene longer because of the heat dissipation problem. In memory applications, for instance, device dissipation is considerable. There is a need for further improvements in discrete drivers for memory elements. As computers become faster, memory cycle times are reduced, thus imposing more stringent requirements on the switching times of the semiconductor drivers.

Increased automation and improved yields have already caused prices to drop steadily. Refinements in processes and other developments have greatly enhanced reliability. Prices will continue to drop because the semiconductor business is highly competitive and reliability will continue to improve largely because of the increasingly stringent demands of the military and large computer manufacturers. ▲

HIGH-VOLTAGE TRANSISTORS

WE tend to think of transistors as low-voltage devices even though some of the newer types reaching the market are capable of operating safely with approximately 1000 volts applied to them.

Advanced diffusion techniques, coupled with other proprietary operations, have enabled the M.S. Transistor Corp. to announce a new family of high-voltage silicon "n-p-n" transistors which includes the 2N5010 through 2N5015 (2-watt units), and MST-50 to MST-100 (also 2-watt units), and the MSP-50 to MSP-100 (5-watt units).

Operating voltage of the new transistors ranges from 500 to 1000, I_C reaches 500 mA, h_{FE} is between 20 and 180, and the transistors are capable of operation to 35 MHz. The MST-xx and 2N50xx series come in TO-5 cans, while the MSP version comes in an MD-14 case.

These new high-voltage transistors open many new areas formerly the sole province of the vacuum tube, for example, the relatively high-voltage deflection circuits for electrostatic CRT's. In addition, many conventional circuits can now be extended. In the case of these transistors, they can be operated from a 120-, 240-, or 480-volt a.c. power line and require only a full-wave rectifier and capacitor filter. They would also be useful as EL panel drivers as the devices can be used to drive the essentially capacitive loads by running class-A stages in series push-pull configurations.

In the area of consumer electronics, the Delco Radio Division of GM Corp. has announced its high-voltage transistor (DTS-0714) having a V_{CEX} of 1200 volts, $V_{CE(SUS)}$ of 750 volts, linear current gain (h_{FE}) at 2.5 amperes of 10 minimum, and a reverse voltage (V_{EBO}) of 5 volts.

The new silicon, triple-diffused, mesa transistor has been used in switching the 3800 volt-ampere load of a 25-inch color-TV horizontal sweep deflection circuit.

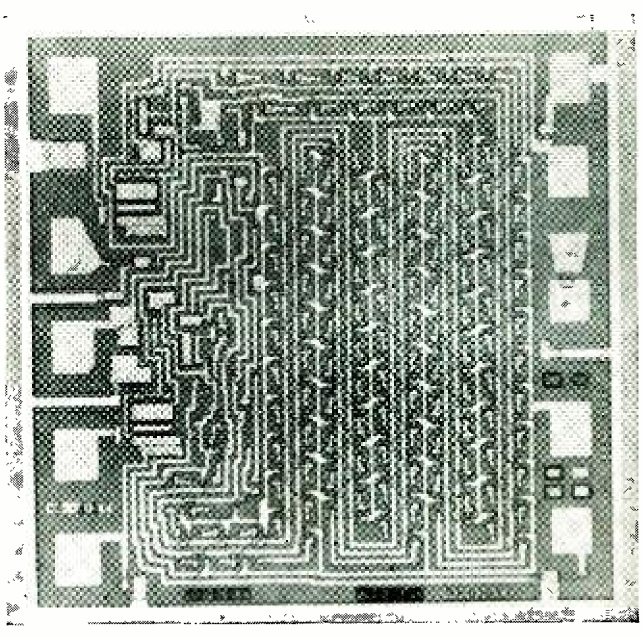
In the TV circuit, a 1050-volt pulse is transformed in the flyback transformer to 25 kV for use by the CRT. The horizontal output transistor switches about 4 amperes during this operation, and is protected from arcing by a diode and RC network.

The transistor, which replaced a pair of 700-volt types used previously (DTS-402), and a vacuum tube before that, is presently available in a strip-mounted epoxy package. ▲

HOW MANY TRANSISTORS?

THE chip shown below, although designed as an integrated circuit, dramatically illustrates the density attained by modern diffusion techniques. The chip is 58 mils square and, as shown, only a portion of it is used for the 415 "p"-channel enhancement-mode transistors.

Fabricated by General Instrument's Microelectronics Division, the chip is a 64-bit serial accumulator capable of operation to 5 MHz. The company is presently embarking on a program having an expected density of up to one million transistors per square inch. They have already produced devices having 250,000 transistors per square inch. ▲



JOHN FRYE

Solid-state devices have materially changed amateur radio equipment, and even greater improvements appear imminent.

HAM RADIO AND SEMICONDUCTORS

WHEN thunder from the July storm started to roll, Mac and Barney grounded the antennas, opened the service bench switches, and started for the front office to comfort Matilda, the office girl, who was deathly afraid of thunder and lightning. Just as they stepped through the door there was a blinding flash of light followed almost immediately by a snapping sound and a great bellow of thunder.

"To quote Thomas Hardy: 'How can such a heavenly light be the parent of such a diabolical sound?' " Matilda asked with a nervous giggle. "Why don't you two talk about electronics? That always quiets my nerves. In fact, it usually bores me so much sleep comes as a defense mechanism."

"Always glad to oblige a lady," Barney replied, perching himself on a corner of her desk. "Mac, I've been wanting to talk to you about the love affair hams have with semiconductors. Right from the beginning, those two have gone together like guitars and folksingers, and you don't need a crystal ball to see a lot more conventional and exotic semiconductors in the future of ham radio."

"It's not hard to understand why hams would take to solid-state diodes and transistors," Mac mused. "For one thing, the tiny size of these devices goes along with the modern trend toward more compact and lighter amateur radio gear. I can remember a few years back when a kilowatt ham transmitter was a truly impressive affair, occupying two six-foot racks and weighing upwards of half a ton. But the days when a ham could take over a spare upstairs bedroom or the basement for his ham shack are going fast. The average small, functional, modern house doesn't *have* a spare bedroom; and if there is a basement, it's likely serving as a playroom or bar. Today's ham has to make do with a corner of the living room, den, bedroom, or even the kitchen. To meet his needs, the modern kilowatt radio station has been compressed until it fits neatly on a table top and weighs less than a hundred pounds."

"You're right, of course, but it's only fair to say that the switch from AM to SSB transmission accounts for much of this saving in weight and size. In that kilowatt AM station you were talking about, one of those six-foot racks held speech amplifier and modulator equipment, together with the husky power supply needed for the latter. Getting rid of the modulator cut the size of the transmitter in half. Since an SSB transmitter need not supply a power-consuming carrier, it imposes much less demand on the power supply. Current peaks drawn under modulation are of very short duration so that the average demand on the power supply, even when the transmitter is inputting 2 kW p.e.p., is modest."

"I know," Mac said. "I never cease to marvel at how those table-top linears can get around 3000 volts out of a transformer only slightly larger than the power transformer for a color-TV receiver. Of course, I know it's done by using voltage-doubling circuits employing series-connected silicon rectifiers. You certainly couldn't do it if you had to use mercury-vapor 866's for rectifiers. Their filament transformer alone would take up more space than all the silicon diodes and would weigh a whopping lot more."

"Silicon and germanium diodes replace bulky tubes lots of other places in SSB transmitters and receivers," Barney said. "They are used as audio rectifiers in the vox and anti-trip circuits and in the balanced modulators that suppress the carrier, and as r.f. rectifiers in the automatic level-control circuits that limit drive to the linear amplifiers so as not to exceed what the amplifier can handle in a linear fashion. A diode rectifies a sample of the r.f. output and feeds it to a milliammeter to provide an r.f. output indicator. Other diodes provide a.g.c. voltage for the receiver or transceiver. Zener diodes provide voltage regulation of critical low voltages in the vox and other circuits."

"How about transistors? Are hams making much use of them?"

"So far, they have used transistors chiefly outside the station receiver and transmitter. The first uses were for code practice oscillators and mike preamplifiers, including speech clipping and limiting circuits. But lots of hams have been experimenting with flea-power transistorized transmitters and with transistorized communications receivers. As far as completely transistorized transmitters are concerned, the chief stumbling block has been a lack of reasonably priced transistors that can efficiently handle a couple of hundred watts input up to 30 MHz. I know there are transistors that can do this, but they are not available to hams, at least not at a price they can afford. While I keep hearing rumors about other solid-state transceivers on the drawing boards, as far as I know there is only one amateur-band transceiver on the market that is completely transistorized—except for the final amplifier tubes."

"Well, how about receivers? We have plenty of transistors that can handle any power requirements there."

"True, but again there are drawbacks—or have been until very recently. The ordinary transistor is essentially a small-signal device. When one is used in the r.f. stage of a communications receiver, it will do a fine job of amplifying weak signals *until* a nearby ham fires up a full gallon on the same band. Then his signal overloads the input of the transistor with resulting cross-modulation that does an excellent job of swamping out the weak station. If that weak station happens to be a rare ZA in Albania or a YI in Iraq, the ham is likely to be very disturbed—to put it mildly!"

"I suppose you're thinking about the FET and its ability to handle both strong and weak signals as the answer to this problem."

"Right you are, and I see no reason why an excellent, fully transistorized amateur receiver cannot be built right now. It would have many advantages, including such things as small size, light weight, practically no generation of heat, indefinite transistor life as opposed to comparatively short-lived tubes, resistance to shock and vibration, and simple power-supply requirements that could be easily and eco-

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nomically met by batteries for mobile or portable operation."

"Well, I'll hazard a guess that if U.S. manufacturers don't get on the stick and come out with something like this at a reasonable price soon, they will be scooped by the Japanese."

