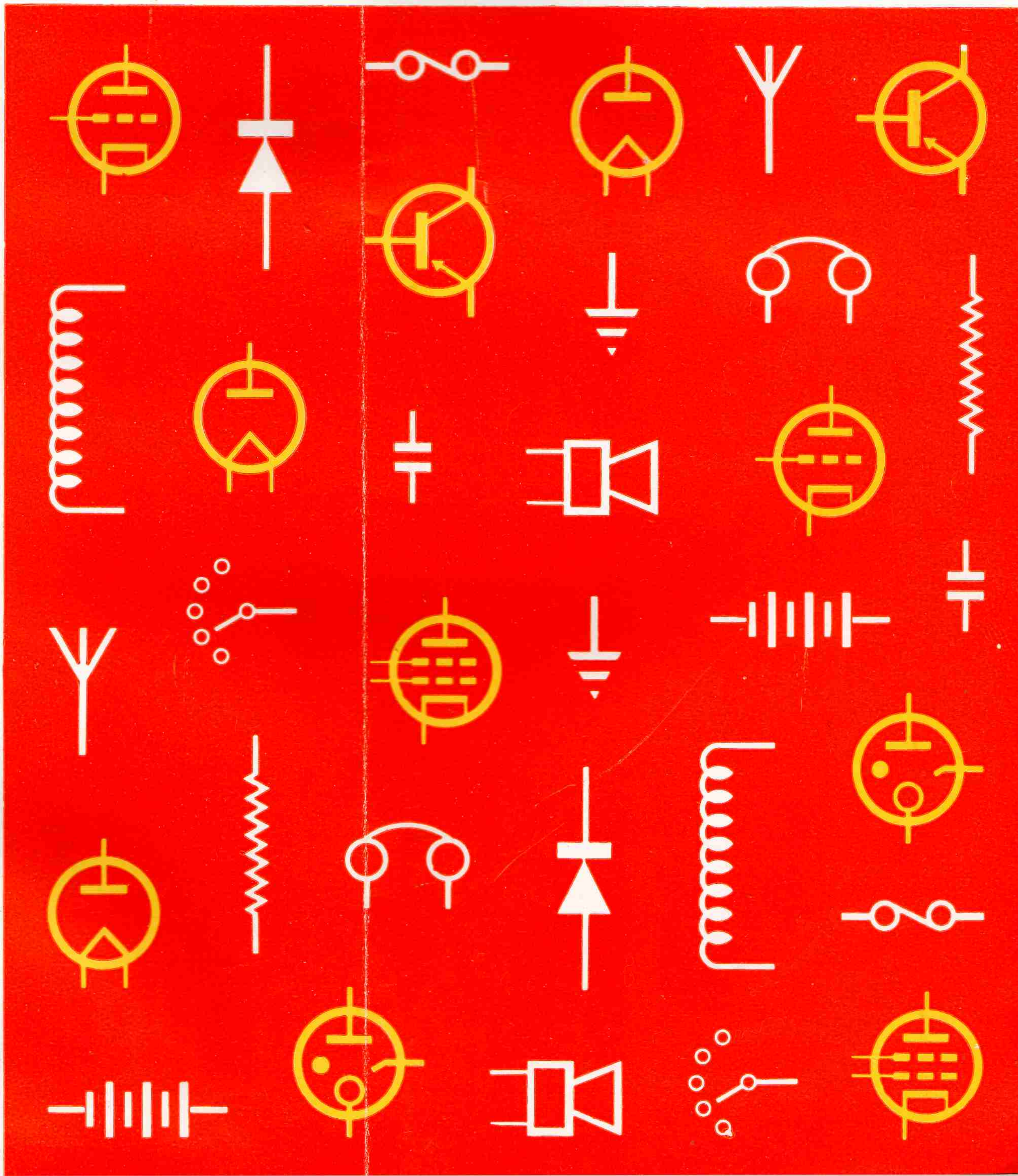
RADIOTRONICS

VOL. 26, No. 11

NOVEMBER, 1961

PRICE ONE SHILLING

REGISTERED AT THE GENERAL POST OFFICE, SYDNEY, FOR TRANSMISSION BY POST AS A PERIODICAL



AN AWV PUBLICATION

RADIOTRONICS

Vol. 26, No. 11, 1961

Editor, Bernard J. Simpson

IN THIS ISSUE

Radiotronics is published twelve times a year by the Wireless Press for Amalgamated Wireless Valve Co. Pty. Ltd. The annual subscription rate in Australasia is 10/-, in the U.S.A. and other dollar countries $1.50, and in all other countries 12/6d.

Subscribers should promptly notify Radiotronics, Box 2516, G.P.O., Sydney, and also the local Post Office of any change of address, allowing one month for the change to become effective.

SEMICONDUCTOR DEVICES

Their Characteristics, Status, and Future

By E. O. JOHNSON, Chief Engineer
RCA Semiconductor and Materials Division, Somerville, N.J.

Since their birth some ten years ago, semiconductor devices have had an explosive impact on the electronics field. Progress has been made so fast that even specialists have had difficulty keeping abreast of new developments. To some extent the dust has now begun to settle, and some basic trends are emerging.

CONSOLIDATION AND REFINEMENT

The first of these trends is that the semiconductor device field is apparently entering a period of consolidation and refinement. The basic physical tools and concepts are well sharpened. The multitude of fabrication techniques—alloying, diffusion, etching, etc.—are being exploited to the utmost, and refined, optimized, and applied in new combinations.

The most important consequence of this trend is that the user can expect to get increasing device performance per unit cost. Performance will improve with respect to frequency, power capability, noise, reliability, ambient temperature, and a general idealization of characteristics. The device cost will eventually be decreased because of technique refinements in quantity production. The increased performance per unit cost will, itself, have an important consequence. Semiconductor devices will rapidly make inroads into applications hitherto dominated by vacuum devices and, in addition, will open up many new electronic applications previously impractical because of performance, reliability or cost.

INTEGRATION OF CIRCUIT AND DEVICES

A second trend will be toward an integration of circuit and device. This result follows because the same semiconductor-device fabrication techniques used to make a transistor or diode can be used, more or less simultaneously, to fashion some of the adjoining connections and components. The extent to which this integration can be pushed will depend upon a complicated interdependence between over-all economics, manufacturing process control, the type of application, the performance requirements, and various marketing considerations. At this time, it is not at all clear that integration beyond a relatively few components, or their equivalents, will be practical, or even desirable.

In my opinion, the extreme physical compactness attainable with integration is of secondary importance except in the few special cases where the substantial miniaturization possible with more-conventional techniques is not adequate. Economics, reliability, energy consumption and density, and other performance requirements will usually be of first importance. For example, in many space vehicles, the electronic-system power-consumption problem dominates. System packing densities beyond a few hundred thousand components per cubic foot are physically possible with integration, but these densities lead to severe heat dissipation problems. Some combination of extensive cooling measures, use of micropower devices, and fairly drastic circuit changes will be required to push back this heat barrier.

As we approach the limiting packing density set by heat dissipation, new problems of reliability, component tolerances, and operating speed will arise. The very short signal-propagation times demanded in ultra-high-speed computers require that components be closely spaced. For example, a computer clock rate of 1000 Mc requires that system dimensions be less than one foot.

BETTER APPRECIATION OF DEVICE POTENTIALITIES

The third trend will be a quickening appreciation of device potentialities. Our maturity has grown rapidly during the "electronics revolution" of the last ten years. This growing maturity will do much to improve focus in directing our over-all electronics engineering effort. New semiconductor devices will find their niche much more rapidly than in the past and with less confusion. New devices will not be judged on novelty, but on a critical assessment of their expected relative worth at maturity. A new device will suffer early demise unless its ultimate performance characteristics are sufficiently superior to justify the relatively large investment in research, development, manufacturing, testing, and marketing needed to reach fruition. The increasing demand for proven reliability, and the substantial cost and time that this requirement entails, will tend to increase the necessity for critical evaluations of this nature. A corollary to the increasing demand for reliability will be a trend toward standardization of devices and their specifications.

No new device capable of challenging the transistor "across the board" has yet appeared. The tunnel and varactor diodes can outperform the transistor only in relatively specialized applications. For computers, my guess is that important discoveries in system organization and the manner of handling digital information will precede the invention of semiconductor devices that could give more performance per unit cost than the transistor.

