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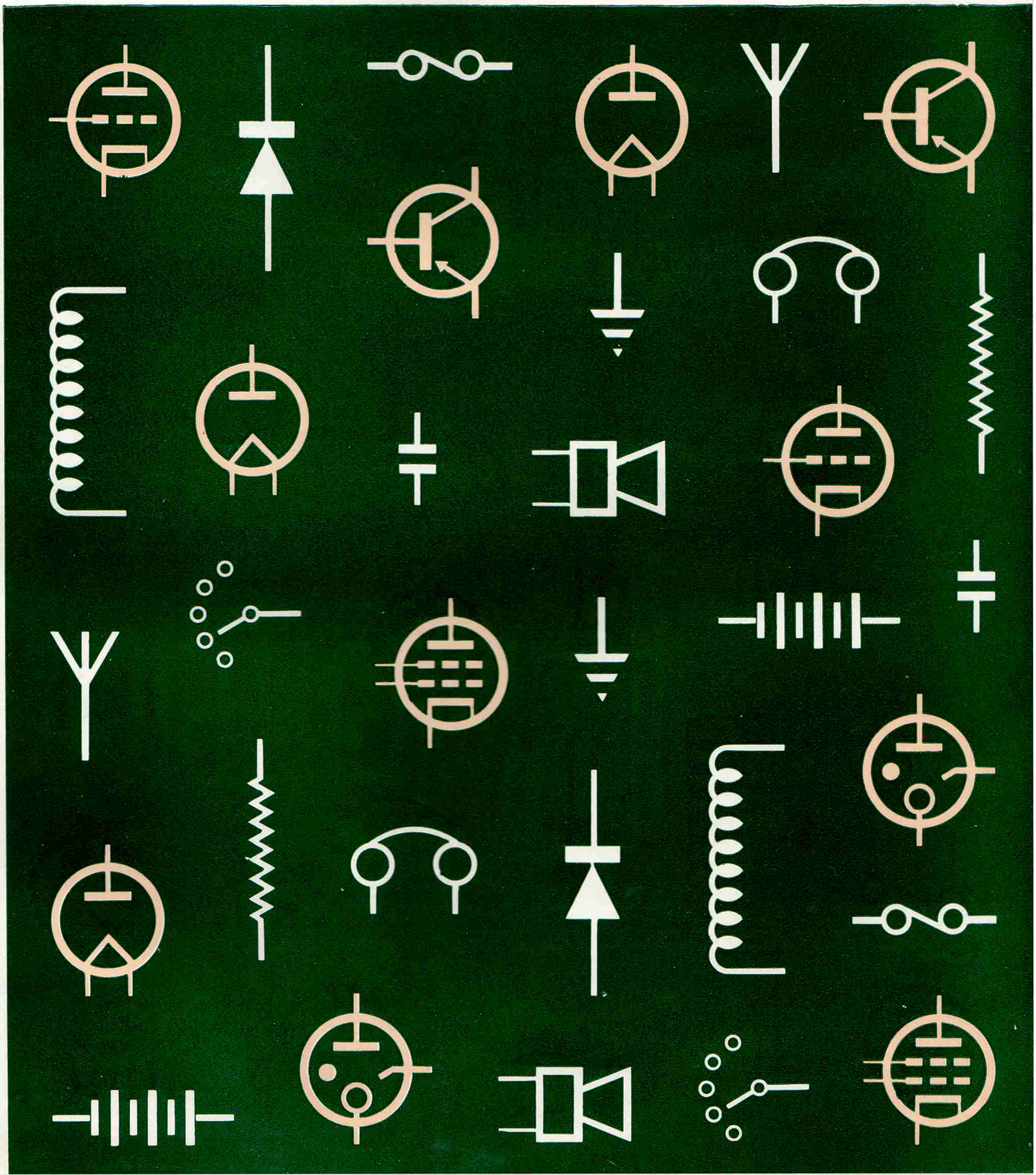

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TUNNEL DIODES

THE LATEST MIDGET PRODIGIES

By H. S. Sommers, Jr. *

The tunnel diode is a semiconductor junction diode requiring only a dc bias supply to become an active device of extreme versatility. It is a simple, low power, low-noise device which is usable from dc to the centimetre range. It is smaller, more rugged, and more stable against changes in ambient conditions and radiation than other active semiconductor devices.

This article describes the theory and characteristics, high - speed - switching applications, use in linear circuits, circuit design and packaging, and inherent limitations of this bilateral device.

INTRODUCTION

The tunnel diode is a semiconductor junction diode requiring only a dc bias supply to become an active device of extreme versatility. This is in contrast to the maser and the variable-capacitance diode, both of which are negative-resistance diodes which are very useful in a restricted range of applications as low-noise amplifiers or high-frequency oscillators.

The tunnel diode should be regarded as a general-purpose device, in the same sense as the transistor. It can perform a great range of functions quite well, but usually falls short of the ultimate performance achieved by the more specialized devices.

WHY ANOTHER GENERAL-PURPOSE DEVICE?

The transistor is indeed a very useful and powerful element. But, it has certain limitations to overcome, a fact which accounts for the great present interest in the tunnel diode as another general-purpose device. Among these limitations are moderately high power dissipation per unit, which becomes a serious handicap in equipment designed for space vehicles, battery-operated systems, and complex computers; other drawbacks are rather large temperature sensitivity and limited speed. This speed limitation is the fundamental difficulty with the bipolar transistor and warrants further discussion, in order to better understand the tunnel diode.

TRANSIT TIME LIMITATION OF BIPOLAR TRANSISTORS

The bipolar transistor is a charge-control device in which the flow of current by one sign of carriers (the majority carriers) is controlled by injecting a few carriers of the opposite sign (minority carriers). The speed of the device is ultimately limited by the rapidity with which these oppositely charged carriers can diffuse or drift through the sea of majority carriers.

Fig. 1 illustrates the transistor speed problem by a crude but useful mechanical anology. The speed of operation of the transistor, shown schematically as p-n-p at the top of the sketch, is limited by the time it takes a signal to travel from the input at the left to the output at the right. In the mechanical analogy, shown in the middle, the input is the hammer which falls

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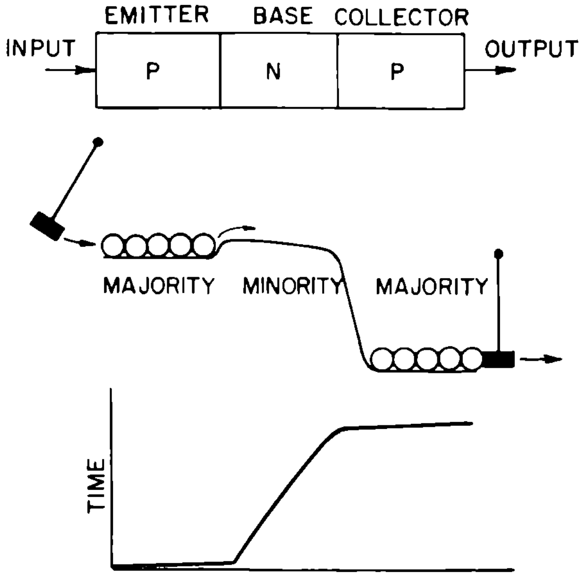

Fig. 1 — Mechnical analogy showing the transistor signalling time problem.

onto the p-region, represented by the racked row of billiard balls. When the hammer hits the first ball, the impulse is transmitted as an elastic wave to the last ball, propelling it into the middle region. Across the middle, the ball rolls with a fixed velocity which corresponds to the drift of the minority carrier through the base region. The anology emphasizes the contrast between majority-carrier signalling by an elastic wave, and minority-carrier, which requires the transport of a discrete charge. Finally, the minority carrier reaches the collector, and the impulse is transmitted to the output as an elastic wave — again, majority-carrier transport.