"You can say that again. I think the Japanese are beginning to eye the ham market the way they did the CB market, and we both know what they did there in the way of transistorized transceivers. Quite recently, I've run across several DX stations who say they are using Japanese-made ham equipment. One thing is sure: the number of Japanese amateurs is increasing rapidly. It used to be you had to listen long and hard to hear a JA station, but now just about any time I point my beam northwest I hear Nippon stations coming in on ten, fifteen, or twenty meters—and with darned good signals, too. Some of the fellows on the islands out in the Pacific complain that the Japanese are beginning to swamp them out the way U.S. hams monopolize the bands in this hemisphere."

"These things sound like straws in the wind to me," Mac said. "We have long produced most of the manufactured ham equipment, probably because the great majority of the world's radio amateurs are located in this country. In no other country has the home ham market been large enough to warrant the research and development necessary for producing this highly specialized equipment. Now, with the ham populations of other countries on the rise and with Americans' ready acceptance of imported electronic equipment, this may be changed."

"Hey, that brings up an interesting chat I had with a ham in The Netherlands the other morning. He suggested that the number of active hams in a country compared to its total population was a good index of that country's electronics know-how and its ability to produce electronic gear. He pointed out the high percentage of hams in England, West Germany, Japan, and the United States as examples."

"He may have something there. We both know that the electronics industry has always displayed an interest in amateur radio that goes beyond that segment's being an important market for electronic products. Take a look at the applications section of any diode, transistor, grid-controlled rectifier, or integrated-circuit manual, and you will find several strictly ham suggestions. And hams return the compliment. Practically every one of their magazines has a regular semiconductor column, or something similar, in which new semiconductor devices are introduced or circuits involving semiconductors are described. In addition, ham magazines often carry full-length feature articles describing the use of semiconductors in ham gear written by top men involved in the production, research, and development of solid-state devices. This is not surprising, considering how many of these people have ham radio for a hobby."

"That brings up an important feature of solid-state devices. They lend themselves to experimenting, home construction, and kit construction. Transistorized gear is almost invariably assembled on a printed-circuit or Vector board. You don't need a machine shop to bend chassis, punch socket holes, or cut out heavy metal areas as you ordinarily do when building equipment using tubes. What's more, since distributed capacitances are easily duplicated with this type of construction, you can build a piece of equipment from an article and expect equivalent performance. The use of IC's is going to make this even more true. No wonder hams who like to build and experiment are in love with transistors!"

"Okay; let's not get carried away. How do you picture transistorized ham equipment of the future?"

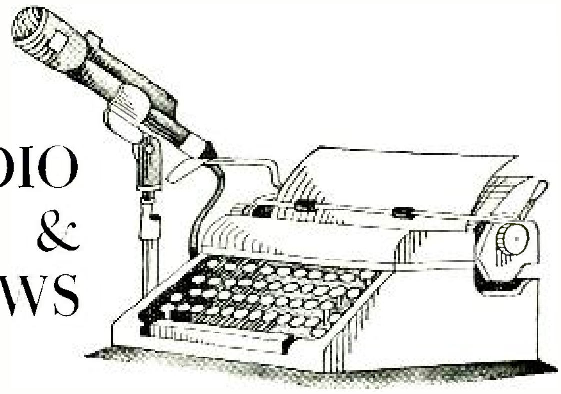
"Well, there's a limit to how much you can reduce the panel area of a ham transceiver. No matter how small the components behind that panel, you still need room to mount all the controls, jacks, dials, and meters necessary for operation. The panel of my present transceiver carries fifteen of these components. Since many controls require a comparatively close adjustment, the knobs cannot be made too small. The tuning dial, for instance, has to be large enough for fine adjustment and for comfortable operation hour after hour. The meter and frequency indication must be large enough for easy reading. So I see the ham transceiver of the near future as not much smaller in height and width but greatly reduced in depth.

"The use of FET's and IC's will produce better, more sophisticated, more trouble-free equipment. The lower voltages required by transistors and their lack of heat generation will greatly reduce component failure. Mobile operation, already stimulated by SSB, will increase even more when solid-state transceivers with their low current requirements are in widespread use. We may still have to use compact ceramic-type tubes in high-powered linears, but medium-power transmitters and exciters will be fully transistorized and will take up much less space than today's equipment—"

His voice trailed off as he nodded to Matilda, sound asleep with her head resting on her folded arms on her desk, oblivious to the intermittent growls of thunder from the retreating storm.

"I thought she was kidding!" he said in a hoarse whisper to Mac. ▲

RADIO & TV NEWS



THE engineers at *Television Manufacturers of America* have a gripe, and it is a real one judging by the experience of others.

After visiting a number of color-TV demonstration showrooms, they (and we) noticed that reception in multi-set demonstrations of large dealers often leaves much to be desired.

According to the *TMA* chief engineer, "Poor tuning of sets on the showroom floor creates as much sales resistance as anything, including the high price of color sets.

"The colors run together, and often the purity and convergence are so poor that colors are quite the opposite of what viewers know they should be . . . in many cases, every figure is surrounded by a reddish halo.

"Big dealers by their very bigness are particularly vulnerable to this problem. They often tend to have too many sets playing at one time to pay attention to each set's fine tuning (and color setup). Thus, a customer sees a variety of colors for the same program."

Many potential customers who overlook bad showroom quality in monochrome sets, seem to know instinctively that the set is not at fault, but balk at buying when the same trouble shows up in a color set demonstration. There are two reasons for this. First, the main attraction of color-TV is color itself. If the customer is not impressed, he sees no reason to change from monochrome. Second, a small percentage are convinced that color is still too primitive. Both views are mistaken, but poor quality in a demonstration set tends to support each belief.

Portable VTR

The *Ampex Corp.* recently demonstrated a battery-powered portable video tape recorder measuring 23 by 13 by 6 inches and weighing only 35 lbs. In its attaché-type case, the unit is mounted on a back pack to enable on-the-spot video tape recordings to be made by news agencies. The new VTR can record up to 20 minutes of action on an 8-inch reel and is compatible for direct re-broadcast over conventional studio tape decks.

A companion camera weighing 13 lbs. complete with its own electronic view-finder is also included in the package. A built-in clock keeps the operator aware of remaining recording time.

Laser Activities

Engineers at *GT&E* recently demonstrated a liquid laser about as thick as a fountain pen and six inches long capable of generating a burst of light energy equivalent to one million watts (10,000 hundred-watt light bulbs).

In this new laser, the medium is formed by dissolving neodymium (a rare earth) in selenium oxychloride (an inorganic compound). The whole process takes about ten minutes to complete. An external flash tube provides the excitation for the laser.

In another use of the ubiquitous laser, scientists at *TRW* Systems Group are using laser holography to record microscopic phenomena moving a few millionths of an inch in less than one millionth of a second. The flights of fruit flies (gnats) and bullets have been "stopped" at 100 billionths of a second and recorded on a 4 x 5 inch photographic plate. And, for the first time, a photographic portrait was taken of a mixture of air and acetylene the instant it was detonated by a spark.

Both *TRW* and other agencies are exploring the possibility of many new breakthroughs because of this new technique. Of course, all images made using the hologram technique are three-dimensional.

Canine Detection

While other countries are looking towards electronics as a means of detecting buried ore deposits, a small item in the Soviet journal *Razvedka i Okhrana Nedr* (Exploration and Conservation of Resources) seems to bear looking into.

It seems that the Soviets now have canine comrades that have been trained to sniff out ore deposits buried under seven feet of earth. These animals are also capable of detecting some ores at even greater depths.

It is assumed that in the vast, still unexplored areas of Central Russia, dogs are easier to come by than batteries. ▲

Neutralizing the Cascode Amplifier

By LEE R. BISHOP

Using a conventional signal generator instead of a noise generator to adjust this widely used front end circuit for minimum noise within its passband.

THE cascode circuit is a two-stage vacuum-tube triode amplifier that has the gain and stability of a pentode but the noise figure of a triode. It is almost universally used in u.h.f./v.h.f. communications gear, radar receivers, and quality TV sets as an r.f. or i.f. amplifier. A basic version of this circuit as commonly found in front-end stages is shown in Fig. 1.

The plate circuit of the first triode amplifier ($V1$) works into the extremely low impedance presented by the cathode circuit of $V2$ and is loaded heavily enough to give a first-stage gain of unity or less. This severe loading provides sufficient damping to completely eliminate any possibility of oscillations in the first stage.

First-stage stability notwithstanding, a neutralizing coil (L_n) is invariably included in most cascode circuits because the amplifier noise figure is greatly improved when the grid-to-plate capacitance of the first stage is neutralized at the center frequency of its passband. Neutralizing coils with a "Q" in the vicinity of 200 have been found to provide the best noise figures. When a receiver alignment is being performed, one adjustment that is not made with gain or passband in mind is that of the inductance of L_n. This coil is adjusted for best amplifier noise figure with the aid of a noise generator.

Such instruments, however, are not common, but conventional signal generators are. By employing a variation of the familiar neutralizing procedure used in transmitter tuning, a conventional signal generator can be made to substitute for a noise generator and enable a respectable job of cascode-amplifier neutralization for best noise figure to be performed.

Method Used

Neutralization is accomplished by disconnecting the cathode lead from the tube socket of the first cascode stage ($V1$) and injecting to the input a c.w. or amplitude-modulated signal at the operating frequency of the cascode circuit. Strong signals can pass from the first to the second stage through the grid-to-plate capacitance of $V1$. If the cascode circuit has been properly neutralized, however, L_n will form a parallel resonant circuit with the grid-to-plate capacitance of $V1$. This circuit should be resonant at the amplifier center frequency; consequently, minimum signal will appear at the output of the cascode circuit. If a v.t.v.m. or some other sensitive indicating device is connected to the output of the cascode circuit, this minimum will show up as a rather broad dip in amplifier output when the signal generator is tuned through the frequency of interest. If the dip does not occur at the proper frequency, the signal generator should be tuned to the required center frequency and L_n adjusted for minimum output.