TRANSISTORS

The extant types of transistors and their relative characteristics are compared in Table I. The grown-junction and alloy-type transistors were introduced at about the same time. The other types followed in the order listed.

The applications listed in Table I are the predominant ones. The mesa structure is sufficiently universal to be usable in almost any transistor application.

The comments on cost in the table are based on current levels with a guess as to what can

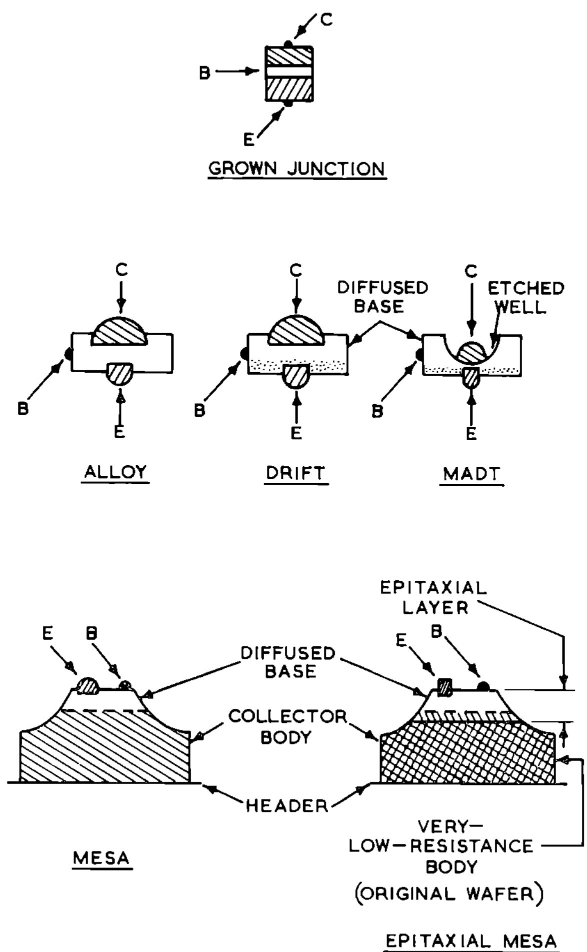


Fig. 1 — Basic transistor types, showing the essential differences in the construction. This diagram also forms a brief history of the transistor over recent years.

be achieved in the next few years when the mesa types, in particular, have had an extended period of quantity production. Current prices of the other older, more mature types would seem to be closer to the ultimate values than those of the mesas.

The predominate material listed for each type is more a result of circumstance than any compelling physical reason. No trend seems in evidence to change the current situation. A new material such as gallium arsenide will most likely make use of the mesa structures.

Alloy, Drift and MADT

The fabrication differences or similarities are summarized in Table I and in Fig. 1 in terms of the electrode construction. Alloy dot emitters and collectors introduce very low series resistance and do not suffer appreciable charge-storage effects. These characteristics are generally

TABLE I—COMPARISON OF VARIOUS TRANSISTOR TYPES

	Grown Junction	Alloy	Drift	MADT	Mesa	Epitaxial Mesa
Fabrication: emitter	Grown	Alloy Dot	Alloy Dot	Alloy Dot	Alloy Dot or diffused	Same as Mesa
base	Grown	—	Diffused	Diffused and micro-etched	Diffused	Diffused epitaxial layer
collector	Grown	Alloy Dot	Alloy Dot	Alloy Dot	Original wafer	Original wafer is substrate of low resistance
Max. Practical Gain—Bandwidth, Mc	10 - 20	10 - 20	200 - 300	1000 - 2000	1000 - 2000	1000 - 2000
Coll. Series Resistance	High	Low	Low	Low	High	Low
Coll. Stored Charge	High	Low	Low	Low	Moderately high	Low
Power Capability	Low	Moderate	Moderate	Low	High	High
Ruggedness	Low to moderate	Moderate	Moderate	Moderate	High	High
Applications	Low power, low frequency	Low to moderate power, low frequency	Low to Moderate power	Low power	All	All
Relative Cost	Moderate	Low	Low	Low	Possibly lowest	Possibly lowest
Predominant Material	S_i	G_e	G_e	G_e	G_e or S_i	G_e or S_i

desirable. The straight alloy process, however, is difficult to handle when the very narrow base widths needed for high frequencies are required. The drift transistor, with its diffused base and resultant drift field to speed up carrier motion, was introduced to extend the capabilities of the alloy transistor. The micro-alloy diffused transistor (MADT) introduces a still further refinement by using a precision etching technique to give very narrow base widths.

Mesa

The mesa construction technique marks a distinct departure from the alloy approach and its various modifications. Maximum advantage is taken of the precision dimensional control possible with the diffusion process. The mesa structure has important advantages. Except for electrode lead attachment, still a troublesome problem, it is admirably suited to large-scale quantity-production techniques. The structure is capable of very high frequencies and is inherently rugged and capable of large power dissipations. These desirable features are sacrificed to some extent by a higher collector resistance and increased collector stored charge. The latter is a disadvantage in saturated switching applications.

Epitaxial Mesa

The recently introduced epitaxial crystal growth technique promises to remove these disadvantages from the mesa transistor. In essence, epitaxial crystal growth is the technique whereby vapour deposition is used to build up a crystal layer upon a crystal wafer. The original wafer and the deposited layer constitute one single crystal, but the layer and the original wafer may be doped with different types and densities of impurity atoms. The electrical and physical dimensions of the layer are susceptible to precise control independently of the nature of the original wafer.

The epitaxial technique will clearly rival the older fabrication techniques in importance for many existing semiconductor devices as well as ones yet to be invented. Epitaxy offers an entirely new dimension in semiconductor-device design flexibility and, combined with the older techniques, will result in better all-round transistor performance as indicated in the table. Although the principle and practice of epitaxial growth have been known for some time, it was only early in 1960 that its immediate practical importance for an existing device was realized and exploited.

Grown-Junction

The grown-junction process represents a technology path which is quite distinct from that of the alloy and mesa types. This process was introduced as the first important practical method for making silicon transistors. Because of its early entry into the field, it has enjoyed widespread use. Performance-wise, however, it cannot compete with the newer mesa units or with the advanced alloy types for the basic reasons noted in the table. Thus, for new circuits the expectation is that the other types of transistors will dominate.

Characteristics

The listed values in Table I of the maximum practical gain-bandwidth products are only approximations. Larger values already have or will be obtained, but these values are costly and

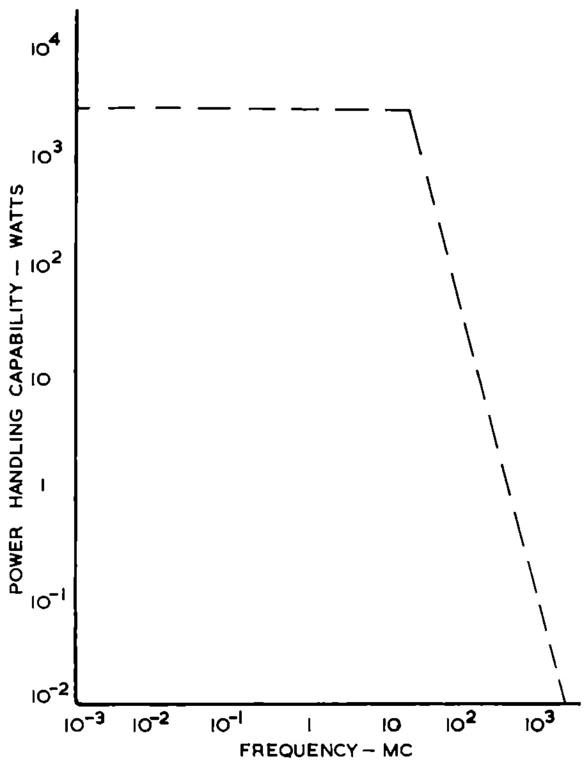


Fig. 2—Power-handling capability of transistors as a function of frequency.

their use at very high frequencies in competition with other devices, such as valves, tunnel diodes, and varactor diodes, is questionable.