The bottom section in Fig. 1 gives an idea of the relative times involved. Since the signal propagates as an electro-magnetic disturbance through the emitter and collector, the overall time is limited by the minority-carrier drift. This drift time is always relatively long, for the drift velocity is relatively slow. The speed of a transistor is thus limited by how short the base region can be made. For a 300-Mc transistor, the thickness is already reduced to around 0.1 mil.

This analogy illustrates one other point: while the diffusion region slows the device, it also gives isolation between input and output. This permits triode action for the transistor. The tunnel diode, having no diffusion region (as discussed further), sacrifices the circuit isolation.

TUNNEL-DIODE THEORY AND CHARACTERISTICS

Some idea of the nature of the tunnel diode can be gained from the mechanical anology just discussed by imagining how the barrier to the injection of minority carriers becomes higher and higher until there is no noticeable flow of the balls over the top of the centre region. At the same time, the middle region becomes thinner and thinner. When it becomes thin enough, there is a small probability (from quantum-mechanics theory) that the ball can go from the one majority-carrier band to the other without going over the top. This process is given the descriptive name of tunnelling; it is the basis of charge transport across the junction in a tunnel diode.

Basic Concept

Just over two years ago, Esaki published a letter in the Physical Review, entitled "A New Phenomenon in Narrow P/N Junctions", which described a junction diode with an interesting voltage-controlled negative resistance. The construction of the diode has an appealing simplicity, illustrated in Fig. 2. A 2-mil dot is placed on a thin 2-mil layer of highly conducting germanium (0.001 ohm-cm). The unit is then heated at 400°C for half a minute, forming the junction. It is mounted by soldering the wafer to one lead and the dot to another.

The I-V characteristic of such a diode is shown in Fig. 3, where it is compared with a more normal type of rectifier diode. The dashed line is the rectifier. In the reverse direction, it is blocking until breakdown; while in the forward, it starts to conduct by injection of minority carriers at around 300 millivolts. The tunnel diode (solid line) is highly conducting for all reverse biases. In the forward direction, the current rises rapidly to a sharp maximum, drops to a deep minimum, and then goes over into the typical minority-carrier injection curve. The drop in current with increasing voltage for modest forward bias is the Esaki effect.

Esaki Effect

The Esaki effect combines the phenomenon of electrons tunnelling through a region where their momentum becomes imaginary with the displacement of the energy bands of the crystal under bias voltage. A fundamental discussion of the effect would require going far more deeply into wave mechanics and the band picture of solids than is warranted here. The following

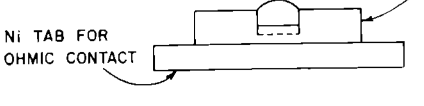

Fig. 2 — Sketch showing the constructional simplicity of the tunnel diode.

simple analogy treats the Esaki effect in terms of transmission through a waveguide. This is not too far-fetched a comparison, for in wave mechanics the electrons are treated as waves and the bands of the semiconductor are associated with the pass band of a waveguide.

Fig. 4 is a waveguide representation of the Esaki effect. The n and p-sides of the semiconductor diode are waveguide sections A and B. The electrons in the semiconductor are electromagnetic waves in the waveguide. The transition region of the diode becomes a connecting piece of waveguide whose dimensions are too small for the impinging wave; i.e., section D is a waveguide beyond cutoff. As a result, the wave leaving A is attenuated exponentially as it traverses section D, and only the most minute amount trickles into B. This is equivalent to the tunnelling of electrons through the transition region.

The Esaki effect is represented as a diaphragm at C in the connecting waveguide. This diaphragm has the property that its transmission coefficient changes with the bias voltage across the diode. In particular, for certain regions of forward bias, the transmission drops with increasing bias.

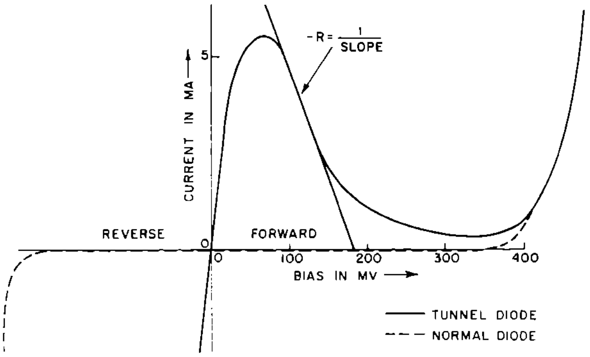

Fig. 3 — Current-voltage characteristics of the tunnel diode.

Transit Time

The waveguide analogy is also very useful as an illustration of the transit time. Through A and B, the signal travels as an electromagnetic wave; i.e., the current is conducted by an elastic wave of majority carriers. Whether or not the only limitation through the transition region D is the wave velocity is not certain yet, but certainly the time delay here will be very short because the thickness is only around 10^{-6} cm. Hence, the tunnel diode does indeed give promise of speeds far beyond the region where bipolar transistors fail.

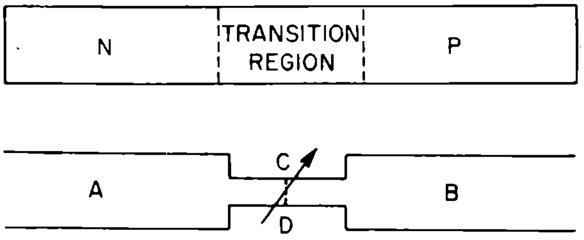

Fig. 4 — A simple waveguide analogy of the "Esaki" effect of the tunnel diode.

Circuit Interpretation

The active character of the tunnel diode (see Fig. 3) is associated with a drop in current for a rise in voltage, which is the negative conductance, or its reciprocal, the negative resistance. Its circuit interpretation is an element with a negative power absorption, i.e., a power generator. The current scale is arbitrary, since the actual current depends on the junction area as well as the transmission coefficient of the barrier. The voltage, however, is roughly representative of the Esaki effect in any material.

The current maximum occurs at a small fraction of a volt, between 40 and 100 millivolts. The current minimum also occurs at small voltages, between ¼ and 2/3 of a volt depending on the material and the processing. To a first approximation, the voltages of the maximum and minimum, as well as the available voltage swing as a device, can be pictured as being constant. This is a great convenience, since the magnitude of the negative resistance can be considered as being determined solely by the peak current.

Equivalent Circuit

The equivalent circuit of the tunnel diode is shown in Fig. 5. The n and p regions act as pure resistances. The transition region is represented as a voltage-sensitive resistance since tunnelling is a function of voltage and junction capacitance. This capacitance is just that of a plane-parallel capacitor with plates separated by the transition region.

Fig. 5-B is the form of the equivalent circuit when the diode is biased to have an operating point in the negative-resistance region. The dynamic resistance is negative, and for small signals both it and the capacitance are constant.

In Fig. 5, a parasitic inductance due to the mounting is indicated (dashed portion). For low-frequency diodes this is unimportant, but at higher frequencies (above 100 Mc) the inductance looms as an increasingly important parameter, as described later.

The figure of merit of a tunnel diode is given by F = 1/(2πRC). This product has two very useful interpretations; it is the diode gain-bandwidth product for linear circuits, and its reciprocal is the diode switching time as a logic element.

This figure of merit gives an inkling of why the tunnel diode is such a flexible element. In most devices, the RC product is practically constant for a given type of structure. For instance, with change in area the capacitance increases at essentially the same rate that the resistance drops, so the product becomes independent of area. The same is true when any one of the linear dimensions is scaled.