The actual point in a complete receiver used to detect the dip will depend upon the sensitivity of the device that is employed as an indicator. To prevent the effect of the i.f. response of succeeding stages from obscuring the dip, it should be detected as close to the output of the cascode amplifier as possible. The optimum point for detection would be $J2$, but because of sensitivity limitations in practical detecting equipment, the dip will normally have to be detected two or three stages of amplification after $J2$.

If large numbers of amplifiers were to be neutralized quickly by this method, a special tube with its cathode pin clipped off could be used. The clipped-pin technique, however, will not produce nearly as good an alignment because of the variation in tube capacitance found in actual practice. ▲

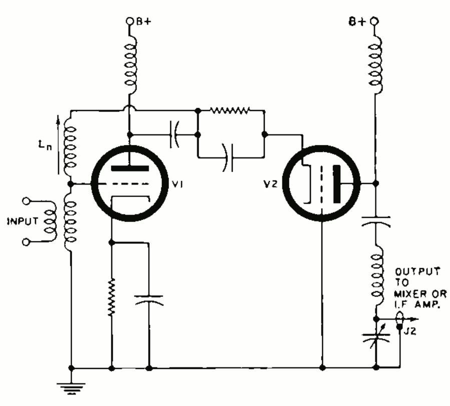


Fig. 1. Basic arrangement of a cascode circuit showing neutralizing coil L_n.

Static Electricity
(Continued from page 23)

Anti-Static Sprays. These sprays apply a chemical coating which forms a conductive surface. The anti-static agents can be incorporated directly into plastics; liquid household bleach bottles often include such agents since merchandisers have found that dust-covered packages are a sales handicap.

Drag Chains. Years ago, safety engineers thought that drag chains on gasoline trucks would bleed dangerous static charges back to the road as fast as they were generated. Now the National Fire Protection Association says that a drag chain is ineffective for this purpose when the road is dry, and it is not needed when the road is wet.

Helicopter Static Discharger. Friction from air currents can cause helicopters to acquire a static electricity charge which may be quite dangerous: it can cause volatile flammable liquids on board to explode or cause explosives on military aircraft to accidentally ignite.

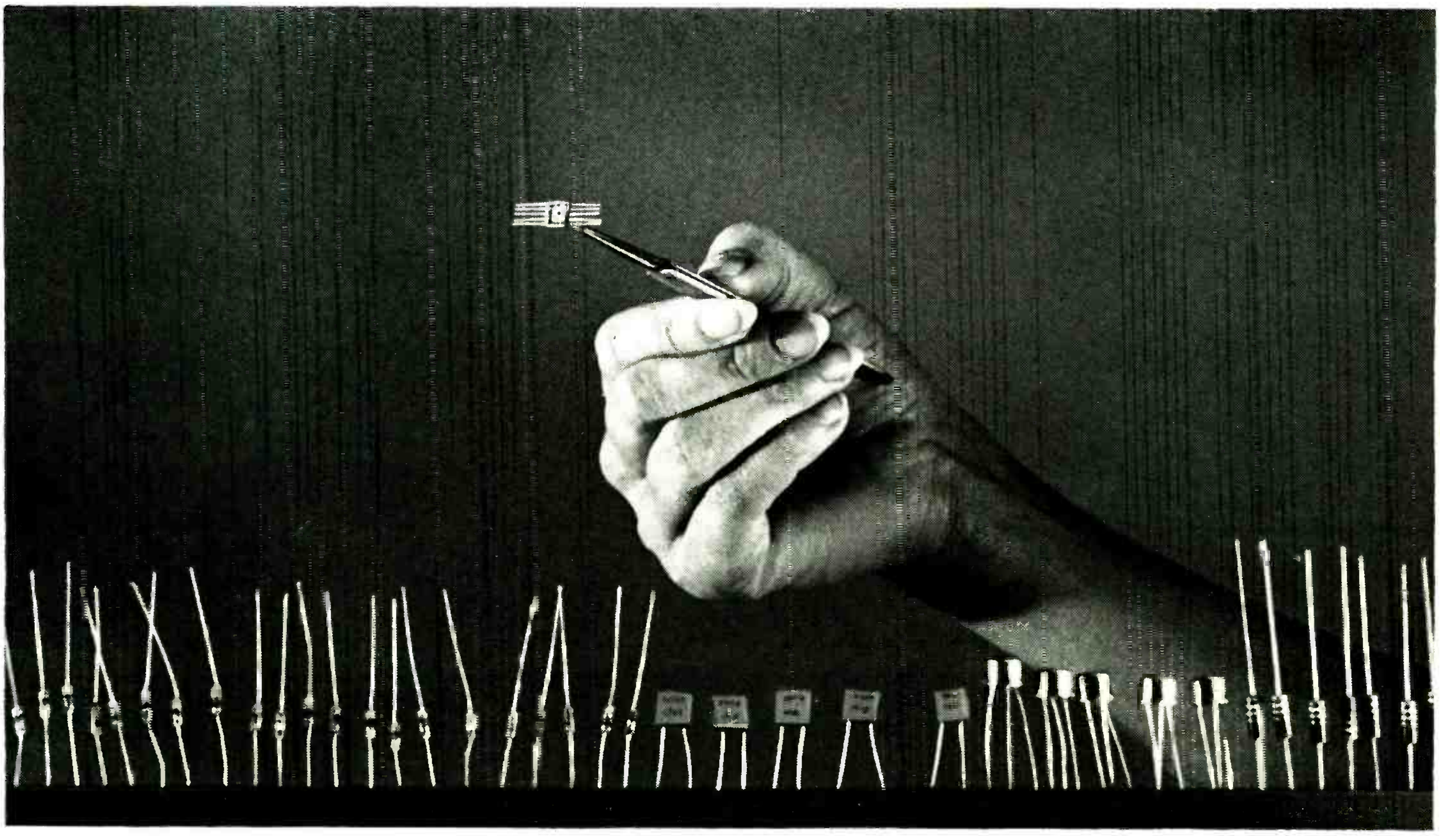
Dynasciences Corporation has developed an aircraft static electricity discharging system which has effectively eliminated these hazards. With this system, a low-voltage unit senses the charge on the helicopter and its polarity, amplifies and compensates this signal, and, depending upon the polarity of the charge on the helicopter, drives either a positive or negative high-voltage generator in order to compensate for the charge.

Advantages of Static Electricity

With all its faults, can anything good be said about static electricity? Yes. It can definitely be put to work in electrostatic painting systems and in Van de Graaff generators which are used in atomic research.

In electrostatic painting, paint droplets are given an electrostatic charge as they pass through an atomizer. Since the paint then tends to converge on the item to be painted, it simplifies the job of painting the back sides of cylinders and knobs. Also, very little of the paint is lost in the process; some electrostatic paint installations claim that paint consumption is 30% that of a standard painting installation.

The Van de Graaff generator consists of a belt traveling over plastic rollers, a charge source, and a metal sphere. Charges are carried up the belt to the sphere where they collect; negative charges come back down the belt. The larger the sphere, the greater the voltage that can be obtained. Conversely, the smaller the sphere, the smaller the possible voltage. Such generators are widely used in research laboratories. ▲



50 functions in a single chip. *The functions of 50 separate transistors, diodes, resistors and capacitors can now be formed by the tiny dot in the center of the integrated circuit held by the tweezers.*

The "Chip"

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THE DEVELOPMENT OF INTEGRATED CIRCUITRY is the dawn of a new age of electronic miracles. It means that many of today's job skills soon will be no longer needed. At the same time it opens the door to thousands of exciting new job opportunities for technicians solidly grounded in electronics fundamentals. Read here what you need to know to cash in on the gigantic coming boom, and how you can learn it right at home.

TINY ELECTRONIC "CHIPS," each no bigger than the head of a pin, are bringing about a fantastic new Industrial Revolution. The time is near at hand when "chips" may save your life, balance your checkbook, and land a man on the moon.

Chips may also put you out of a job...or into a better one.

"One thing is certain," said *The New York Times* recently. Chips "will unalterably change our lives and the lives of our children probably far beyond recognition."

A single chip or miniature integrated circuit can perform the function of 20 transistors, 18 resistors, and 2 capacitors. Yet it is so small that a thimbleful can hold enough circuitry for a dozen computers or a thousand radios.

Miniature Miracles of Today and Tomorrow

Already, as a result, a two-way radio can now be fitted inside a signet ring. A complete hearing aid can be worn entirely inside the ear. There is a new desk-top computer, no bigger than a typewriter yet capable of 166,000 operations per second. And it is almost possible to put the entire circuitry of a color television set inside a man's wrist-watch case.

And this is only the beginning!

Soon kitchen computers may keep the housewife's refrigerator stocked, her menus planned, and her calories counted. Her vacuum cleaner may creep out at night and vacuum the floor all by itself.

Money may become obsolete. Instead you will simply carry an electronic charge account card. Your employer will credit your account after each week's work and merchants will charge each of your purchases against it.

When your telephone rings and nobody's home, your call will automatically be switched to the phone where you can be reached.

Doctors will be able to examine you internally by watching a TV screen while a pill-size camera passes through your digestive tract.

New Opportunities for Trained Men

What does all this mean to someone working in electronics who never went beyond high school? It means the opportunity of a lifetime—if you take advantage of it.

It's true that the "chip" may make a lot of manual skills no longer necessary.

But at the same time the booming sales of articles and equipment using integrated circuitry has created a tremendous demand for trained electronics personnel to help design, manufacture, test, operate, and service all these marvels.

There simply aren't enough college-trained engineers to go around. So men with a high school education who have mastered the fundamentals of electronics theory are being begged to accept really interesting, high-pay jobs as engineering aides, junior engineers, and field engineers.