The collector stored charge usually completely dominates the base stored charge and is mainly of importance for saturated switching applications. The lowest values of the collector stored-charge time constant are obtained with the MADT type and have a value of the order of 15 nanoseconds. The best mesa units have somewhat higher values. Epitaxial mesa transistors are shortly expected to equal or closely approach the best values obtainable with the MADT type. Further improvements in the collector stored charge may be very difficult to achieve.

The power capability of transistors has increased steadily with the introduction of improved packages, silicon, better junctions, and better over-all design. The best high-power transistors, which are of the diffused-junction silicon type, can handle more than one thousand watts. Further improvements can be expected. From the standpoint of practicality the highest transistor power dissipation is now of the order of several hundred watts.

The frequency-power capability of transistors is shown in Fig. 2. All frequency-power combinations between the curve and the axes are possible. The slanted line indicates the approximate limits achieved by the best transistors known today. For example, some tens of milliwatts of rf power have been generated at 1000 Mc and a few tens of watts have been generated at 100 Mc. Design optimization can be expected to improve these values somewhat. However, as frequency capability increases the transistor must get smaller in size, and this reduction decreases the power capabilities. Thus the physics of the situation sets an upper limit on the power-frequency capabilities which is not more than a few-fold removed from the best values already achieved, which lie on the slanted line. Introduction of a superior material, such as gallium arsenide, will improve the situation a few-fold more.

The device impedance level, which gets lower with increasing frequency, may, however, set a limitation on what can be achieved in an actual application. For example, in a transistor which can generate 10 watts at 100 Mc the input impedance is a few ohms. The horizontal line which sets an upper limit on the power-handling capabilities corresponds to the practical limit mentioned earlier.

At the other end of the power scale, low-power transistors will gain in importance, particularly for space applications and for applications where high component packing densities cause a heat problem. Some transistors with operating powers below 1 mw, which is substantially below that of conventional types, have already been announced.

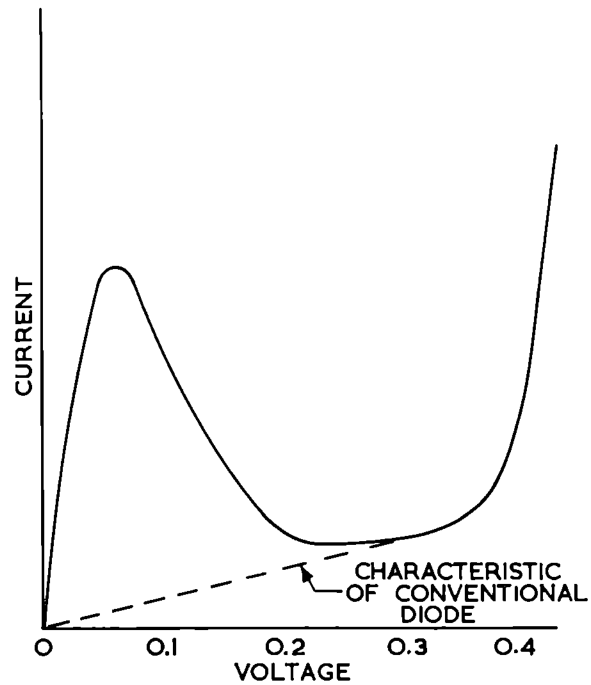


Fig. 3 — Current/voltage characteristics of germanium tunnel diodes.

The highest degree of ruggedness is most easily obtained with the mesa structures because the collector, which constitutes the main body of the device, can be soldered directly down to the header, as shown in Fig. 1. While the other structures are not so amenable to this construction, they are sufficiently rugged for most applications.

TUNNEL DIODES

The tunnel diode is a fairly recent addition to the family of active semiconductor devices. Like an ordinary switching diode, it is a p-n junction device. The tunnel diode features semiconductor material which is so highly doped with impurities that radically different electrical behaviour takes place under forward bias, as shown in Fig. 3. Instead of the usual monotonically increasing current of the ordinary diode, a current peak, followed by a valley, occurs. The portion of the curve between the peak and valley currents provides a negative resistance which can be used for oscillation, amplification, switching, and other functions.

The voltage scale of the characteristic is fixed, with the entire range of interest appearing below one-half volt. At best, the scale can be expanded by a factor of about two by using a wide-band gap material like gallium arsenide. The peak current is increased by an increase in junction area and also by an increase in impurity density in the semiconductor material. The junction shunt capacitance varies directly with junction area and approximately as the square root of the impurity density. Accordingly, the highest-frequency diodes have a small junction area and very high impurity densities. As a rough rule of thumb, the gain-bandwidth product of the diode in cycles per second is numerically equal to the peak current in amperes divided by the shunt capacitance in farads.

Advantages

The advantages of the tunnel diode as a device are considerable. It is extremely simple and compact, and will be very inexpensive when manufactured in volume. It can be manufactured to close tolerances and, compared to a transistor, its characteristics are relatively unaffected by nuclear radiation, temperature, moisture, and other deleterious environments. Low noise with frequency capability into the microwave region is relatively easy to obtain. For the same frequency capability it can operate with substantially less power than the lowest-power transistors and thus can be useful where power consumption or heat dissipation is a problem.

Disadvantages

On the other side of the balance sheet, the tunnel diode has some troublesome disadvantages. The most important of these is that it is a two-terminal device and, as such, suffers bidirectional signal flow and all the feedback problems that follow as a consequence. With respect to linear applications the dynamic range of the device is small so that it cannot easily handle a wide range of signal amplitudes, nor can it handle high powers. This limitation causes circuit complications for both linear and non-linear applications. For linear amplification, especially with cascaded stages, operation is most convenient at microwave frequencies where isolator techniques can be used to introduce unilateral behaviour. For non-linear applications, such as switching in a computer, bidirectional behaviour necessitates circuitry which is more complicated than that needed for a unidirectional device like a transistor. Computer applications may demand that diode and other component tolerances be held to at least ±5 percent.

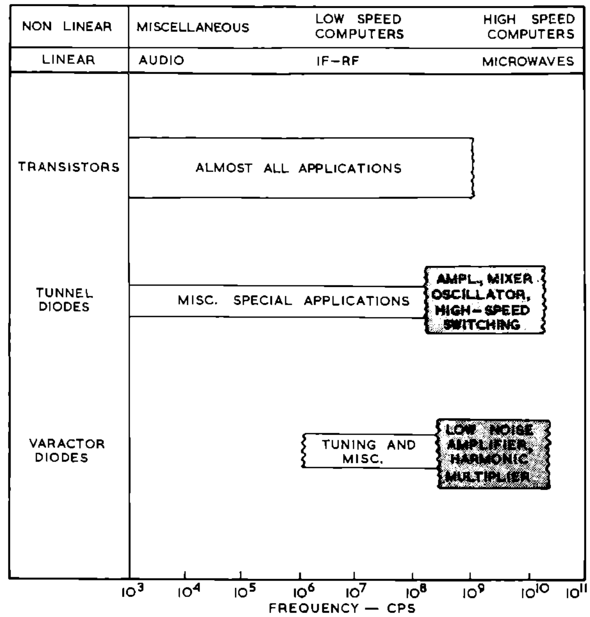


Fig. 4—Device application domains.

Applications

In my opinion, the peculiarities of the tunnel diode will tend to restrict it to the application domains shown in Fig. 4. At low frequencies, it will be in competition with transistors for miscellaneous switching applications. In sheer mass of applications the transistor will unquestionably dominate up to frequencies approaching the microwave region. From here up into the microwave region, the tunnel diode will take over. Its small size, economy, modest power supply requirements, low noise, and general versatility will make it a strong competitor to valves in this frequency range for small signal levels, both linear and non-linear. In many respects the tunnel diode is a "device man's device." The device, itself, is comparatively simple; most of the difficulty is in the circuitry.

Available diodes have the approximate ranges of parameter values noted in Table II. Future developments will lead to reduced shunt capacitance, increased gain-bandwidth products, and increased temperature range. Much more information will be obtained about its stability under different operating conditions and ambients. Because of its simple construction the tunnel diode promises to approach design maturity much faster than the transistor.