For the tunnel diode, however, a new result may be expected. True, the product should again be independent of area; nevertheless, since the capacitance is a classical quantity while the negative resistance is due to tunnelling — a strictly quantum-mechanical concept — R and C may be expected to vary independently of each other. This proves true; the RC product can be changed indefinitely by varying the doping of the semiconductor. As a result, the figure of merit of one structure can be changed from cycles per second to many gigacycles per second simply by increasing the free-carrier concentration in the bulk material.

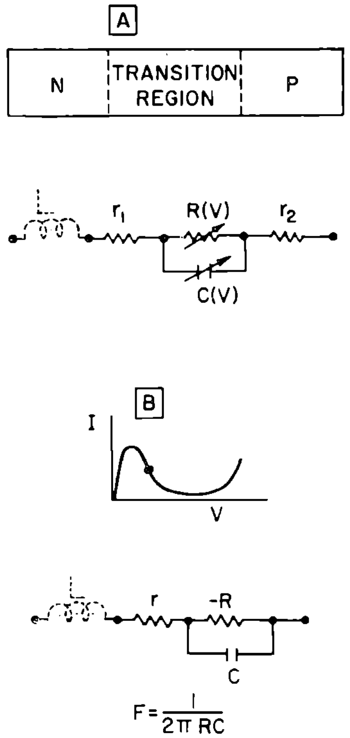

Fig. 5 — Tunnel-diode equivalent circuit, including parasitic inductance due to the mounting.

HIGH-SPEED-SWITCHING APPLICATIONS

As a first example of the applications of tunnel diodes, the switching speed of a diode is graphically analyzed as shown in the equivalent circuit of Fig. 6. This indicates how currents divide inside the diode when a constant-current step is supplied to the diode. It is assumed that the diode, originally in the low-voltage state, is pulsed with a current I_0. Of course, the static curve of the tunnel diode, the ordinary characteristic curve, gives the resistive component through the diode at any voltage. This is the tunnelling current. The rest of the current is used in charging the junction capacitance; the larger this component of current, the faster the diode will switch.

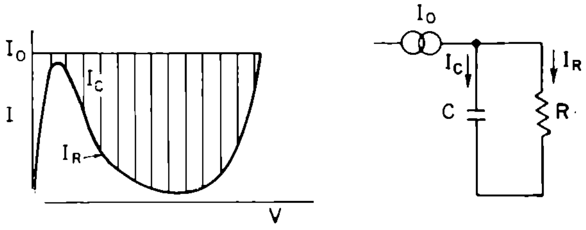

Fig. 6 — Equivalent circuit of the tunnel diode switch showing how currents divide inside the device.

Thus, there will be two distinct regions in the switching transient. Near the current peak is the region where the charging current is quite small and depends very critically on the amount that I_0 exceeds the peak current of the diode. Beyond the peak is the region where the charging current is high and the diode voltage builds up rapidly. The rate of build-up in the switching region will depend on both the slope of the diode characteristic curve and on the capacitance of the junction; hence, the switching time should be determined by the RC time constant of the diode.

Accurate analysis shows that for an appreciable overdrive, the delay in getting over the hump is small and the switching time becomes approximately 2πRC. A rather curious factor in this switching transient is that the capacitive component of the current increases with time over the mid-region of the response.

Fig. 7 is a switching test of a moderate-speed diode. An unbiased diode was driven with a current pulse, and the voltage across the diode monitored on a sampling scope. In the test example, the overdrive was kept small to exhibit the delay, the current pulse exceeding the peak current by perhaps 10 per cent. The delay after

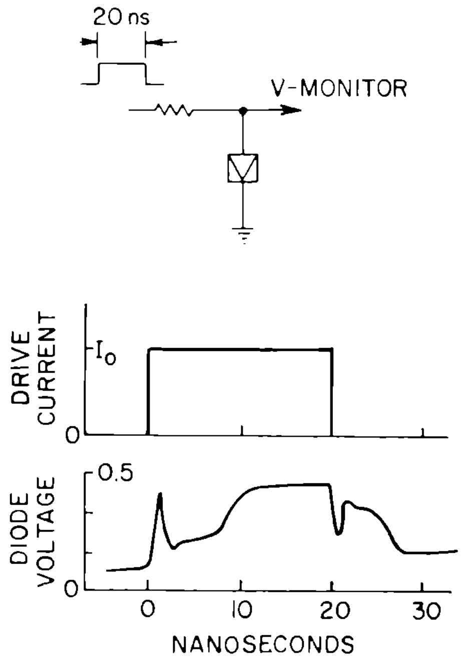

Fig. 7 — Switching-test waveforms showing the total elapsed time for an unbiased, moderate-speed diode.

the application of the pulse is about 8 nanoseconds and the final switching time after passing the hump about 4, giving a total of 12 nanoseconds. On removal of the pulse, the delay was only 4 nanoseconds plus 4 more to get back to zero. From such tests, for a 10 per cent overdrive the total elapsed time is only slightly greater than $2\pi RC$ for the diode.

On application of the pulse, there is a voltage spike caused by the inductance of the diode mount (in this case a transistor stem.) This inductance must be kept very small on high-speed diodes to prevent serious transient effects.

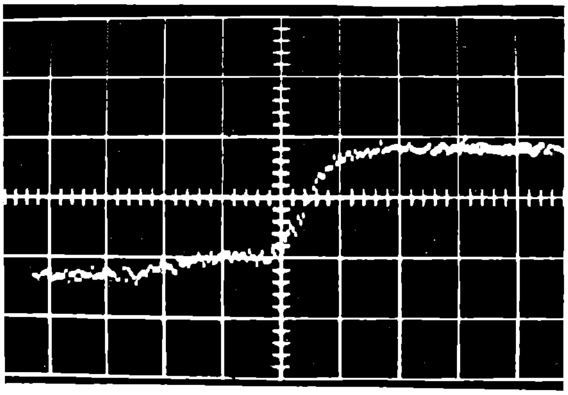

Fig. 8 — Sampling-scope picture of a faster diode than that used in Fig. 7, and in a lower-inductance mount.

For microwave applications, special packaging of the diodes will be required.

Fig. 8 gives a sampling-scope picture of a faster diode in a lower-inductance mount. The overdrive is sufficient so the switching delay is negligible. The scale is 10^{-9} second/division; notice there is no inductive transient for this diode, and the rise is that of the sampling scope.

USE IN LINEAR CIRCUITS

The application of tunnel diodes to linear circuits requires that an operating point be established in the negative-resistance region. The dc load line in Fig. 9 must be very steep so as to intersect the static characteristic at only one point; thus, the dc source must have a resistance r_1 smaller than R. This still permits two possibilities for the ac load line: either steep with one intersection as the load line for an amplifier (a highly-damped circuit), or flat with three intersections, giving oscillation.

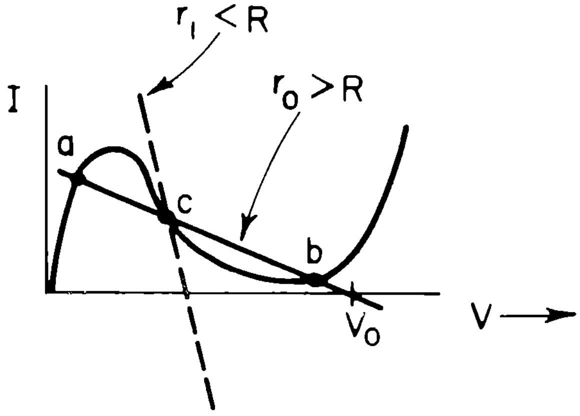

Fig. 9 — Tunnel diode load lines.

Oscillators

Fig. 10 is the circuit schematic of a tunnel-diode oscillator. The left side is the bias supply, the right the tank circuit. The tank is an inductance in parallel with the diode capacitance; the capacitor C_0 is a dc blocking reactor which offers no impedance at the tuned frequency. From D, the tunnel diode, there are two circuits — the tuned circuit B and the input circuit A.