How To Get The Training You Need

You can get the up-to-date training in electronics fundamentals that you need through a carefully chosen home study course. In fact, some authorities feel that a home study course is the best way. "By its very nature," stated one electronics publication recently, "home study develops your ability to analyze and extract information as well as to strengthen your sense of responsibility and initiative." These are qualities every employer is always looking for.

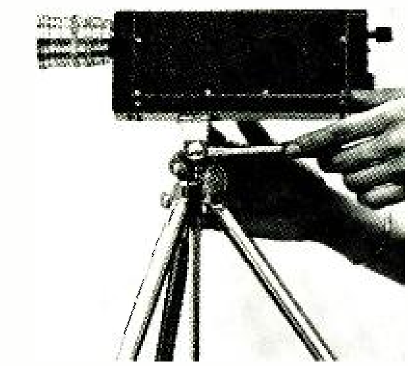
If you do decide to advance your career through spare-time study at home, it makes sense to pick an electronics school that specializes in the home study method. Electronics is complicated enough without trying to learn it from texts and lessons that were designed for the classroom instead of correspondence training.

The Cleveland Institute of Electronics has everything you're looking for. We teach only electronics —no other subjects. And our courses are designed especially for home study. We have spent over 30 years perfecting techniques that make learning electronics at home easy, even for those who previously had trouble studying.

Your instructor gives your assignments his undivided personal attention—it's like being the only student in his "class." He not only grades your work, he analyzes it. And he mails back his corrections and comments the same day he gets your lessons, so you read his notations while everything is still fresh in your mind.

Always Up-To-Date

Because of rapid developments in electronics, CIE courses are constantly being revised. Students receive the most recent revised material as they progress through their course. This year, for example, CIE students are receiving exclusive up-to-the-minute lessons in Microminiaturization, Logical Troubleshooting, Laser Theory and Application, Single Sideband Techniques, Pulse Theory and Application, and Boolean Algebra. For this reason CIE courses are invaluable not only to newcomers in Electronics but also for "old timers" who need a refresher course in current developments.



Tiny TV camera *for space and military use is one of the miracles of integrated circuitry. This one weighs 27 ounces, uses a one-inch vidicon camera tube, and requires only four watts of power.*

Praised by Students Who've Compared

Students who have taken other courses often comment on how much more they learn from CIE. Mark E. Newland of Santa Maria, California, recently wrote: "Of 11 different correspondence courses I've taken, CIE's was the best prepared, most interesting, and easiest to understand. I passed my 1st Class FCC exam after completing my course, and have increased my earnings $120 a month."

Get FCC License or Money Back

No matter what kind of job you want in electronics, you ought to have your Government FCC License. It's accepted everywhere as proof of your education in electronics. And no wonder—the Government licensing exam is tough. So tough, in fact, that without CIE training, two out of every three men who take the exam fail.

But better than 9 out of every 10 CIE-trained men who take the exam pass it.

This has made it possible to back our FCC License courses with this famous Warranty: you *must* pass your FCC exam upon completion of the course or your tuition is refunded in full.

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All CIE courses are available under the new G.I. Bill. If you served on active duty since January 31, 1955, or are in service now, check box on reply card for G.I. Bill information.

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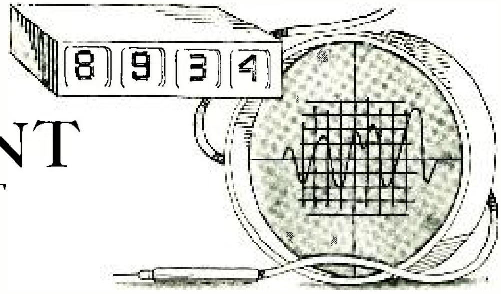
PRODUCT REPORT



Fairchild Model 7050 Digital Voltmeter

For copy on manufacturer's brochure, circle No. 36 on Reader Service Card.

ONE of the hits of the recent IEEE Show in New York was the compact digital voltmeter just introduced by *Fairchild Instrumentation.* The meter is easily held in the palm of one hand; it measures only about 6 inches wide by 3 inches high by 7 inches deep and it weighs just under 4 pounds. More impressive than this, however, is the price. The meter costs only $249 in quantities of 25 or more, or $299 in quantities of 1 to 4. The main reason for the small size and low price (for a DVM) is the use of the company's integrated circuits in the instrument.

The Model 7050 is a "3½-digit" meter. This indicates that there are three full decades, each with its indicator digit, plus a fourth digit indicating an overrange of 50%. The fourth digit is either a "0" or a "1" so that the instrument is able to give a full-scale readout of 1500 volts with no loss of accuracy.

The meter has four d.c. voltage ranges, from 1.5 volts to 1000 volts full scale, plus five resistance ranges, from 1500 ohms to 15 megohms full scale. External current shunts are available for current readings.

The accuracy of the instrument is ±0.1% of reading, ±1 digit for d.c. voltage measurements. Accuracy of resistance measurements is somewhat lower.

The instrument is rugged, easy to operate and read, and was designed to replace conventional analog meters and panel indicators as well as more expensive digital voltmeters. It is suitable for production, general test, servicing, and educational applications.

Using the dual-slope technique (as described on page 64 of our May, 1967 issue), the Model 7050 combines the noise-rejection capabilities of integration with the accuracy and stability of automatic comparison to an internal standard. Fast response time is assured by its speed of six measurement samples per second. The meter has an input impedance of greater than 1000 megohms, a floating input which may be operated 500 volts above ground, and readout storage providing a non-blinking display. ▲

Bird Model 6155 R.F. Wattmeter

For copy of manufacturer's brochure, circle No. 37 on Reader Service Card.

THE Model 6155 is a dual-range absorption-type r.f. wattmeter. It is a portable instrument designed for direct output power measurements of radio transmitters up to 150 watts from 50-ohm coaxial transmission lines. It is intended for general field or laboratory service use on c.w., AM, and FM modulation envelopes, but not pulsed modes. The instrument is also useful for line-loss measurement and for checking coaxial insertion devices. Modulation may be monitored across the meter terminals or fed to the scope directly from the d.c. jack with meter disconnected (for higher audio signal levels). When used in 50-ohm applications, it has a termination v.s.w.r. of less than 1.1:1 from 2 to 30 MHz.

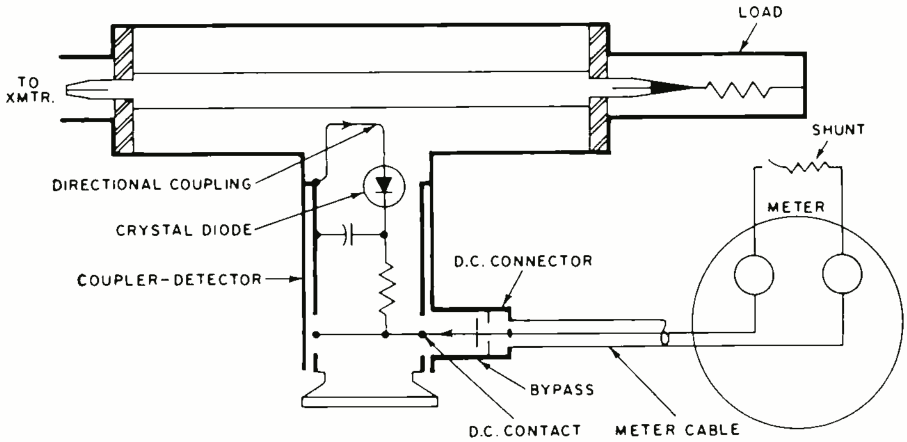
When series (I^2R current) or tangential thermal-type devices are used for r.f. power measurement, calibration adjustments or charts are required for accuracy. Series devices, when inserted in the line, introduce resistive and reactive components which disturb the uniform impedance above the milliwatt level. (At signal-generator power level, a compensating network may be incorporated to match the line impedance. This is impractical at higher power because the resistive elements would become large and cumbersome.)

The major problem encountered with shunt measurement techniques is the design of a voltage divider which will maintain a constant ratio at all r.f. frequencies for which the wattmeter is intended. Basically, there are three types of shunt dividers: resistive, inductive, and capacitive.

Of the three, the capacitive divider is best because it remains purely capacitive over a very wide frequency range. Since X_c increases as capacitance is reduced, the high values of reactance needed to divide the r.f. line voltage to less than a volt are easily obtained with small values of capacitance. However, as frequency is decreased, capacitance must be increased. The lowest frequency of measurement

finally limits further size reduction, or *vice versa*: a physically practical capacitive divider limits power measurement to frequencies above 25 MHz.

An excellent technique for r.f. power measurement would be a capacitive divider coupled with a current-sensing loop. It would permit accurate measurement at lower frequencies without adjustments or references to charts. The new *Bird* Termaline® r.f. wattmeter utilizes this technique. (See diagram.) A special coupler-detector samples the r.f. energy from the traveling waves present in the detector block by both mutual inductance and capacitance. The inductive loop length is a small



fraction of a wavelength at the operating frequency, making the loop, for all practical purposes, a lumped-constant *L*. The capacitive coupling is accomplished with a plate on top of the loop. This sampling system does not interfere with either line impedance or the traveling waves and exhibits uniform response over the frequency range of the wattmeter. The r.f. energy extracted by the coupling circuit is rectified, filtered, and displayed on a sensitive meter calibrated directly in watts, with a full-scale accuracy of ±5%.

The Model 6155 measures power under non-radiating conditions (transmitter output feeding into wattmeter only). The wattmeter includes a coaxial load resistor immersed in a dielectric coolant enclosed within a finned radiator. Fastened to the radiator is the meter housing which may be removed to permit remote meter readings. The scale is direct-reading in watts and is expanded at lower levels to increase legibility. A slide switch on the front face of the sloped meter case selects either the 0-50 or 0-150 watt range.