VARACTOR DIODES

In essence, the varactor is a small, carefully constructed, p-n junction diode with very low series resistance R and shunt capacitance C. A very small RC product, combined with operation restricted to the reverse part of the current-voltage characteristic, enables the diode to perform at frequencies well up into the microwave region. Amplification at frequency f_s can be made to occur when the reverse bias (hence junction capacitance) is modulated at the "pump" (power supply) frequency f_p, which is generally higher than f_s. Very low noise levels are possible because the dominant current across the junction is reactive and shot-noise components are absent. Reactive nonlinearity, without an appreciable series resistance component, enables the device to generate harmonics with very high efficiency. For example, conversion efficiencies as high as 23 percent. for the third harmonic can be obtained.

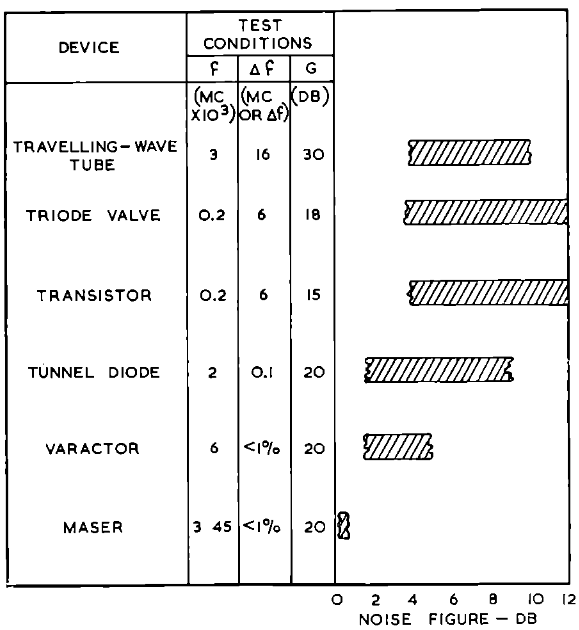


Fig. 5—Device noise figures.

TABLE II

AVAILABLE TUNNEL DIODE CHARACTERISTICS

Material	Ge, Si, or GaAs
Peak Current	1 – 50 ma ± 2% tol., or better
Peak — Valley Current Ratio	6 – 40
Shunt Capacitance	5 – 60 pf
Gain—Bandwidth Prod.	100 – 10,000 Mc
Resistive Cutoff Freq.	200 – 8,000 Mc
Temperature Range	– 269 to + 150°C
Series Inductance	0.3 – 5 mμh

Characteristics

Currently available diodes have characteristics which fall in the approximate ranges noted in Table III. The RC cutoff frequencies will be extended in the future to values as high as 200,000 Mc, or even higher, especially with the new material gallium arsenide, which has generally more desirable characteristics than silicon for varactor diodes. During the time of manuscript preparation, the Semiconductor and Materials Division commercially announced gallium arsenide diodes with cutoff frequencies close to 200 Gc. Improved design will also result in higher values of the voltage exponent and allow the pump power to be minimized. For harmonic-generator service, diodes will be designed for an improved optimum between the cutoff frequency and the parameters C, V_o, and M_m, which determine the diode's power-handling capabilities. Power-handling capabilities of a few tens of watts in the microwave frequency range between 1000 and 10,000 Mc seem possible. In fact, harmonic power outputs of several watts have already been achieved near 1000 Mc.

Applications

The noise figures attainable with varactor diodes compared to other devices, including triode vacuum valves and travelling-wave tubes, are shown in Fig. 5. Since noise figures are affected by the type of circuit and other application details, only the rough ranges could be given. After a few years of development, varactor diodes are giving a good account of themselves in the front end of various types of microwave receivers. Although they cannot give as low a noise figure

TABLE III

AVAILABLE VARACTOR DIODE CHARACTERISTICS

Material	S_i or G_aA_s
RC Cutoff Frequency	30,000 – 150,000 Mc
Series Resistance, R	~ 1 ohm
Shunt Capacitance, C	0.5 – 3 pf
Max. Reverse Voltage, V_O	5 – 15 volts
Series Inductance	~ 1 mμh
Voltage Exponent, n*	0.25 – 0.45
Max. Allowable Power Dissipation	25 – 100 mw
Max. Allowable Reactive Power	0.5 – 5 watts

*$C \propto .1/V^n$

as the maser, they and their supporting equipment and circuitry are much lighter, smaller, and more convenient to use, particularly in vehicles.

HIGH-TEMPERATURE OPERATION

The permissible temperature ranges of devices made out of germanium, silicon, and gallium arsenide are shown in Fig 6. Germanium devices have an adequate temperature range for many applications, but for many other applications, particularly military, the greater temperature range of silicon devices is a necessity. This necessity stems from a combination of the required ambient operating temperature and the power dissipation in the device itself.

A number of applications, particularly in high-speed vehicles, require device temperature capabilities and margins of safety beyond those attainable by any present or future silicon devices. A great majority of these requirements will be met by a relative newcomer to the semiconductor materials field, gallium arsenide. As shown in Fig 6, this material has a temperature range 200°C beyond silicon. Besides its obvious advantages at high ambient temperatures, this extra range should be useful in giving improved reliability over silicon devices operated close to their upper temperature limit. Another consequence of an improved temperature margin is that gallium arsenide devices should be amenable to higher packing densities and, also, have less dependence upon package size and design.

Another advantage of gallium arsenide devices is that, unlike silicon devices, they do not sacrifice frequency capability compared to germanium devices of comparable dimensions. Recently, a number of manufacturers (particularly RCA) have made gallium arsenide diodes available. In the next few years other devices, including transistors, will be available.

Silicon carbide offers the possibility of device operation in the extreme cases where the temperature is 600°C, or even higher. Unlike gallium arsenide, however, this material has decidedly inferior electrical characteristics at ordinary temperatures and so will probably be of interest only for the few special applications required at extreme temperatures.

RELIABILITY

Semiconductor devices have rapidly acquired a reputation for reliability, notably in large computers where the number of components is very large. In these applications, unit component failure rates, which might be low by other standards, can seriously disrupt the operation of the equipment. In such applications semiconductor devices have achieved a failure rate of the order of 0.01 percent. per thousand hours' operation per device. Certain military applications, however, now require reliability extending down to a failure rate at least ten times smaller. This latter rate is about equal to the level reached by some passive components. Consider that this means a failure, on the average, of one device per 100 million hours (approximately 10,000 years) of operation. Or, in other words, to observe one average failure in a month of operation would require a test sample numbering 100,000 units.

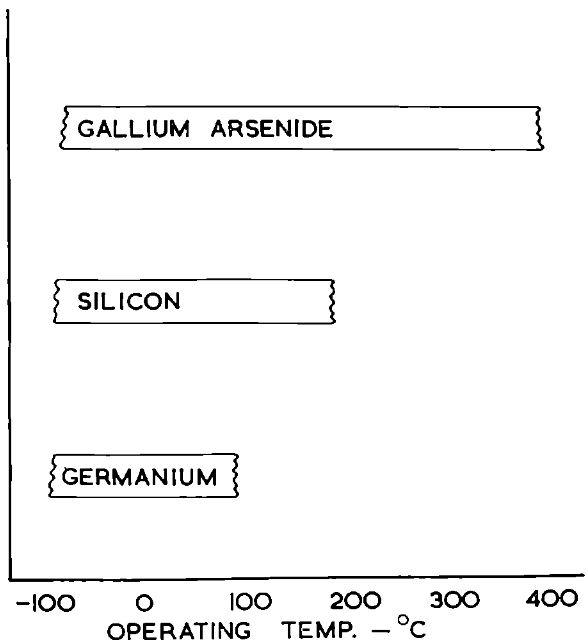


Fig. 6—Device temperature operating ranges.

It is quite apparent that even to detect whether or not a device has high reliability is, in itself, an expensive and time-consuming task. The higher the degree of reliability desired the more difficult and expensive the whole operation becomes. Attempts to discover accelerated life-test procedures also require prolonged evaluation tests and, although valuable progress is now being made in these attempts, no adequately satisfactory accelerated life test of general applicability is yet available.

Accelerated life tests have a foundation in the fact that semiconductor device failure is mostly of a chemical nature (surface effects near junctions) and so should be accelerated by increased temperatures. These types of failures appear as increased junction leakage currents, increased noise, or as changes in the current gain of a transistor.