Since the bias supply must have a very low internal resistance r_1 to establish the operating point, the diode actually looks into two tank circuits and can choose between them. In general, it chooses the battery circuit. It takes intelligent circuit design to make the diode work into the tank circuit, but there are a number of examples. They all involve terminating the battery circuit in such a way that from the battery the effective resistance is positive while from the tank circuit it is negative.

Amplifiers

The circuit diagram of a lumped-circuit amplifier made by Chang (see Bibliography) to demonstrate what can be done with a tunnel diode is given in Fig. 11. The battery circuit is connected across the blocking capacitance. Provided C_0 is large enough to satisfy the relation $C_0 > L_0/Rr_0$, the battery looks into a positive resistance at all frequencies and so is stable. The autotransformer T performs the double purpose of tuning the diode capacitance to give a band-pass at the design frequency and of matching the diode to the input and output. The condition for amplification is that the shunt conductance be higher than 1/R, the magnitude of the diode conductance. The circuit becomes a video rather than an if amplifier when the inductance T is omitted.

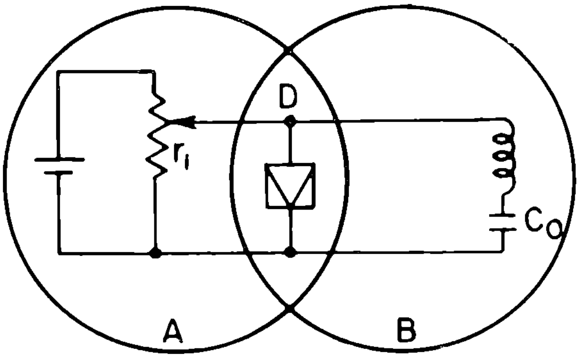

Fig. 10 — Tunnel-diode oscillator, including bias.

The gain of such an amplifier, as well as the gain-bandwidth product, is readily calculated. Since the noise of the diode comes from the shot noise of the bias current, the noise figure can also be calculated. Table 1 shows some early circuit measurements made by Chang. The expression for power gain at the bottom of the table shows that high gain can be achieved by making the parallel conductances cancel each other. Of course, the better the cancellation, the more subject to drift the amplifier gain becomes. Some studies have shown that with passive elements for the input and output, 20 db of gain is a usable level. The next expression is the voltage gain times the bandwidth, which is the usual figure of merit of a circuit. This is determined solely by the constants of the diode for this single-tuned circuit. Thus the diode figure of merit, $F = 1/(2\pi RC)$, can be interpreted as the gain-bandwidth product of the device.

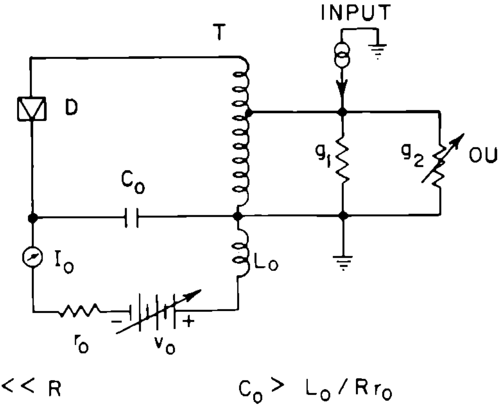

Fig. 11 — Lumped-circuit amplifier.

The third and fourth columns of Table 1 compare the measured values of gain and bandwidth with theory. With proper circuit constants, a gain-bandwidth was obtained equal to the diode figure of merit. The last column shows the comparison of the measured noise figure of the amplifier with the calculated factor, assuming all the noise of the diode is due to the white noise of the bias current.

The agreement is satisfactory, meaning both gain-bandwidth and noise figure can be predicted from the static characteristic of the diode. For germanium diodes at room temperature, a noise figure of about 3 db exists; stated another way, the germanium diode has a noise temperature of about 300° K, independent of frequency up to the diode limit.

A variety of amplifiers have been made that give performance in agreement with predictions. Among these are if amplifiers with 3-db noise figure and 10-percent bandwidth at 20-db gain

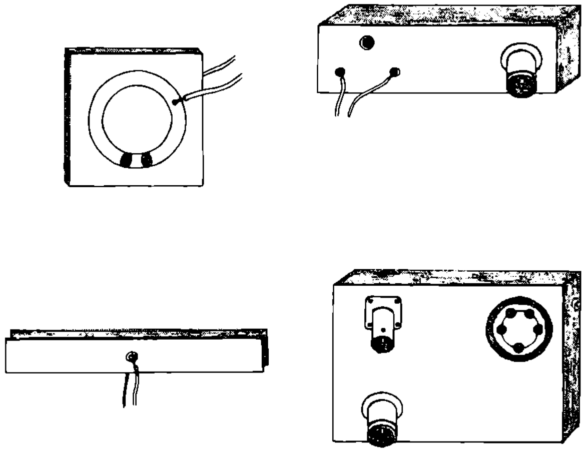

Fig. 12 — An assortment of stripline oscillators for low-microwave frequencies. Top left, ring oscillator; top right, waveguide; bottom left, quarter-wave oscillator, bottom right, packaged stripline oscillator.

TABLE 1 — AMPLIFIER RESPONSE AT 30 MC

Diode Current, μa	Diode Conductance, milliohm	Power Gain, db		Bandwidth, Mc		Noise Factor, db	
		Meas.	Comp.	Meas.	Comp.	Meas.	Comp.
250	−2·7	20	23	0·20	0·30	4·5	4·7
300	−3·2	40	36	0·19	0·16	6·3	5·5
350	−4·8	27	26	0·8	1·05	8·0	6·8

$$\text{Power Gain} \equiv G_p = 4_{g_1 g_2}/(g_1 + g_2 - g)^2 \qquad \text{Noise Figure} = 1 + \frac{1/g}{2KT/e}$$

$$\text{Gain-Bandwidth} \equiv 2G_p{}^{1/2}\,\Delta f = \frac{g}{2\pi C}$$

for frequencies up to nearly 1 Gc, and video amplifiers with 20-db gain and 70-Mc bandwidth. The utility of such amplifiers has not been established as yet, however, because of their sensitivity to the input and output circuits — a sensitivity enhanced by the fact that they are bilateral rather than unidirectional. At present they can only be used successfully when they are inserted between isolating stages rather than with other tunnel-diode amplifiers in cascade.

Circuit-Design Mechanics

Again, consider the tunnel-diode oscillator, which is a simpler use because there is no question of cascading stages. Fig. 12 shows an assortment of stripline oscillator circuits for low-micro-wave frequencies — a very tempting and easy way to make breadboard circuits. The starting point is a printed-circuit board, with copper sheathing on both sides of a 10-to-20-mil sheet of insulation. The circuit is cut out with a pair of scissors and a razor blade. The only additional elements in each circuit are a tunnel diode and a resistor; these are inserted by cutting away the insulation and sandwiching the element between the two copper foils.

The simplest is the quarter-wave stripline oscillator shown in Fig. 12. This has the geometry of a plane-parallel transmission line a quarter-wave long. Looking down on the upper conductor, the left end is the open end of the line; thus it is the voltage-maximum in the standing-wave pattern. One quarter wavelength away, a noninductive resistor with small resistance is inserted, establishing a voltage null at this point and fixing the mode of oscillation. Just beyond this point, the diode is inserted at the extreme right end of the line, so that the diode capacitance is tuned by the wave reflected from the open end of the line. The parallel combination of diode and resistor presents a positive resistance to the input leads, suppressing oscillation in the biasing circuit. When 100 millivolts dc is supplied to the leads shown, the circuit oscillates at 500 Mc. It can be tuned over a considerable band by snipping off segments from the open end with a pair of scissors, or splicing on sections with Scotch tape.