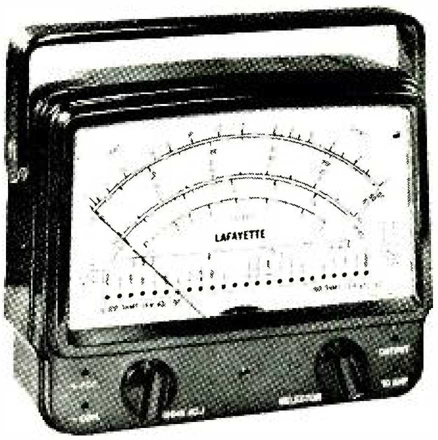
The r.f. input connector is a patented "quick-change" female "N" which permits easy interchange with other "QC" connectors without the use of adapters. The price of the Model 6155 is $215 with one "QC" connector. ▲

Lafayette 99-5065 Volt-Ohm-Milliammeter

For copy of manufacturer's brochure, circle No. 38 on Reader Service Card.

In spite of the emergence of compact, low-cost digital voltmeters, the conventional analog-type v.o.m. remains the most versatile and widely used piece of test equipment. In those large numbers of cases where the 2% or 3% accuracy of this type of instrument is entirely adequate, it is hard to beat the analog meter, especially where price is considered.

The new *Lafayette* Stock No. 99-5065 "Lab-Tester" v.o.m. is an imported instrument with several unique features. First, it has the very high (for a v.o.m.) input resistance of 100,000 ohms volt, which means that it has a higher input resistance than does a conventional v.t.v.m. on ranges over 100 volts. Second, the meter has a single, unmarked 24-position selector switch to change ranges and function. As this switch is rotated, the range and function of the instrument are "flagged" by means of a colored marker in one of the small windows located below each range-function marking. In this way, the user can tell what range he is on without removing his eyes from the large, 6½-inch scale meter face.



The switch itself is interesting from a mechanical point of view. It is a special 4-pole, 24-position unit with all its contacts arranged in a straight line. The wiper is a chain-driven, trolley-like assembly which moves in a straight line across the entire width of the meter, carrying the indicator flag with it. Side-by-side recesses in the switch housing contain individual multiplier and shunt resistors in a most accessible arrangement.

The meter movement used is a sensitive 9-μA, 135-mV type with double-diode overload protection. The instrument can measure a.c. and d.c. voltages up to 1000 volts, d.c. current up to 10 A, and resistance up to 100 megohms.

The instrument case has a stiff carrying handle that can be used to tilt it up for easy reading. Price is $14.95. ▲

Challenges in SST Program

(*Continued from page 27*)

conditions, which was standard in the early days of commercial air transportation, has generally declined but still remains with us. Systems now ready for adoption by the airlines enable departures and arrivals under weather conditions which until now were considered too hazardous for civil transport. A system which allows for safe take-off and landing under any weather conditions has not yet been developed. A "hands-off" take-off and landing, that is, one without aid of human control, appears a desirable goal. This accomplishment requires a complex system that brings together the techniques previously mentioned (autopilot, DME, CAS) as well as navigation. The U.S. Navy has already demonstrated that an aircraft can be landed "hands-off"—a jet fighter has been successfully brought down aboard an aircraft carrier without benefit of guidance by the pilot.

Navigation Problems

The problems of air navigation become more prominent as planes cruise at faster speeds. Less time is permitted for course changes to avoid storms or for other reasons. Present weather radars have a range of approximately 150 miles. This range must be increased to at least 350 miles for use on the SST. The weather-radar dome must have low attenuation for transmitted and received r.f. energy and at the same time must be capable of withstanding the high temperatures of the aircraft skin. The SST cruising altitude of 60,000 to 70,000 feet means that fewer storms will be encountered, just as today's jetliners cruising at 30,000 to 40,000 feet avoid the lower altitude storms, but weather radar remains as an important system.

For course navigation, the SST will borrow the inertial guidance concept long in use aboard space vehicles. A redundant system will be employed, providing back-up subsystems if one subsystem fails. More precise fixes of aircraft position will result in operating economies for the user. Here again, electronics appears to hold the key to improved performance.

Two concepts underlie all the ideas that have been discussed: the notion of system reliability and system maintainability. Beyond the importance of reliability in insuring the safe conduct of aircraft operations, there is an economic implication. If the airlines are to operate the SST profitably, the availability of the airplane must be high. "Downtime" for the SST will mean higher costs to the carrier than is the case for today's aircraft. Hence, downtime must be minimized. Maintainability now enters the picture. The systems must be quickly repairable and possess the ability to be maintained with long time intervals between servicings. A self-diagnosing system, one that not only indicates a failure but also points to where the failure has occurred, is a worthwhile goal. Some electronic computers already have some measure of this capability.

Instrumentation System

Related to maintainability is the instrumentation system of the SST. In addition to the usual instruments for recording flight parameters, a means for monitoring critical performance characteristics would provide information useful in maintenance planning. At least one such system is already in use. Since March, 1965, *Eastern Airlines, Garrett-AiResearch,* and *IBM* have been operating AIDS (Aircraft Integrated Data System). Additional airlines, both foreign and domestic, have since placed orders for AIDS.

A step beyond AIDS is AMAS (Airborne Maintenance Analysis System). The AMAS would not only record data, as AIDS does, but would also transmit this information in real time for analysis by a ground station. AMAS could thus provide a warning to the pilot of impending trouble while the airplane is in flight. If a serious failure appears imminent, the pilot could land his craft at the first opportunity, preventing a critical situation.

The piloting of a huge jet aircraft requires a high degree of skill, particularly during landing and take-off. If the pilot is not to be overburdened with a maze of instruments and controls, he must be supplied with a well-designed man/machine interface. This refers to the link between the controller and the controlled. Electronics can lessen the burden of the pilot's task by providing instrument displays that are easily read and hence quickly transmitted to the mind of the operator. The use of TV cameras to monitor wheel position during taxi is an example of such a display. A moving-map indicator, showing the aircraft superimposed upon a map of the local geographic region, can also provide "quick look" information. Proper layout of the instrument panel and placement of controls can also do a great deal to prevent pilot fatigue and reduce the possibility of pilot error in operation.

From our discussion, it should be clear that electronics has much to do with the planned success of the SST program. Many of the problems facing us are not unique to the SST. The aircraft/airline industry in general will profit by new developments in electronic systems. The public will benefit by having rapid, safe, low-cost transportation available. The industry has been given the challenge, and we have every reason to believe the challenge will be met. ▲

Troubleshooting Integrated Circuits

(*Continued from page 36*)

with $D5$ and $D6$ operating as capacitors and R11 and R12, act as a conventional discriminator. The two-stage audio preamplifier consists of Q11 and Q12.

By comparing Figs. 6 and 7, it is immediately apparent that certain defects can occur in the IC chip itself which will affect either one of the two sections or, possibly, both. Although the entire IC may have to be replaced, it is still important for the technician to know in which stage the defect occurs. The reason for this is that a defect in the discriminator transformer, the input transformer, or any of the external bypass capacitors could cause a loss of output signal.

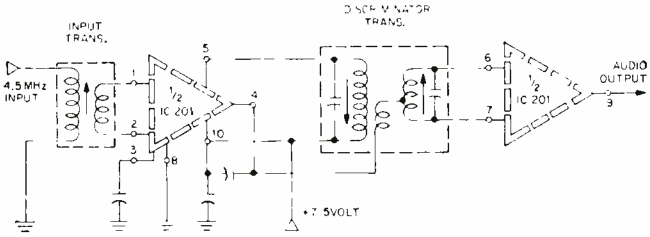


Fig. 6. Interconnections for the integrated circuit used in set.

It is interesting to see how *RCA*'s troubleshooting instructions are directed towards testing everything else before the IC itself is tackled. Referring to the block diagram of Fig. 5, the manufacturer first suggests injecting an audio signal at the input of the transistor driver stage to make sure that the transistor section, the output transformer, and the speaker are all functioning normally. If audio is present at the speaker, the company recommends injecting a 4.5-MHz FM signal at the video detector. A probe is connected to the audio output terminal, 9, of the IC. If audio can be seen on the scope, it is assumed that the IC and its associated components are good. Next the volume control and the wiring to the transistor driver stage would have to be checked. If, however, the scope does not show a suitable audio signal, the IC and its associated components must be suspected.

To facilitate troubleshooting, the manufacturer provides a voltage chart in the service data which requires a v.t.v.m. and, in some instances, a scope. On terminals 5, 6, and 7, for example, the scope should show a peak-to-peak voltage ranging between 4 and 6 volts. *RCA* points out that improper bias readings on pins 1, 2, 4, or 5 might be caused by defects in the input or the discriminator transformer. The manufacturer does not suggest unsoldering the leads of the discriminator transformer to check its resistance because this would require removing the transformer from its printed-circuit mounting, a procedure which is quite involved and which can easily damage the terminals or printed wiring.

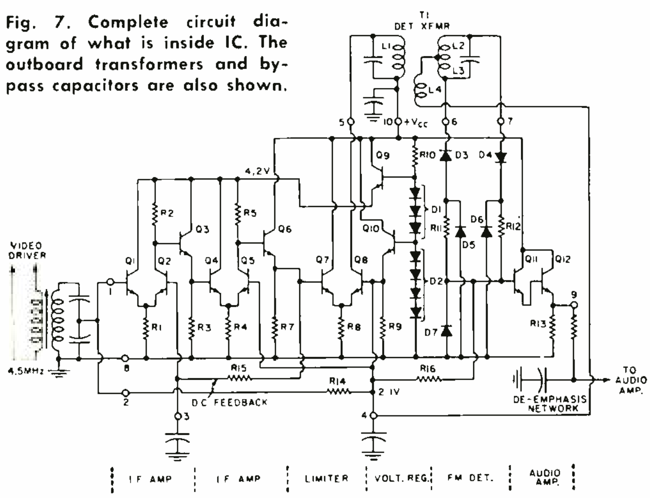


Fig. 7. Complete circuit diagram of what is inside IC. The outboard transformers and bypass capacitors are also shown.