Attempts to improve semiconductor device reliability are based on some combinations of the following steps:

1) make design refinements of an existing device which promises, or has already demonstrated, good reliability;
2) exert meticulous control over the manufacturing process;
3) subject devices to a vigorous obstacle course;
4) carefully analyze each failure and vigorously pursue corrective measures;
5) pursue a comprehensive life-testing program.

The industry is very confident that the reliability needed, even in most extreme cases, can and will be achieved.

CONVENTIONAL DEVICES

Conventional diodes and rectifiers, not specifically treated here, will enjoy much of the sort of improvement and refinement described for the active devices. Diode switching speed will be improved along with reliability, uniformity, and general performance. Rectifier reliability, power capability, temperature range, and current and voltage ranges will be extended substantially in the years ahead.

CONCLUSIONS

The semiconductor device field is apparently entering a period of consolidation and refinement that will lead to a considerable improvement in over-all performance for a given cost. This development will have many important consequences. Semiconductor devices will find many new applications besides performing in old applications with greatly improved efficacy and reliability. Eventually, to some degree, these devices will incorporate portions of the adjoining circuitry. New devices, of which the tunnel and varactor diodes are an example, will outperform the transistor only in relatively specialized applications. New devices of greater general importance will, I believe, await new innovations in system organization and methods of handling digital information.

(With acknowledgments to RCA)

SUBSCRIPTION RENEWALS FOR 1962 ARE DUE BY DECEMBER 1st.

After a lapse of some years, we are now preparing to publish again modern constructional articles using local parts and designed for local conditions. Several units are now under preparation in our laboratories specifically for these pages, and will appear progressively during 1962. Units of all types are being considered, and will include several high fidelity audio amplifiers of high quality, and sometimes unusual design.

AN AUTOMOBILE TACHOMETER

by B. J. Simpson

A simple transistorized unit for indicating engine revolutions, using two transistors and a zener diode. A very satisfactory version of this design can be built using a readily-available meter and a few parts.

Circuit Description

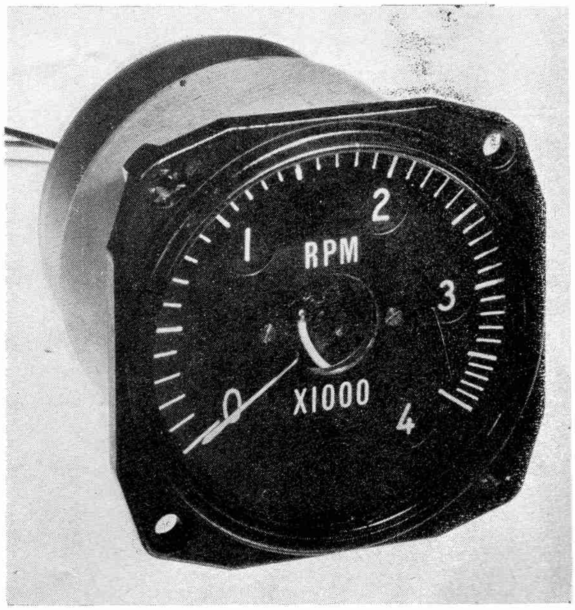
The basic circuit of this tachometer was developed some time ago by Mr. J. A. L. Hooke, B.E., B.Sc., the AWV Semiconductor Division, and it is virtually unchanged in this version. The circuit of the unit consists of a triggered or one-shot multivibrator, which is of course normally in the quiescent condition, with Q1 conducting and Q2 cut off. When the car engine is running, pulses from the distributor make-and-break contacts are fed into the multivibrator, causing it to trigger over to the opposite condition.

It is a function of this type of circuit that once the circuit has been triggered from the stable condition into the unstable condition, i.e., with Q1 cut off and Q2 conducting, it will stay in the unstable condition for a period of time determined by the circuit constants. When this time has expired, the circuit will revert to the original stable condition.

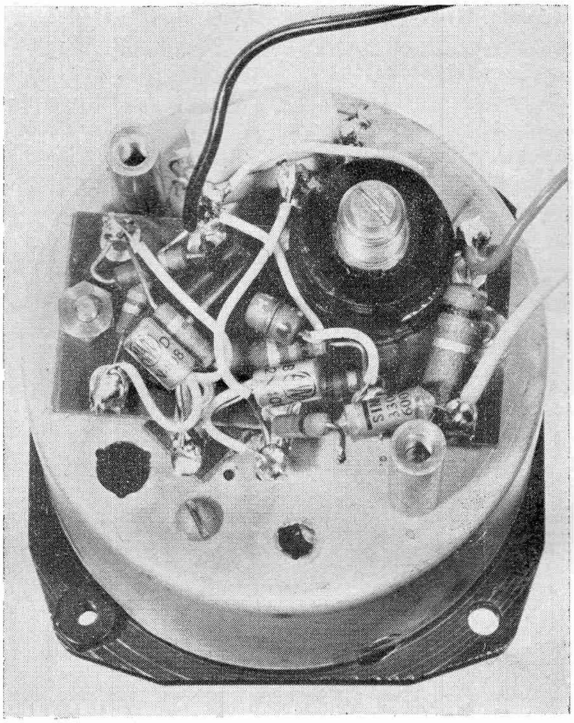
The change from the stable to the unstable, and then back again, occurs at the same speed, irrespective of the type of input pulse and the frequency of the input pulses. This is not strictly true as a general statement, but is for all intents and purposes true for the pulses and frequencies with which we are concerned in this application. This means that under the influence of the pulses from the distributor, a series of square pulses is produced at the collector of Q2, of constant amplitude and duration, but varying at a rate determined by the engine speed.

We now have the condition where we have one variable quantity, the mean collector current of Q2, and this is directly proportional to the number of pulses per second, i.e., the engine speed. It will be seen that if the width of the pulses were allowed to vary with engine speed, or if the amplitude of the pulses were allowed to vary in a similar manner, this would not apply. This explains the choice of the type of circuit, and the reason why it works so well.

The method of measuring the mean collector current in Q2 is to place a milliammeter in the circuit, as shown in the diagram. If the meter has a highly-damped movement, or is heavily shunted in order to provide the required full scale deflection, the meter will successfully integrate the pulses and provide a steady reading.



A view of the completed unit. At the time this photograph was taken, the final scale had not been fitted. The general appearance can however be seen.



Rear view of the unit with the rear cover removed. This shot shows how the circuitry has been condensed into the small space behind the meter proper.

If this is not the case, as with the meter used in the sample given later, the problem can be overcome quite simply by shunting the meter with a large capacitor.

In the circuit diagram shown, the meter can have any range between 0-1 and 0-5 milliamperes, the necessary adjustment being made in setting the 1,000-ohm preset calibration resistor. The value of one resistor is not given in the diagram, the base resistor for Q1; the value of this component should be 33,000 ohms for a 4-cylinder car and 47,000 ohms for a 6-cylinder car. As shown, the diagram is suitable for a car with battery negative grounded, positive active. For the opposite condition, the only change suggested is to transfer the 100 ohm resistor in the +12 volt line to a similar position in the —12 volt line instead.

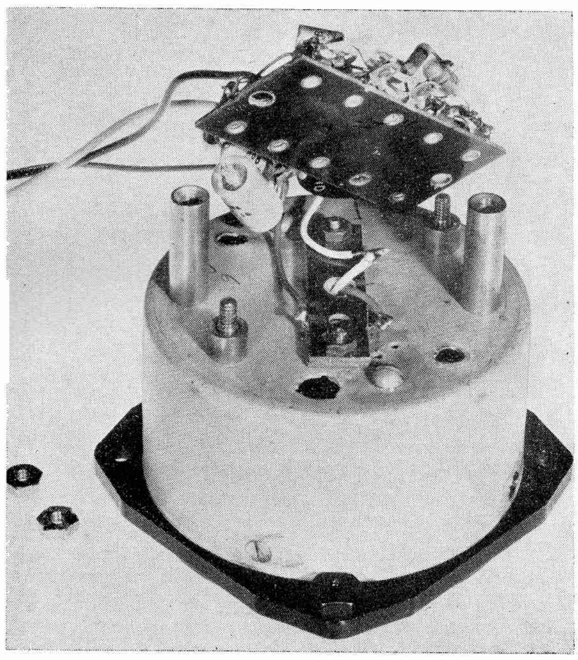
The circuit diagram carries no earth or ground point. This will be automatically taken care of when the unit is installed, via one of the battery connections. The value of the capacitor in series with the lead to the distributor is not critical, and in fact the unit appears to work satisfactorily without it. Any value between 200 and 1,000 pf would probably suffice. The capacitor was included for two reasons. Firstly it isolates the distributor contacts from the unit as far as dc is concerned, and it also reduces the chance of a fault in the unit preventing ignition. Secondly, it provides a degree of differentiation in the input pulse, to render triggering more certain.