To the right in Fig. 12 is a packaged oscillator of this same type. The dc leads are brought in through a BNC connector and the output is transformed from the 10-ohm level of the strip to a 50-ohm output at the type N connector with a quarter-wave transformer. When this is coupled out through a reactive element in the 50-ohm line, by feeding through a tuning stub, the circuit can be tuned from 1000 to 1500 Mc. The output power is somewhat in excess of one milliwatt.

A modification of this same circuit is shown at the left of Fig. 12. This is a ring oscillator derived from the quarter-wave circuit by closing it around onto itself. The top plate is the ring and the under copper foil is a ground plane. A diode and resistor are inserted, as before, at appropriate points. A radial oscillator is at the top, with the resistor in the centre of the disk and the diode an appropriate distance out along a radius. This oscillator has worked to 2300 Mc but with no output.

The final circuit, at the right in Fig. 12, is a waveguide made from a stripline by closing up all edges. The input circuit incorporates the diode and resistor, which are placed between the end of the top lead and the copper sheet; the output is again matched to the 50-ohm type N connector.

This unit has delivered power to the 50-ohm line but is not yet fully tested; it is designed for operation from 3000 to 6000 Mc. At present the full possibility of this higher-frequency range has not been achieved because the inductance of the diode case is too high to permit stabilization of the dc circuit. To get a milliwatt at 6 Gc, the diode case inductance must be reduced to 10^{-10} henry.

The simplicity and compactness of these circuits are outstanding. The small size can be appreciated by scaling them against the output connectors, which cover a large share of the entire construction. Obviously, miniature connectors are going to be in demand.

PACKAGING TUNNEL DIODES

For the kind of circuitry in Fig. 12, the tunnel diode must of course be in a flat package, the most desirable geometry in microwave applications, for several reasons; first, the tunnel diode is inherently a low-impedance unit, since it has a large capacitance ranging from 10 to 100 pf for commercially available units. The flat packaging reduces the series inductance and still does not introduce appreciable capacitance. Also, this type of mount is naturally very small and permits high-packing density.

Probably some version of the mount with pigtail leads will be the cheapest and so the popular one for low frequencies. In the uhf region, however, the stripline mount becomes desirable because of its inherently smaller inductance. Some form of this will probably be used for micro-wave devices.

INHERENT DIFFICULTIES

Along with the attractive features of the tunnel diode, the circuit engineer should be aware of certain application limitations. Negative-resistance diodes are in a class different from ordinary devices and generally cannot be directly substituted into existing circuits.

The tunnel diode suffers with all diodes in being bilateral for small signals — it has nothing to define in from out. In general, the engineer must build into his circuits the function that the extra electrode in the triode serves — isolation beween input and output. This is a relatively new problem and one for which no general solution yet exists.

Also, the tunnel diode is by its nature a low-impedance, low-power device. Since its voltage swing is less than a volt, power output comes only from large current, which means low impedance. For germanium diodes, an approximate relationship for available power is $P = (2 \times 10^{-3})/R$ watts, where R is the resistance of the circuit. From a 10-ohm diode, 0.2 milliwatt of power is obtained. While it is conceivable that tunnel diodes can be made with a milliohm resistance, it is not so obvious that milliohm circuits can be readily made; if they can be produced, then 2-watt diodes are possible.

CONCLUSIONS

The tunnel diode is a simple, low-power, low-noise device which is usable from dc to the centimeter range. It is smaller, more rugged, and more stable against changes in ambient conditions and radiation than other active semiconductor devices. However, it is of lower impedance than present devices, and it is bilateral.

These factors mean general application of tunnel diodes will require much circuit research. Probably the first uses on any scale will be in applications where a single operation is performed in a manner analogous to present functions, such as oscillators, discriminators, or detectors. The full possibilities of the device will only be disclosed as the new circuits and the device characteristics become adapted to each other.

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- **Switching speeds to 1/5 millimicrosecond.**
- **Peak current of 5, 20, and 50 ma controlled to ±5%.**
- **Wide operating temperature range — –65 to +150°C.**
- **Low-inductance ceramic-to-metal package — makes possible extremely short rise time.**
- **Match-head size — permits high-density equipment packaging.**
- **Hand- or dip-solderable — withstand immersion for 10 seconds at 275°C.**
- **New type internal construction — permits tighter control of characteristics than has heretofore been practicable in tunnel diodes.**

ULTRA-HIGH-SPEED SWITCHING AND PULSE-GENERATING DEVICES FOR COMPUTER APPLICATIONS

Germanium Tunnel Diodes

1N3128 is a low-current type for applications employing clock (pulse-repetition) rates up to 100 Mc with typical switching times of two millimicroseconds or less. The very low power dissipation (2.5 mw) permits its use in high-density packages operating at high temperatures.

1N3129 is an intermediate-speed type for applications employing clock rates up to 500 Mc with typical switching times of ½ millimicrosecond or less. As a memory device, the 1N1329 can operate at a clock rate of 1000 Mc at high ambient temperatures.

1N3130 is an ultra-high-speed type for applications employing clock rates up to 1000 Mc with typical switching times of 1/5 millimicrosecond or less.

Gallium-Arsenide Tunnel Diode

1N3138 is a high-speed type for use as a switching device in digital-pulse circuits and memory matrices, and in other applications requiring switching times of ½ millimicrosecond or less and clock rates up to 1000 Mc.

Maximum Ratings, Absolute Values:

Forward Current	100	ma
Reverse Current	200	ma
Dissipation at $T_a = 25°C$: *		
1N3128 — 1N3130	40	mw
1N3138	75	mw
Ambient Temperature Range:		
Operating	–65 to + 150°C	
Storage	–65 to + 175°C	
Case Temperature for immersion in molten solder for 10 seconds max.	275	°C

* Derate linearly to zero watts at 150°C.

Electrical Characteristics at $T_a = 25°C$:

1N3128

I_p	5±5%	ma
I_v, minimum	0.45	ma
typical	0.6	ma
I_p/I_v, minimum	8/1	
typical	11/1	
V_p, minimum	45	volts
maximum	65	volts
V_v, minimum	280	volts
maximum	330	volts
$V_f{}^1$, minimum	445	volts
maximum	485	volts
C_D †, typical	7	pf
maximum	15	pf
L_s, typical	0.4	nh
r_s, maximum	1.5	ohms
R_D, typical	–22	ohms
P_{OPR}, ‡ typical	2.5	mw
I_p/C max.	0.33	ma/pf

†‡ See next page.

1N3129

I_p	20±5%	ma
I_v, minimum	1.8	ma
typical	2.4	ma
I_p/I_v, minimum	8/1	
typical	11/1	
V_p, minimum	65	volts
maximum	90	volts
V_v, minimum	300	volts
maximum	360	volts
V_f^1, minimum	500	volts
maximum	550	volts
C_D †, typical	10	pf
maximum	20	pf
L_s typical	0.4	nh
r_s, maximum	1.5	ohms
R_D, typical	−6	ohms
P_{OPR}, ‡ typical	12	mw
I_p/Cmax.	1.0	ma/pf

1N3130

I_p	50±5%	ma
I_v, minimum	4.5	ma
typical	6.0	ma
I_p/I_v, minimum	8/1	
typical	11/1	
V_p, minimum	90	volts
maximum	120	volts
V_v, minimum	350	volts
maximum	430	volts
V_f^1, minimum	540	volts
maximum	600	volts
C_D †, typical	12	pf
maximum	25	pf
L_s typical	0.4	nh
r_s, maximum	1.2	ohms
R_D, typical	−2.4	ohms
P_{OPR}, ‡ typical	32	mw
I_p/Cmax.	2.0	ma/pf

1N3138

I_p	50±5%	ma
I_v, minimum	2.5	ma
typical	3.5	ma
I_p/I_v, minimum	13/1	
typical	20/1	
V_f, minimum	120	volts
maximum	260	volts
V_v, minimum	510	volts
maximum	620	volts
V_f^1, minimum	1100	volts
maximum	1400	volts
C_D †, typical	10	pf
maximum	30	pf
L_s typical	0.4	nh
r_s, maximum	2.6	ohms
R_D, typical	−2.6	ohms
P_{OPR}, ‡ typical	73	mw
I_p/Cmax.	0.9	ma/pf

† Capacitance measured at I_v and includes case capacitance of 0.3 pf.