The manufacturer's troubleshooting instructions end with a warning that all outboard or external components associated with the IC should be checked individually before changing the IC itself. If it is necessary to replace the IC, a soldering iron with a suction bulb is recommended for removing the solder from the pins in order to be able to insert the pins of the replacement IC without too much difficulty or damage to the circuit.

But is it Practical?

The reader will ask, with some justification, whether or not the above troubleshooting instructions are really practical and efficient. If any of the parts associated with the IC fail, the troubleshooting procedure will be much longer than would be the case if vacuum tubes or transistors were used.

One simple approach to the problem posed by the circuits shown in Figs. 6 and 7 would be to connect a low resistance, such as 50 ohms, across terminals 1 and 2 and another one across terminals 5 and 10. These four terminals are available at the input and the discriminator transformer, and the two resistors can be tacked to them. Next, we connect a 50-ohm signal generator (operating at a suitably low level) to the input, preferably at 4.5 MHz but some other convenient frequency can be used because the tuned circuits are shunted by 50 ohms. The scope, with a high-gain preamplifier, is connected across the 50-ohm resistor at the primary of the discriminator transformer and we can now measure the gain of the amplifier portion of the IC.

Unfortunately, the manufacturer's data does not indicate the amount of gain that can be expected in that stage with a 50-ohm load. Even without a detailed specification, however, we can assume that the voltage ratio would indicate that the amplifier is operating correctly. Next, the signal generator would be connected directly across the discriminator transformer primary with the oscilloscope connected across the secondary.

We can expect a reduction in amplitude but we should not expect a total absence of signal at the secondary of the discriminator transformer. When the signal generator is tuned to 4.5 MHz with an FM modulation of at least ±7.5-kHz deviation and a 4.5-MHz signal is observed at the secondary, the next check is to see whether audio is obtained at the output of the IC. If audio is not obtained at the stage, the IC itself must be assumed to be defective and the defect will of course be in the FM detector and audio section of the IC. Should the external bypass capacitors be defective, this will also become apparent during this troubleshooting procedure.

To avoid soldering the two 50-ohm resistors temporarily across the transformer terminals, a still simpler test procedure could be used. The 4.5-MHz frequency-modulated signal could be inductively coupled to the input transformer and another inductively coupled probe could detect its presence in the discriminator transformer. Once the relative signal amplitudes are known, it is simple to determine whether the amplifier functions or not. Next the signal generator would be inductively coupled to the discriminator transformer and the audio output monitored. This troubleshooting method is even more rapid than the one just discussed but requires that a properly designed inductive coupling scheme be available for the signal generator as well as for the scope probe.

"It takes more technical knowledge to troubleshoot IC's and use the test equipment effectively than it took to replace tubes or simply make a few volt-ohm-milliammeter measurements."

The use of sweep generators with low-impedance outputs and calibrated output attenuators, together with suitable scope probes and high-gain, wide-band oscilloscopes makes even more efficient and versatile troubleshooting techniques possible. Testing of capacitors in the circuit is possible by using calibrated pulse generators together with a good scope. Pulse circuits, such as used in the sync section of TV receivers and color-demodulator circuits can be tested without unsoldering leads by using more sophisticated test equipment. These techniques will be covered in detail in Part 2.

For efficient color-TV servicing, a wide-band, high-gain scope; a crystal-controlled sweep generator; and a color bar generator are essential. For efficient audio servicing we also need a well-calibrated signal generator, an oscilloscope, and, possibly, a distortion analyzer. Many technicians have managed to run service operations with much less than this minimum of bench equipment by using the trial-and-error method of troubleshooting. As long as they could locate most defects with v.o.m. measurements and occasional transistor substitution, they were able to repair most sets. With the advent of IC's, however, quality test equipment is absolutely essential to successful servicing. As will be shown in next month's article, a number of adapters and fixtures will be needed to permit present signal sources and scopes to be used for IC work.

Needless to say, it takes more technical knowledge to troubleshoot IC's and use the test equipment effectively than it took to replace tubes or simply make v.o.m. measurements.

(Concluded Next Month)

SOLID-STATE IMAGE SCANNER

UNLIKE the vidicon or orthicon, the scanistor produces image dissection without the use of electron beams. Although at present only a laboratory curiosity, the scanistor may be the first of a line of semiconductors that may eventually lead to a solid-state TV camera.

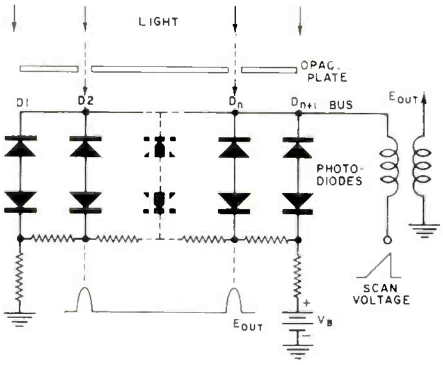
Although the physics of the device is beyond the scope of this article, a simplified schematic is shown in Fig. 1.

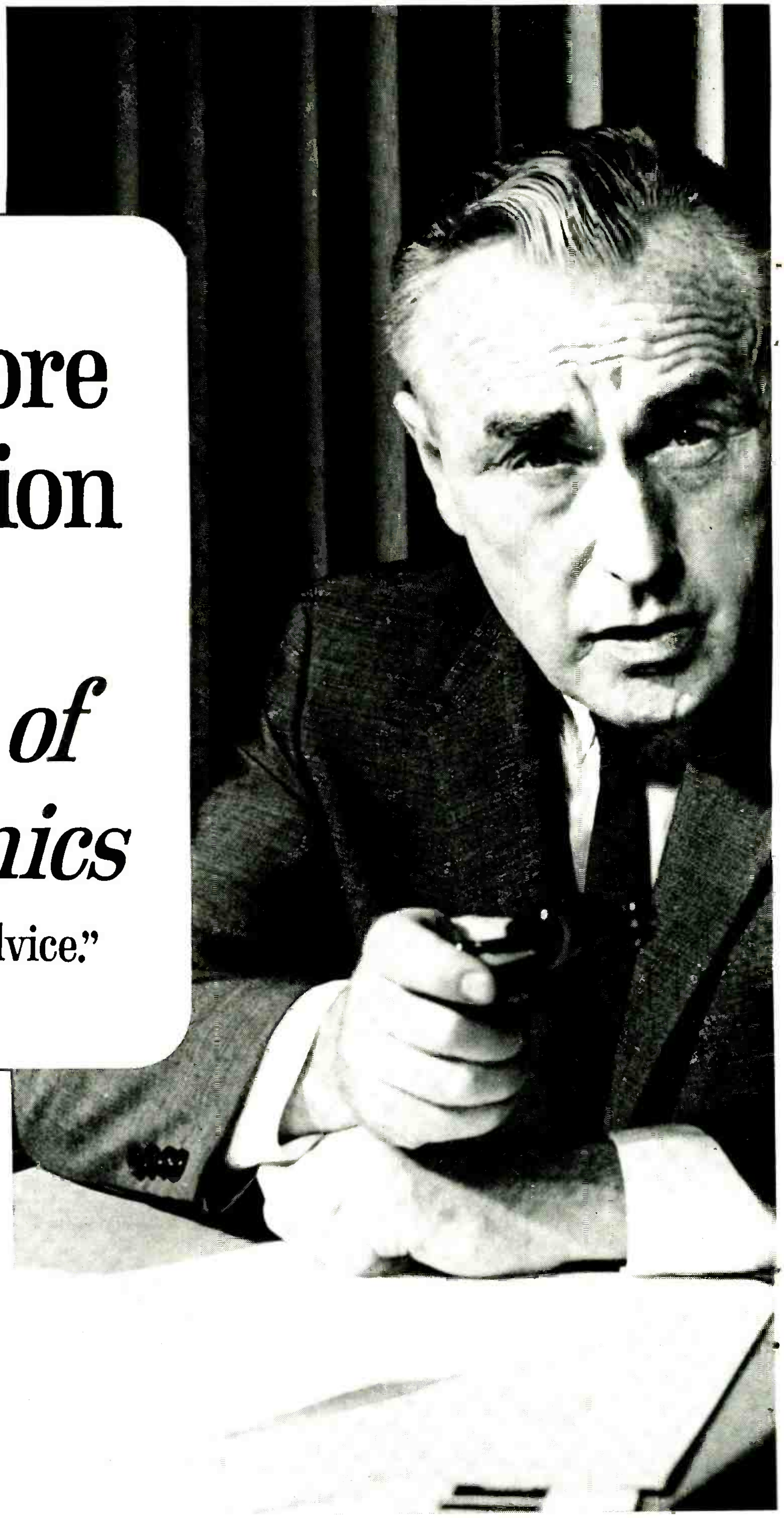
Assume that the photodiodes are arranged in a row with one end connected to a bus line and the other end connected down a resistive network. Depending on the level of V_B, each diode pair will see a different voltage between V_B and ground, so that each pair is back-biased out of operation. If the voltage applied to the upper bus comes from a ramp voltage generator, and if that voltage sweeps from ground to the level of V_B, that means that during each scan interval, each pair of photodiodes will, in turn, have the same voltage on both ends (null) enabling it to conduct for the period of time that it is nulled, with an amplitude dependent on the level of light impressed on it. The null point is swept across the photodiodes at a velocity dependent on the ramp shape.