The purpose of the zener diode is to provide a regulated voltage for the multivibrator, so that the constant operating conditions mentioned previously as being so necessary will be obtained. The diode chosen operates at 6.8 volts, and this is the supply voltage for the two transistors. Any operating voltage around this figure should be satisfactory. Without the diode, variations of battery voltage would completely nullify the system.

Installation

The installation of the unit is very simple. The mechanical features are at the discretion of the user, the placement of the unit depending on the make of car and personal preferences. Electrically, connect one of the 12-volt battery leads (whichever is active in your car) into the electrical system at a point where power is only made available when the ignition switch is on. Most cars will have a suitable point at the fuse board; check the wiring diagram for your car, or ask your garage man to locate a suitable point. The other battery lead is then connected to the chassis of the vehicle.

The distributor lead is to be connected to the junction of the distributor and the ignition coil. This lead is easily identified, and the lead



A further view of the rear of the unit with the rear cover removed. This shot shows how the main tag board, which carries the entire circuit except the meter, can be swung aside to give access to the meter connections.

from the tachometer may be clamped under an existing terminal at either the distributor or the coil. This lead should be well insulated and protected in the engine compartment, as a short circuit on this lead will not only prevent ignition, but will pass a constant steady current through the coil; this may damage the coil.

Calibration

The calibration of the tachometer is linear. This means that if the zero of the meter is correctly set, and the calibration resistor adjusted for the correct reading at any one point, this is all that is required. There are two quite simple ways of doing this.

One way is to calibrate the unit against the 50-cycle mains supply, using a low voltage from a transformer, and adjusting the calibration resistor for the RPM reading corresponding to 50 cycles per second. The number of pulses per second can be calculated by multiplying the engine revolutions by 2 (for a 4-cylinder car) or by 3 (for a 6-cylinder car), and then dividing by 60. This means that 50 cycles corresponds to 1500 RPM for a 4-cylinder engine and 1000 RPM for a 6-cylinder engine. Some additional peaking or differentiation of the input signal may be necessary to obtain good triggering from the sinusoidal input. Alternatively an audio oscillator may be used with similar methods, provided sufficient output is available.

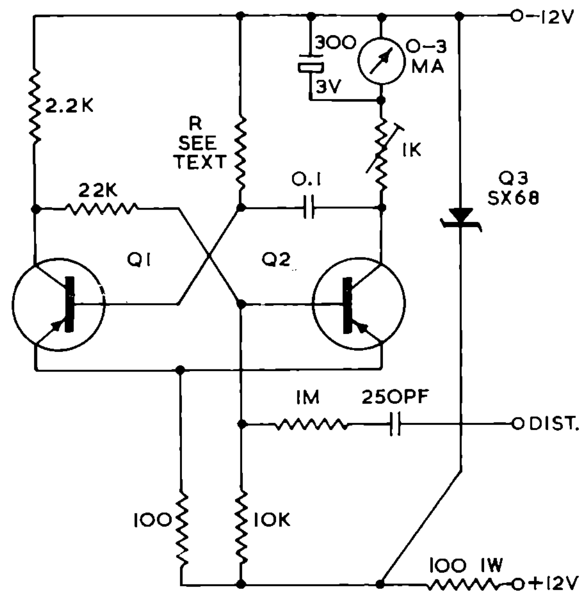
An alternative method is to calibrate the unit against the speedometer of the vehicle by setting the tachometer to read the appropriate RPM at a known road speed. The RPM per mile per hour is often quoted in the car makers' handbooks for top gear operation, or can be calculated from the known ratios of the gear box and differential. This method has the disadvantage that the speedometer error is incorporated in the tachometer reading, and its accuracy depends on the accuracy of the speedometer.

The Meter

Meters of a size and/or shape suitable for a job of this kind are fairly dear. The meter of course has to be of a size that is easily observed in a moving vehicle at a glance. A radio altimeter indicator instrument was found which does the job very well after modification.

This instrument has a meter about three inches in diameter, with a scale covering about 270 degrees. The instrument has two switches operated through small knobs at the front; one of these switches operates a scale calibration shift by mechanically moving a set of figures visible through holes in the main scale.

Quite a bit of modification is required to use the meter for this tachometer, but this is very simply carried out. The first step is to remove the cover at the rear, which carries a multi-way connector and protects the two switches. Remove the two switches and the multi-way connector. A two-way tag strip carries the two connections into the meter case itself. These should be unsoldered before attempting to remove the meter movement.



Circuit diagram of the tachometer. For modifications to accommodate different battery polarity and different engine sizes, see text. Q1 and Q2 are AWV 2N217 transistors.

To remove the movement, release the front cover, held in place by four small countersunk screws in the side of the case. By releasing two round-head screws at the rear of the case, the movement may now be removed. The work of modifying the movement itself, and the casing of the instrument, may now be carried out.

The movement is fitted with a shunt, wound on a small bobbin. Remove the shunt and discard. The movement has the return springs so adjusted as to have, in effect, a suppressed zero. This must be corrected by a readjustment of the settings of these springs. The lugs holding the outer ends of the springs are held under the lock screws which secure the adjustment of the pivot screws, and this operation must be carried out with considerable care. The lockscrews are sealed with a black substance, which can be loosened with a gentle application of heat. The problem then is to re-position the lugs so that the meter pointer comes to rest on the zero mark, without disturbing the adjustment of the pivots.

Construction

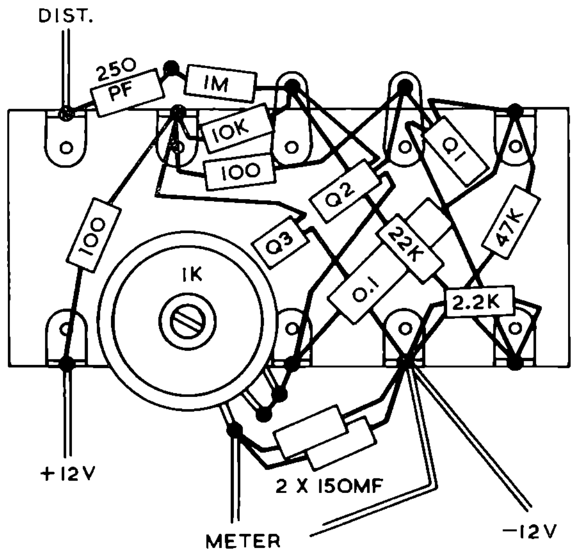
The mechanical device already mentioned for changing the meter scale was stripped out and two new wires soldered onto the meter movement. The calibration of the meter dial is unfortunately non-linear with respect to the meter deflection current, and therefore cannot be used for the tachometer. It is necessary to draw a new scale on a sheet of good quality paper and paste it over the existing scale. Other methods could be used if you wish. Select the scale range you desire, and then divide up the scale length accordingly on a linear basis.

The rear cover for the two switches has two cutouts in the side. The cover was cut down all round to the bottom of the two cutouts, and arranged to fit flush onto the back of the meter case, being held in place by two one-inch stand-off pillars attached to the back of the meter case. In this way a small space was made behind the meter case itself, which houses the electronic portion of the unit.

The small two-way terminal strip carrying the meter connections should be removed, the two rivets holding the assembly together removed, and the unit remounted directly over the centre of the back of the meter case, with the solder lugs bent up, using two small nuts and bolts through the original rivet holes. This is done to conserve space inside the unit. It will be remembered that there is a large hole through the centre of the back of the meter case where the scale change mechanism passed. The two-way tag strip now covers this hole. Drill a quarter-inch hole through the centre of the two-way tag strip for the meter leads.