‡ Steady-state power with tunnel diode switched to V_f^1.

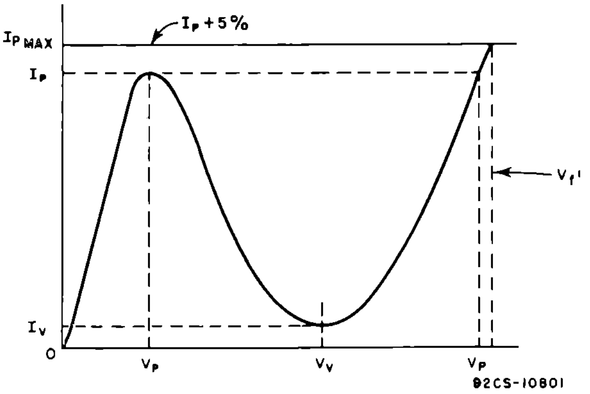


Fig. 1 — Static Forward Characteristic of a Tunnel Diode.

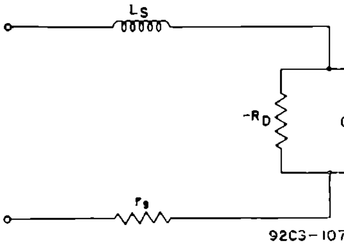
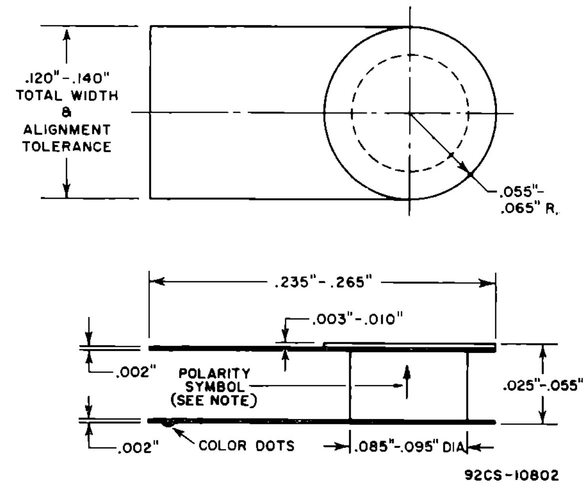


Fig. 2 — Equivalent Circuit of a Tunnel Diode in the Negative Resistance Region.

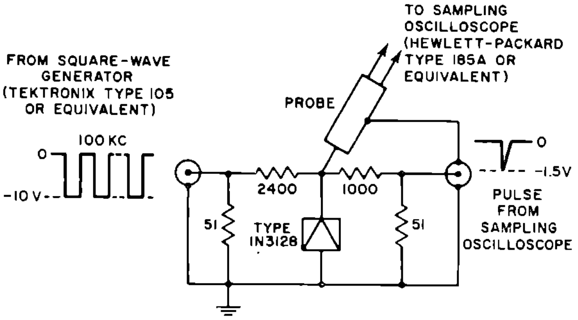
COLOUR CODES

1N3128	Red/Grey
1N3129	Red/White
1N3130	Orange/Green
1N3138	Yellow/Black

DIMENSIONAL OUTLINE



NOTE: ARROW INDICATES DIRECTION OF FORWARD CURRENT FLOW AS INDICATED BY DC AMMETER.



NOTE 1: ALL RESISTANCE VALUES IN OHMS.
NOTE 2: SAMPLING OSCILLOSCOPE TRIGGERED BY SYNCHRONIZING SIGNAL FROM SQUARE-WAVE GENERATOR.

92CS-10800

Fig. 3 — Circuit used to Measure Rise Time of Type 1N3138.

DEFINITIONS OF SYMBOLS

The static characteristics are defined with respect to the static forward characteristic shown in Fig. 1.

I_p = Value of the static current flowing at the lowest positive voltage at which $d_I/d_V = 0$.

I_v = Value of the static current flowing at the second lowest positive voltage at which $d_I/d_V = 0$.

V_p = The lowest positive voltage at which $d_I/d_V = 0$.

V_v = The second lowest positive voltage at which $d_I/d_V = 0$.

P/V = The peak-to-valley ratio = I_p/I_v.

$V_f{}^1$ = The positive voltage at which $I = I_{Pmax}$.

The dynamic characteristics are defined with respect to the equivalent circuit shown in Fig. 2. Because C_D and R_D are functions of the operating voltage, a statement of the operating voltage is necessary to define the equivalent circuit.

L_S = The total series equivalent lead inductance.

r_S = The total series equivalent lead resistance.

C_D = The barrier capacitance of the intrinsic diode.

R_D = The negative resistance of the intrinsic diode.

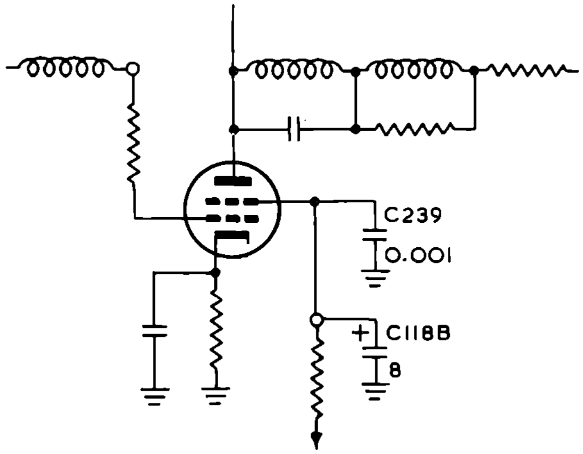
I_p/Cmax = Figure of Merit. The figure of merit for a gallium-arsenide tunnel diode for switching applications is approximately 1/2 that for a germanium tunnel diode having the same I_p and C_D because of the increased voltage swing.

CAPACITOR CHARACTERISTICS

You may have noted that electrolytic and other large-value capacitors sometimes have small-value capacitors placed in parallel with them. There is good reason for this. The larger capacitors introduce inductive characteristics in high-frequency circuits that in certain instances must be compensated for. The small value capacitors offset the inductive reactance inherent in the larger capacitors and contribute considerably to circuit performance.

This arrangement is often found in video amplifiers, as shown in the partial schematic. In this circuit, C239 compensates for the inductance inherent in C118B, the electrolytic by-pass capacitor. In this instance, if the inductance of the electrolytic (which is appreciable at 4 megacycles) was not compensated for, a degenerative action would take place in the screen circuit which would impair the response of the video amplifier.

Small capacitors paralleling larger capacitors in television receivers serve to improve receiver performance and minimize signal radiation; recognizing their importance can sometimes be of advantage to a technician attempting to attain optimum performance from a television receiver. Always check these capacitors when servicing a receiver that is lacking proper frequency response or suspected of undesirable signal radiation.



HIGH-VOLTAGE RF PROBE

By Joseph Talavage *

A 500-volt rf probe, useful for obtaining the resonance point of transmitter tank circuits, grid circuits, and other high voltage rf circuits, can be easily constructed with readily available components and two silicon rectifiers. Fig. 1 shows the simple schematic diagram for the probe. C1 is a 500 pf ceramic capacitor with a 1 Kv rating, and R1 a 4.7 megchm half-watt resistor.