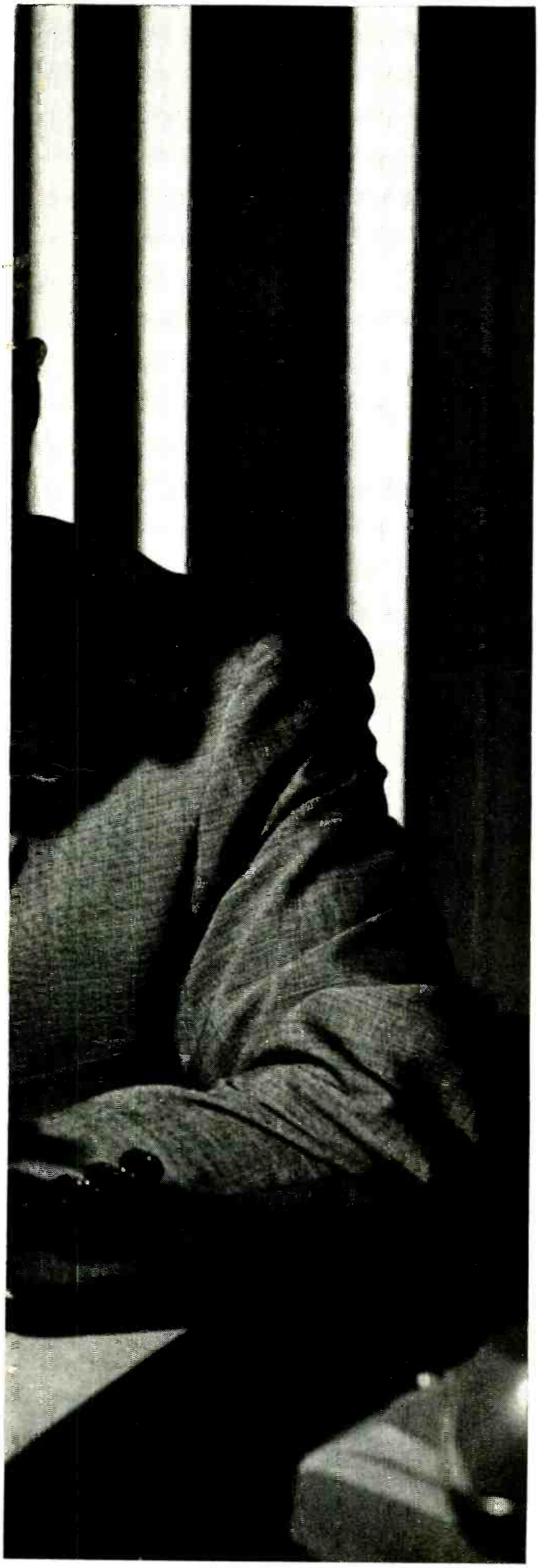
As shown in Fig. 1, assume that an opaque plate having two holes is placed between the photodiodes and the light source. Under this condition, D_1 is dark, D_2 is illuminated, D_n is illuminated, and D_{n+1} is dark. As the ramp null sweeps from ground to V_B and each photocell pair is nulled in turn, there will be an output only from diodes D_2 and D_n.

Research is currently under way to produce a solid-state photo mosaic to improve the resolution of the system. Some experimental devices have been made that show great promise in scanning a typewritten document for facsimile display on an oscilloscope. ▲

Fig. 1. Basic operation of the scanistor. As the ramp voltage produces a null down the line of photodiodes, the output is a function of which diodes are illuminated.







Ask any man who really knows the electronics industry. Opportunities are few for men without advanced technical education. If you stay on that level, you'll never make much money. And you'll be among the first to go in a layoff.

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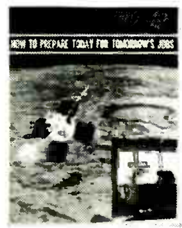

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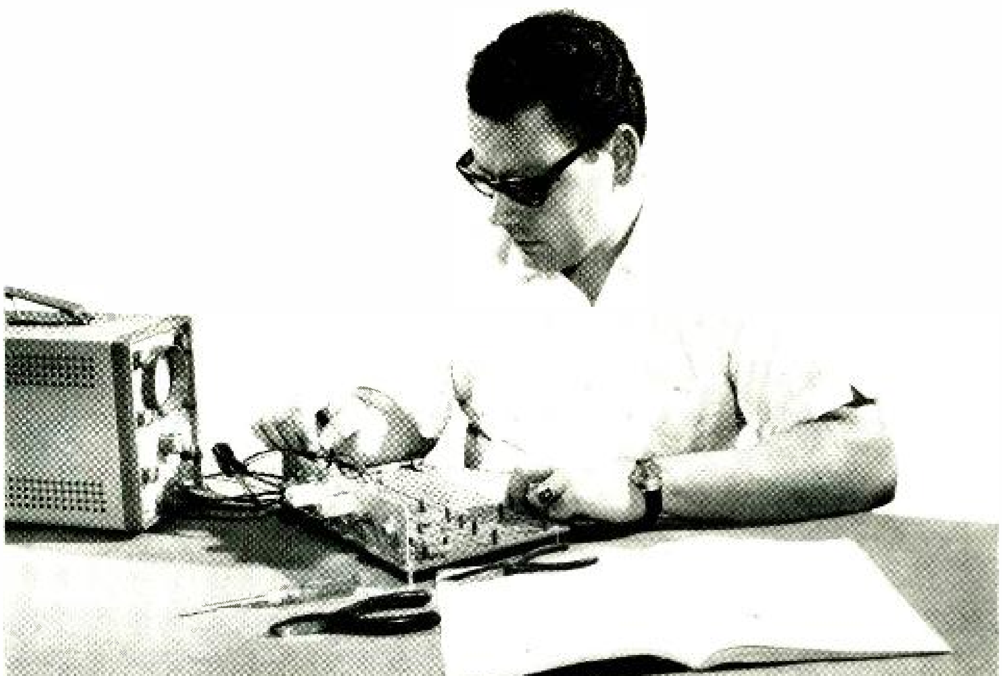

Performing transistor experiments on programmed breadboard — using oscilloscope.

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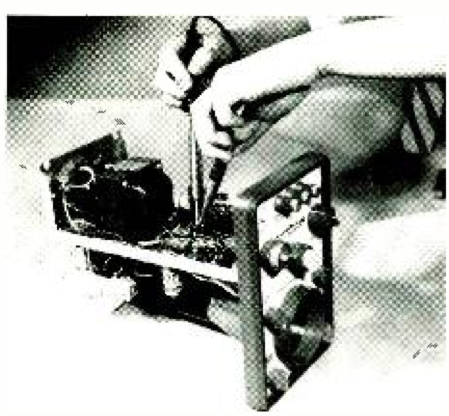

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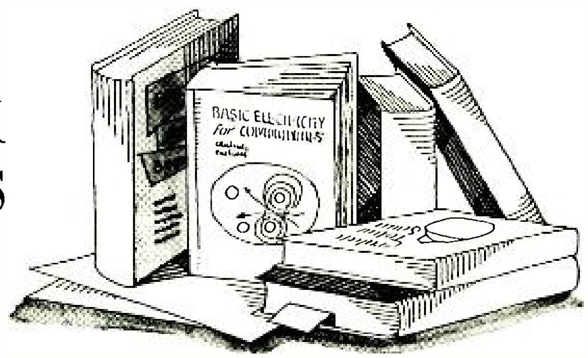

"RCA SILICON POWER CIRCUITS MANUAL" compiled and published by *RCA Electronic Components and Devices,* Harrison, N.J 412 pages. Price $2.00. Soft cover.

Although this new technical manual (SP-50) has been prepared especially for circuit and system designers who work with solid-state power devices, there is much information which will also be of interest to students, hams, and others using semiconductor devices and circuits.

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The text is lavishly illustrated by line drawings, schematics, and graphs.

* * *

"MODERN CONTROL SYSTEMS" by Richard C. Dorf. Published by *Addison-Wesley Publishing Company, Inc.,* Reading, Mass. 01867. 379 pages. Price $12.50.

This textbook has been written for college seniors and others with a comparable technical background. It covers the analysis and design of feedback control systems in industry and in the laboratory, as would be encountered by electrical, mechanical, aeronautical, and chemical engineers.

The text is divided into ten chapters and five appendices. Chapter 1 provides an introduction to control systems and the book then goes on to cover mathematical models of systems, feedback control system characteristics, the performance of feedback control systems, the stability of linear feedback systems, the root locus method, frequency response methods, stability in the frequency domain, time-domain analysis of control systems, and the design and compensation of feedback control systems. The appendices include Laplace transform pairs, symbols and units, conversion factors, an introduction to matrix algebra, program transition, and an evaluation of the transition matrix of a linear time-invariant system by means of a computational algorithm. References for further study are appended to each chapter.

Since this book is directed to a specific audience who presumably have the prerequisite background, there has been no attempt to "pamper" the reader. Mathematics is used throughout and the author has assumed his readers are familiar with the operations.

* * *

"MICROWAVE SYSTEMS PLANNING" by K.L. Dumas & L.G. Sands. Published by *Hayden Book Company, Inc.,* New York. 138 pages. Price $8.00.

The ever-increasing needs of the communications industry — because of the burgeoning requirements of industry and business—has stimulated interest in point-to-point FM systems. This book has been prepared for non-technical personnel who must make decisions regarding the planning, engineering, and installation of microwave equipment used for communications purposes.

The terminology and symbols used are telephone-oriented and, where required, are explained by the authors. The book starts with a discussion of the theoretical aspects—from frequency and wave theory to hardware—then continues to an investigation of the practical aspects of setting up a microwave system.

The text is well illustrated by photos of equipment, line drawings, graphs, nomograms, and charts. Mathematics is used where required but anyone with a knowledge of simple algebra will be able to handle the equations.

* * *

"G-E SCR MANUAL" edited by F.W. Gutzwiller. Published by *Semiconductor Products Dept., General Electric Company,* Syracuse, N.Y. 496 pages. Price $3.00. Soft cover.