With the exceptions of the modifications to the meter already discussed above, there are no problems. A short length of tag board with five pairs of tags was mounted in the space provided, and the circuit components mounted on it. The calibration resistor used must be a miniature type, and it is cemented directly onto the tag board in the position shown in the diagrams. When the rear cover is placed in position, the bushing and shaft of the potentiometer will protrude through a hole in the cover, and a nut and knob can be fitted if desired.

The arrangement of the two-way tag strip, the two pillars for carrying the rear cover, and the mounting of the five-pair tag strip for the other components is shown in the accompanying diagrams. It will be seen that all the original pillars and studs at the rear of the meter case



Wiring diagram of the main tag board, which carries all the circuitry with the exception of the meter itself.

were removed, with the exception of two of the switch-mounting pillars, which were retained as a mounting for the five-pair tag strip. One tag on this strip was removed to make way for the potentiometer.

The rear cover has now a number of holes that are not required. The easiest way to cover these holes and improve the appearance of the unit is to cut a disc of thin aluminium the same size or slightly smaller than the back of the cover, and fasten it over the back of the cover using the same fixing screws. A hole will have to be provided for the potentiometer.

AFTERTHOUGHTS

You know, it's a funny thing, that after you have made a unit and look back over what has been done, there is always an obviously better way to have done it. If you cannot see this better way yourself, there are always plenty of helpful friends who, unencumbered by the weight of thought and endeavour that you feel you have expended, are able to point out where you went wrong.

At the last moment before this article went to press, I had myself decided on a scale range of 0-4,000 RPM, for use with a six-cylinder car with comparatively low compression. Some of the younger members of the staff who are interested in building this unit, and who drive smaller cars at higher speeds with the aid of smaller engines, immediately pointed out that this scale range was too small for them. Stemming from this discussion, the difficulty of producing a pro-

Page 200 Please

6939 In RF-Amplifier and Tripler Service

This article discusses the application of the 6939 twin power pentode in Class C rf-amplifier and frequency-tripler service at frequencies up to 500 megacycles. Circuits illustrating the use of this valve in a "straight-through" amplifier stage and in frequency-tripler service are described.

The 6939 is a twin power pentode of the nine-pin miniature type. At 500 megacycles, the 6939 can deliver an average of 5 watts of useful power under CCS conditions and 6 watts under ICAS conditions. In frequency-tripler service, it can deliver an average of 1.8 watts of useful power under CCS conditions and 2.2 watts under ICAS conditions.

Design Features

The 6939 uses frame-type control grids (grids No. 1) wound with gold-plated lateral wires, zirconium-sprayed molybdenum plates, and a screen grid (grid No. 2) which is carbon-coated to minimize secondary emission and increase heat-dissipation capabilities. The cathode and screen grid are common to both pentode units. In addition, the 6939 features an internal neutralizing system.

Extremely close spacing between the cathode and grid No. 1 makes possible a transconductance of 10,500 micromhos for each unit. The valve is especially useful in a push-pull output amplifier, driver, or frequency tripler because its design minimizes problems of instability and cathode degeneration often encountered in push-pull systems using separate valves.

The cathode of the 6939 is indirectly heated; the heater is centre-tapped for use with either a 6.3-volt, 0.6-ampere heater supply or a 12.6-volt, 0.3-ampere heater supply.

Stable amplifier operation over a relatively wide frequency range is assured by the internal capacitive neutralizing system which compensates

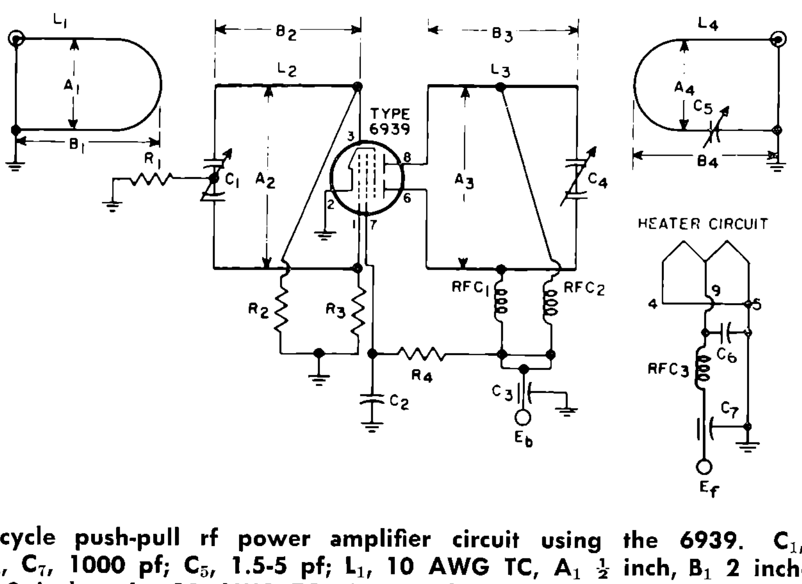


Fig. 1—500-megacycle push-pull rf power amplifier circuit using the 6939. C_1, C_4, 2.2-8 pf; C_2, C_6, 250 pf; C_3, C_7, 1000 pf; C_5, 1.5-5 pf; L_1, 10 AWG TC, A_1 $\frac{1}{2}$ inch, B_1 2 inches; L_2, 10 AWG TC A_2 $\frac{1}{2}$ inch, B_2 3 inches; L_3, 10 AWG TC, A_3 $\frac{3}{4}$ inch, B_3 3 inches; L_4, 10 AWG TC, A_4 $\frac{3}{4}$ inch, B_4 $1\frac{1}{2}$ inches; R_1, 220 ohms; R_2, R_3, 27K ohms; R_4, 100 ohms; RFC_1, RFC_2, 0.2 microhenry; RFC_3, 20 turns 26 AWG enam., $\frac{3}{16}$ inch dia. X $\frac{1}{2}$ inch long.

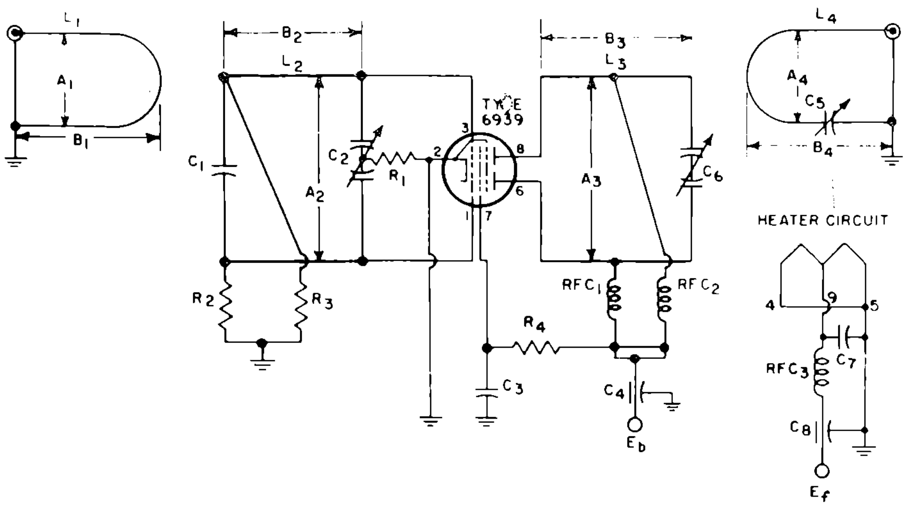


Fig. 2—166.6-megacycle to 500-megacycle frequency-tripler circuit using the 6939. C_1, C_4, C_8, 1000 pf; C_2, C_6, 2.2-8 pf; C_3, C_7, 250 pf; C_5, 1.5-5 pf; L_1, L_2, L_3, L_4, as in Fig. 1; R_1, 100 ohms; R_2, R_3, 82K ohms; R_4, 1200 ohms; RFC_1, RFC_2, RFC_3, as in Fig. 1.

for the capacitive feedback from plate to grid No. 1. The neutralizing capacitors consist of metal tabs mounted on the top mica spacer near each plate. Each tab is connected to the grid of the opposite unit of the tube.