1N1764 silicon rectifiers are used in the probe. Because these rectifiers have a peak inverse voltage of 500 volts each, the two connected in series permit the probe to be useful to peak voltages of 500 volts, or about 350 volts rms. The addition of more rectifiers raises the peak-voltage rating of the probe by 250 volts for each additional rectifier, a decided advantage over a typical crystal-diode rf probe which has a maximum operating voltage of about 28 volts peak.

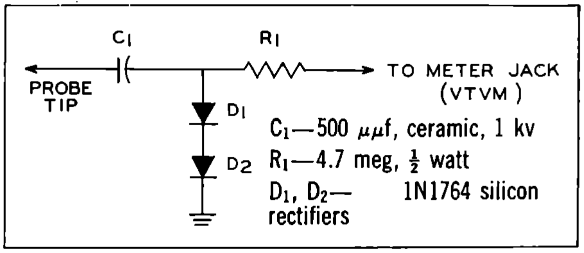


Fig. 1 — Simple schematic diagram of the author's half-kilovolt rf probe.

It must be remembered that if further 1N1764's are added to produce a higher operating range, then the rating of capacitor C1 should be adjusted accordingly.

Circuit operation is such that the dc output of the probe is proportional to the peak value of the input wave. For this reason, and because

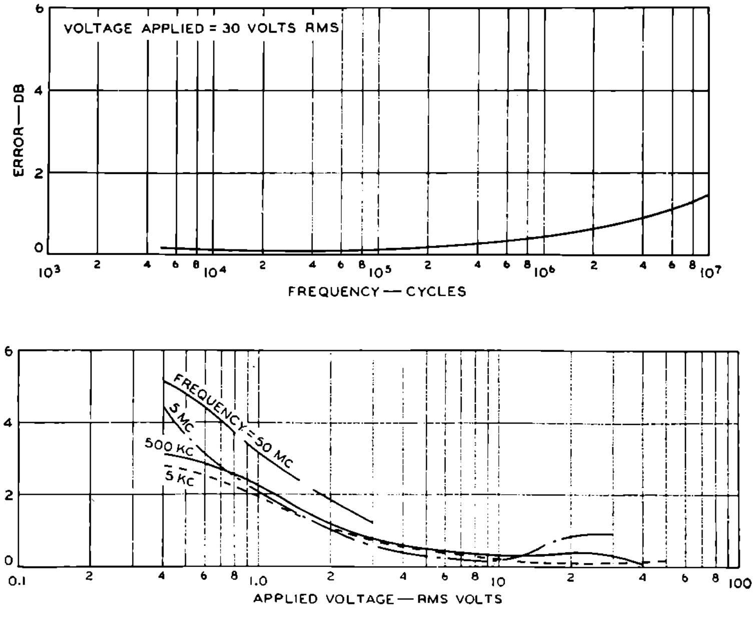


Fig. 2 — Error versus frequency and error versus applied voltage curves show that for frequencies up to 50 Mc, the greatest accuracy is obtained at voltages over 30 volts.

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* RCA Semiconductor and Materials Division, Somerville, N.J.

of the value selected for R1, best accuracy is obtained when the input wave is sinusoidal.

An increase in the value of C1 will extend the low-frequency response, but will also affect the accuracy of the reading. However, if C1 is increased in value, the accuracy of the probe can be adjusted to an optimum value by means of compensating changes in the value of R1.

The probe circuit can be constructed to fit easily inside a discarded low-capacitance probe case. It was connected directly to a Senior Volt-ohmyst, through a shielded cable, and tested over a frequency range from 5 kilocycles to 50 megacycles, and a voltage range from 0.4 to 50 volts rms. Fig. 2 shows that for frequencies to 50 Mc, the greatest accuracy is obtained at voltages greater than 3 volts. The loading effect of the probe on resonant tank circuits was found to be negligible to at least 10 Mc.

Although all the tests were made with only one rectifier in the probe, the accuracy above 3 volts is relatively unaffected by the addition of the second rectifier.

Use of the probe involves a few simple steps: (1) place the selector switch of the VTVM in the "-DC" position; (2) apply the probe tip and ground wire to the correct points; and (3) read the rms value of the rf voltage on the appropriate dc scale.

(With acknowledgements to RCA)

VHF BROADCASTING IN GERMANY

Imperative necessity is often the best incentive to technical progress. This was again demonstrated by Germany, who, after its collapse in 1945, faced political and economic distress and had to struggle hard for recovery and to provide subsistence for its 50 million inhabitants.

Among many other systems, the excellently-organized German broadcasting system was also completely destroyed. The German broadcasting companies were dissolved; the numerous and powerful broadcasting transmitters had been partly destroyed, some of these transmitters had been disassembled and moved to other localities. Even the number of existing broadcast receivers was reduced to a fraction, since the effects of warfare had reached into almost every home.

In consequence of the first new regulation on frequency allocations after World War II, by the Copenhagen Conference, Germany was deprived of nearly all of its formerly-utilized broadcasting frequencies. The number of German transmitters was limited, they were reduced in power, and were given only the most unfavourable wavelengths. Even these unfavourable wavelengths were also utilized by more distant but much more powerful foreign transmitters.

However, the entire standard broadcast band was already over-crowded and, for the ever-increasing number of new transmitters, it was difficult to obtain suitable frequencies which would not interfere with each other. Since Germany is situated in the centre of Europe, the interferences originated from all directions, and in the first postwar years it was hardly possible to obtain reliable and undisturbed broadcast reception. This unfortunate situation made it necessary to seek a solution by utilizing a new and hitherto unused region of the radio spectrum. Since, however, all previously utilized wavelengths for transmissions by wireless (down to very low-frequency waves of a length around 20,000 metres and up to short waves beginning with a length of 10 metres) had already been allocated and fixed internationally, only the region of the so-called very-high-frequency waves remained. These are the wavelengths in the band from 10 to 1 metre, from which the region of about 3 metres wavelength, the so-called 100-megacycle band, was chosen.

These very-high-frequency waves have many advantageous properties: they propagate only in a straight line and, therefore, do not follow the curvature of the earth. Consequently, the range of the vhf waves coincides approximately with the optical range. The range of vhf waves depends on the elevation of the transmitting antenna, offering the advantage that stations situated beyond the horizon can no longer interfere with the reception of the desired station. Moreover, very-high-frequency waves are reflected only to a small degree by the Heaviside layer. The radiation of these waves requires only very reduced output powers. Finally, a further advantage of vhf waves consists in the possibility of accommodating a considerable number of stations next to each other even at increased frequency spacing of the transmitters.

Certain experience in the new vhf technique had been gained already. The exceptional possibilities of these vhf waves had been recognized during experiments which were made in Germany already in 1925 by Professor Esau and continued by Telefunken. Very-high-frequency waves had already been used for television and for establishing radio links — these waves had also been utilized for radio-telephone communications in most countries during the war. Several vhf transmitters for broadcasting purposes confined to certain localities had already been employed in the U.S.A.

However, the characteristics of the vhf channels offered yet a further possibility. Already during the first experiments made in Germany it was recognised that it would be possible to use this wave in a different way from that hitherto customary for the carrier of the sound and voice modulation. Whereas conventional broadcasting transmitters on all frequencies had used amplitude modulation, now the newer type of transmission, frequency modulation, was used. Frequency modulation has the advantage of a much wider frequency band. This leads to a considerable improvement in the tone quality of the voice and of the music reproduced. At the same time, the frequency-modulated wave is far less sensitive to interference. A higher quality of tone and better selectivity can thus be obtained by frequency modulation. One of the possible disadvantages results from the more complicated circuits which frequency modulation requires in the transmitters and receivers.