This is the Fourth Edition of what has turned out to be a "bestseller" among *G-E* manuals, and marks the tenth "anniversary" of the introduction of the SCR in 1957.

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This Fourth Edition includes much new information, new chapters on triacs, regulating circuits and motor controls and specifications on hundreds of new higher-performance thyristors. In addition, there are several chapters devoted to other power semiconductors and light-activated thyristors.

The table of contents is extremely comprehensive—combining as it does an index with the contents—enabling the user to locate the exact material he needs. The text is well illustrated, concise, and complete—making this a real bargain for the reference library of anyone interested in electronics.

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"BASIC MATHEMATICS FOR ELECTRONICS" by F.L. Juszli, N. Mahler, and J.M. Reid. Published by *Prentice-Hall, Inc.,* Englewood Cliffs, N.J. 439 pages. Price $12.00.

If you have a working knowledge of arithmetic you can use this book to obtain the skills you require to work with electric circuit problems. Since no background in electricity is prerequisite, chapters on electrical fundamentals are inserted at key points throughout the text—permitting the user to learn about the behavior of electric circuits at the same time he is studying the related mathematics.

The text can be used in connection with an electrical course at the first-year technical school level or used alone. There are 18 chapters, each with a large number of "exercises" for the students to work. The answers are provided for self-checking. The appendices provide common log tables, natural trigonometric functions, schematic symbols used in circuit diagrams, and electric symbols to make this volume as self-contained as possible.

* * *

"FUNDAMENTALS OF VACUUM-TUBE AMPLIFIERS" condensation of the U.S. Navy Training Manual in the "Fundamentals of Electronics" series. Published by *Techpress, Inc.,* Brownsburg, Ind. 46112. 303 pages. Price $3.95. Soft cover.

This condensation of a popular Navy manual involves pertinent material on triode amplifiers, tetrode and pentode amplifiers, paraphase amplifier circuits, and audio power amplifiers as well as data on microphones and speakers.

Since the excerpted material is all audio-oriented, this volume will be useful to audiophiles and hi-fi enthusiasts as well as students. For instructional purposes there are problems at the end of each chapter which can be used as class assignments. Answers are not provided for the do-it-yourself student, however. ▲

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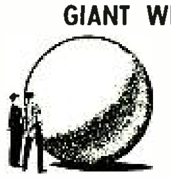

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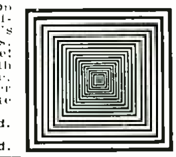

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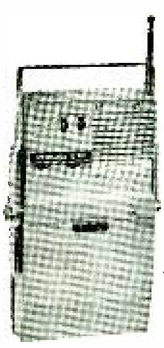

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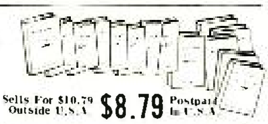

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200	.20	.60	1.50	7.50
400	.25	.80	2.00	15.00
600	.35	1.20	2.50	20.00
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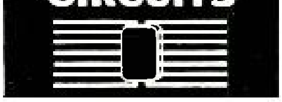

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400	.20
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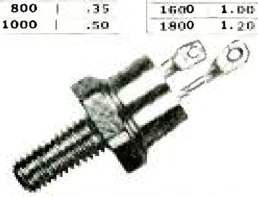
800	.35
1000	.50

Top Hat & Epoxy 750 MA

PRV	
100	.07
200	.09
400	.12
600	.20
800	.25
1000	.50
1200	.65
1400	.85
1600	1.00
1900	1.20



Silicon Control Rectifier #7A

Silicon Control Rectifiers

PRV	3A	7A	20A
50	.35	.50	.80
100	.50	.70	1.35
200	.75	1.05	1.90
300	1.25	1.60	2.45
400	1.50	2.10	2.85
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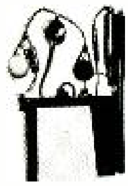

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8.0	22	51		120
9.1	24	56		130
10	27	62		150
12	30	68		160
[illegible]	33	75		180

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200	39¢	1000	79¢
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AMPS	50 PIV	100 PIV	200 PIV
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15	27c	40¢	65¢
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100	48	70	1.05	1.20
200	70	1.05	1.30	1.70
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500	1.60	2.80	3.00	3.30
600	1.90	3.00	3.30	3.90

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ELECTRONICS WORLD JULY 1967

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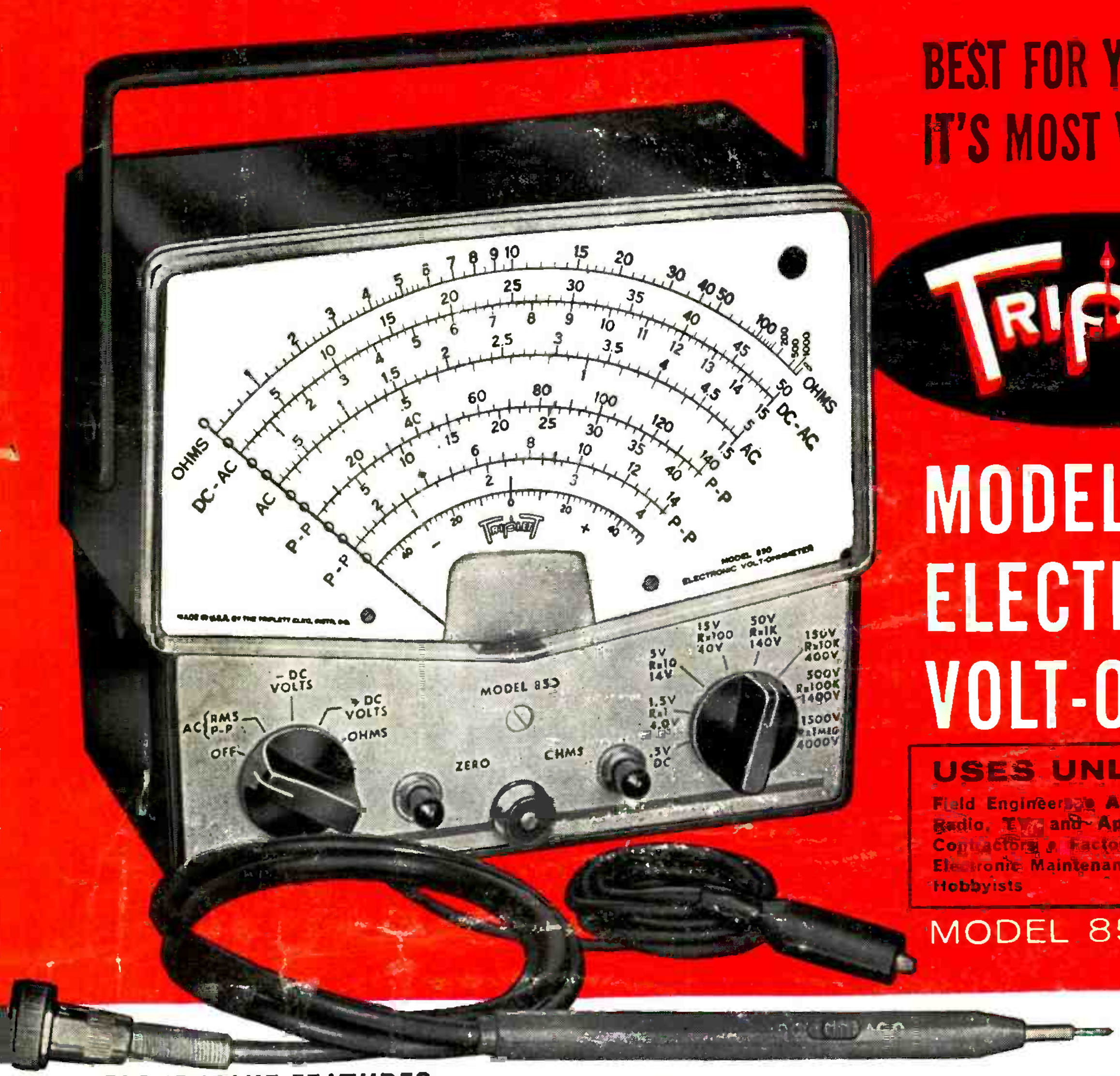

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Case 859—OP—Black leather Padded Carrying Case. $22.00 Net

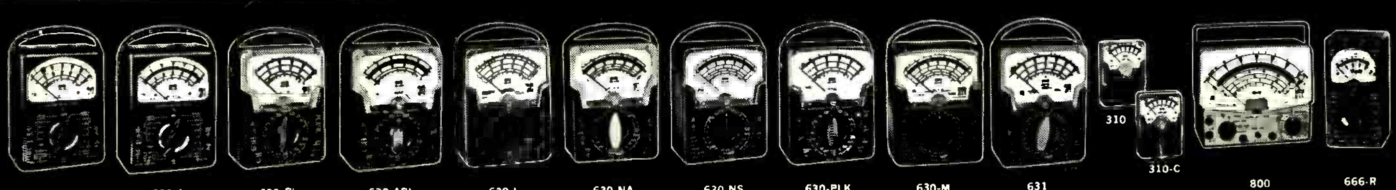
RANGES

8 DC VOLTS RANGES	0-.5-1.5-5-15-50-150-500-1500
7 AC RMS VOLTS RANGES	0-1.5-5-15-50-150-500-1500
7 PEAK-TO-PEAK VOLTS RANGES	0-4-14-40-140-400-1400-4000
7 RESISTANCE RANGES	0-1000-10,000-100,000 OHMS; 1-10-100-1000 MEGOHMS.

FREQUENCY RANGE 15 CPS to 3MC; (Up to 250 MC with accessory diode probe available extra.)

INPUT IMPEDANCE DC Volts 11 Megohms; AC Volts minimum of .83 Megohms.

TRIPLETT ELECTRICAL INSTRUMENT COMPANY, BLUFFTON, OHIO



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