Basic RF-Amplifier Considerations

The maximum useful operating frequency of a conventional rf-amplifier is determined by the natural resonant frequency of the internal inductances and capacitances. In a push-pull circuit the input capacitances of the two valves are in series across the input tuned circuit. This arrangement halves the effective input capacitance of the circuit and thus makes it possible to achieve much higher operating frequencies than in a single-ended circuit. The same considerations apply for the output capacitances of push-pull circuits.

At high frequencies, two separate valves operating in push-pull have certain disadvantages. For example, the separate lead inductances of the valves introduce degeneration, and the separate screen-grid leads often cause circuit instability. The 6939 overcomes these difficulties by incorporating in one envelope two pentodes having a common cathode and a common screen grid. Low lead inductances and freedom from cathode degeneration are achieved, and the other disadvantages of separate valves are avoided.

Class C 500-Mc Push-Pull RF Power Amplifier

Fig. 1 shows a circuit diagram of a 500-megacycle push-pull rf power amplifier using the 6939. In this circuit, the open-ended resonant lines in the grid No. 1 and plate circuits are both electrically one-half-wavelength long. For applications involving stringent space limitations, it is possible to obtain a resonant plate circuit by use of a quarter-wavelength closed-end resonant line. With such an arrangement, the plate voltage is applied through an rf choke to the centre of the closed end. Under these conditions, however, coupling losses may prevent full utilization of the rf power developed by the valve.

It should be noted that the plate capacitor C_4 is ungrounded. The two rf chokes in the plate-voltage supply are connected at points on the transmission line where the rf voltage is at a minimum, i.e., at approximately the mid-point of each leg. Care should be used in determining the location of these points to avoid loss of output power and excessive heating of the chokes.

Pins 4 and 5 of the 6939 are grounded as close as possible to the socket to minimize absorption of rf power by the heater circuit. Isolation of the ungrounded heater terminal (pin 9) is provided by an rf choke (RFC_3) and a low-inductance bypass capacitor (C_6). Any rf in the heater supply lead is bypassed by a feed-through capacitor (C_7) located at the point at which the heater lead passes through the chassis.

The cathode terminal (pin 2) is grounded directly to the chassis by the shortest possible connection to minimize series inductance.

In this push-pull rf-amplifier circuit, the screen-grid and plate voltages are obtained from the same source. The screen grid is bypassed to ground by a low-inductance capacitor (C_2). In addition, a 100- or 200-ohm resistor (R_4) is connected in series with the screen-grid supply lead at the socket to minimize parasitic oscillations. To minimize self-oscillation due to parallel resonance in the grid-No. 1 circuit, the rotor of the input tuning capacitor (C_1) is connected to ground through a 220-ohm resistor (R_1).

The grid-bias resistors are connected to the input transmission line at points where the rf voltage is a minimum. The point of minimum rf voltage in this circuit is at the socket. The use of separate grid resistors is advisable for circuit symmetry.

A grounded shielding strip is mounted across the socket to prevent feedback of rf power from the plate to the grid No. 1. This shield is installed so that it crosses the socket between pins 4 and 5 and between pins 1 and 9.

Optimum coupling to the single-ended input and output loops (L_1 and L_4) is obtained when the closed end of the coupling loop faces the tuning capacitors. The separation between the resonant lines and the coupling loop is generally between one-half and three-quarters of an inch.

Because the maximum permissible bulb temperature of the 6939 is 225 degrees Centigrade, normal convection cooling is sufficient for all operating conditions. The 6939 should never be operated in a closed shield unless the shield has a mat black internal finish and is either corrugated or finned.

Table I lists typical operating values for the amplifier.

	CCS	ICAS	
DC Plate Voltage	180	200	volts
DC Grid-No. 2 Voltage	180	200	volts
DC Grid-No. 1 Voltage	–20	–20	volts
DC Plate Current	55	60	ma
DC Grid-No. 2 Current	12.5	14	ma
DC Grid-No. 1 Current	1.5	1.5	ma
Plate Input	10	12	watts
Plate Dissipation	4.2	5.2	watts
Grid-No. 2 Input	2.25	2.8	watts
Driving Power	1.2	1.2	watts
Useful Power Output	5	6	watts

Table I—Typical operating values for 500-megacycle rf-amplifier circuit shown in Fig. 1.

166.6-Mc to 500-Mc Push-Pull Frequency Tripler

Fig. 2 shows the diagram of a 166.6-megacycle to 500-megacycle frequency tripler circuit using the 6939. In this circuit, the 6939 is capable of delivering 1.8 watts of drive to the following stage. The design considerations given previously for the 500-megacycle amplifier circuit also apply when the valve is used in a frequency-tripler circuit, except that the shield across the socket is not required for tripler operation. The input resonant line (L_2) is a quarter wavelength at 166.6 megacycles. The grid-bias resistors (R_2 and R_3) are connected at the end of the input resonant line where the rf voltage is a minimum. Because the closed end of L_2 is terminated by a high-value capacitor (C_1) which does not change the rf characteristic of L_2, two separate grid resistors are used to provide a symmetrical push-pull input circuit.

Table II lists typical operating values for the frequency-tripler circuit.

	CCS	ICAS	
DC Plate Voltage	180	200	volts
DC Grid-No. 2 Voltage	180	190	volts
DC Grid-No. 1 Voltage	–74	–74	volts
DC Plate Current	40	46	ma
DC Grid-No. 2 Current	9.7	11	ma
DC Grid-No. 1 Current	1.8	1.8	ma
Plate Input	7.2	9.2	watts
Plate Dissipation	4.9	6.1	watts
Grid-No. 2 Input	1.65	2.05	watts
Driving Power	1.1	1.1	watts
Useful Power Output	1.8	2.2	watts

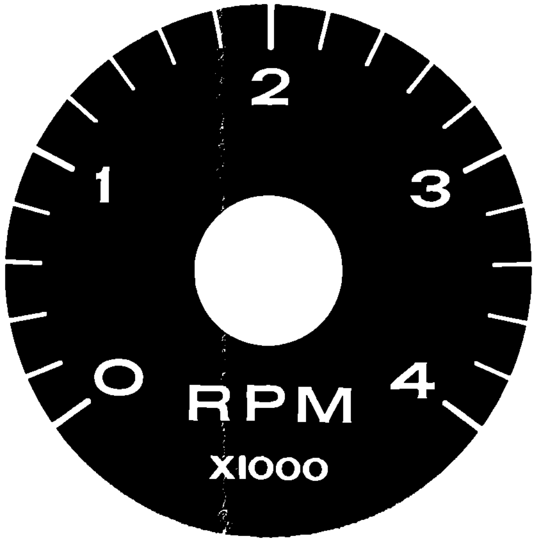
Table II—Typical operating values for frequency-tripler circuit shown in Fig. 2.

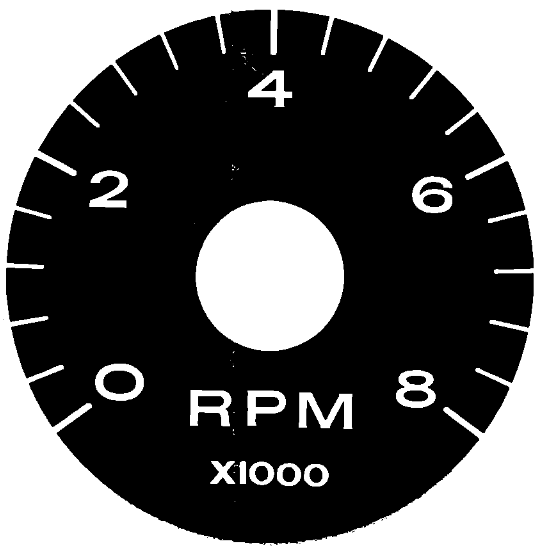
(With acknowledgements to RCA)

AN AUTOMOBILE TACHOMETER

(continued)

fessional-looking scale by hand and the desirability of black markings on white background, it was decided to prepare two cut-out-and-paste-down scales for readers wishing to make this unit. The alternative scales have full-scale deflections of 4,000 and 8,000 RPM, and are printed inside the back cover.


0
1
2
3
4
RPM
X1000


0
2
4
6
8
RPM
X1000

AWV