At the time when the radio field in Germany faced the necessity of introducing vhf broadcasting as the sole means of solving the perplexing broadcasting problem, it was rightly realized that the progress resulting from the development of frequency modulation should not be neglected. In spite of all the economic distress during the reconstruction of the German broadcasting network, the idea of this new development in radio was taken up by Professor Dr. Werner Nestel, who at that time was the technical director of the most important German broadcasting institute; he is now a member of the management of Telefunken and head of its research institute. With the adoption of this new development, Professor Nestel created for the German broadcasting system a new instrument of outstanding technical quality and organization.

The reduced range of the transmitters made it necessary to set up a relatively dense network of stations throughout the German Federal Republic. On the other hand, in view of their limited ranges, it was possible for transmitters which were situated at a sufficient distance from each other, to use the same frequencies without interfering with each other. This property had also the advantage that no objections were raised, even on the part of the occupational powers, to the introduction of vhf broadcasting in Germany. For it was precisely the limited range which had excluded the broadcasting of German programmes to the neighbouring countries.

In the spring of 1950, the Copenhagen Conference decisions became effective. The standard broadcast band, which was congested already before the war, hardly offered any possibility of receiving a station within Germany without suffering considerable interference from other European transmitters surrounding Germany. Now it became evident that the German Federal Post Office and the new broadcasting companies had taken the proper measures. The first vhf transmitters by Telefunken had started to transmit in Munich and Hanover in February, 1949. Since a single transmitter equipment operates with low power, it was possible to build up the network rapidly. In 1953 this network comprised already 80 transmitters and, at the beginning of 1960, about 150. Today there is hardly any place in the German Federal Republic where it is not possible to receive at least one programme on vhf. With modern radio sets it is possible to receive 5 or 6 and even 10 and more different programmes on vhf, without interference of any kind and with excellent quality of sound.

Along with the completion of the transmitter network in Germany, it was also necessary to adapt the receivers to the new wave band. Only about half of all broadcast receivers in Germany had survived the war. At the time of its postwar reconstruction, the German radio industry realized the opportunity given and immediately undertook to provide new radio sets with a vhf band in addition to the long-wave, short-wave and standard broadcast bands. For those older models of radio sets, many of which were in possession of listeners who, at the beginning of the postwar period, could not afford to buy new radio sets, the industry provided adapters that permitted the old radio sets to be used for vhf reception.

(With acknowledgements to Telefunken)

3746

DOUBLE-EMITTER DRIFT-FIELD TRANSISTOR

- **Excellent high-frequency response.**
- **High gain.**
- **Low feedback capacitance.**
- **As a superheterodyne mixer-oscillator: eliminates need for separate oscillator transistor.**
- **Provides superior agc without use of overload or clamping diodes.**
- **Permits agc to be applied directly to mixer section without affecting oscillator performance.**
- **Assures freedom from oscillator blocking under transient strong-signal conditions.**
- **Permits independent optimization of mixer - circuit and oscillator - circuit operating conditions.**
- **Excellent performance as a two-signal mixer.**
- **Suitable for switching applications utilizing either additive or coincident control.**

The RCA 3746 is a general-purpose drift-field transistor of the germanium p-n-p alloy type, with two emitters. These two emitters permit the 3746 to be used in a wide variety of applications requiring control of an output current by signals from two sources. Such applications include: mixer-oscillator circuits in superheterodyne receivers, mixer-amplifier circuits, and switching circuits.

GENERAL DATA

Electrical, at $T_a = 25°C$:

Maximum DC Collector-to-Base Voltage (V_{CB}), with emitters No. 1 and No. 2 tied together, dc collector current of -50μa, and dc base-to-emitter voltage of -0.5 volt	–34	volts
Maximum DC Collector Cutoff Current (I_{CBO}) for a dc collector-to-base voltage of -12 volts, and both emitters open	–16	μa
Maximum DC Emitter Cutoff Current (I_{EBO}), with emitters No. 1 and No. 2 tied together, dc emitter-to-base voltage of -0.5 volt, and collector open	–16	μa
Thermal Resistance:		
In free air	400	°C/w
With infinite heat sink	100	°C/w
Intrinsic Base Resistance	55	ohms
Collector-to-Base Capacitance	3.8	pf

Mechanical:

Outline and Base	JEDEC To–44

Maximum Ratings, Absolute Values:

DC Collector-to-Base voltage	–34	volts
DC Emitter-No. 1-to-Base voltage	–0.5	volt
DC Emitter-No. 2-to-Base-voltage	–0.5	volt
DC Collector current	–20	ma

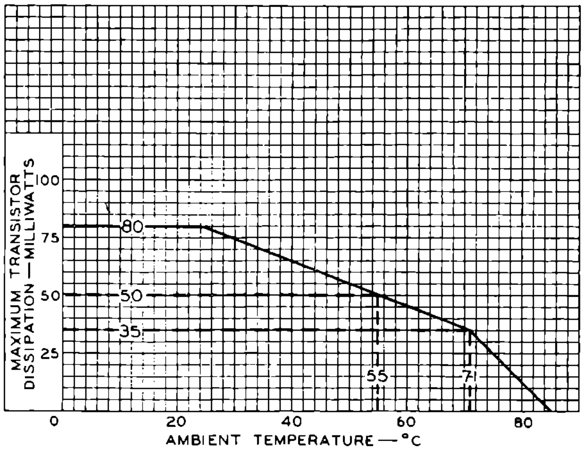
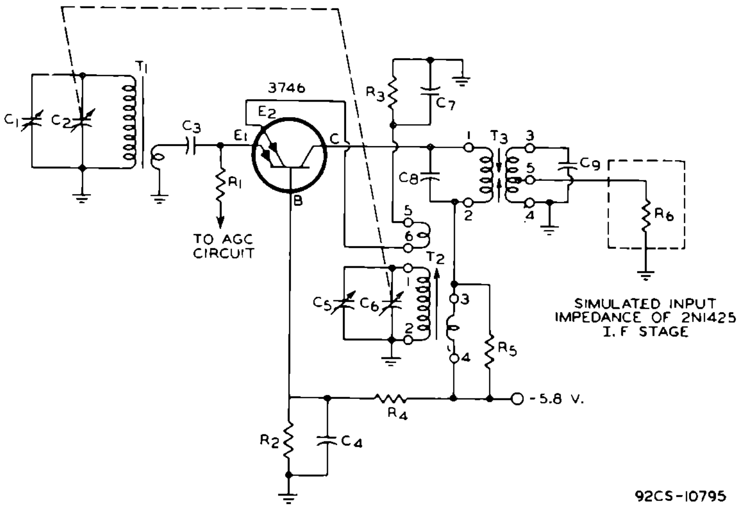


Fig. 1 — Rating Chart for Type 3746.



C_1, C_5: Trimmer capacitors, 2-14 μμf
C_2: Antenna tuning capacitor, 7-158 μμf, ganged with C_6
C_3: 0.05 μf, paper, 6 v.
C_4: 0.47 μf, paper, 6 v.
C_6: Oscillator tuning capacitor, 7-78 μμf, ganged with C_2
C_7: 0.005 μf, paper, 6 v.
C_8: 36 μμf, silver mica, 500 v.
C_9: 40 μμf, silver mica, 500 v.

R_1: 1200 ohms, 0.5 watt
R_2: 4700 ohms, 0.5 watt
R_3: 2200 ohms, 0.5 watt
R_4: 12,000 ohms, 0.5 watt
R_5: 3300 ohms, 0.5 watt
R_6: 1800 ohms
T_1: Antenna transformer
T_2: Oscillator transformer
T_3: Intermediate-frequency transformer

Fig. 2 — Capacitor-Tuned Oscillator-Mixer Stage Utilizing Type 3746.

DC Emitter current ($I_{E1} + I_{E2}$)	+20	ma
Transistor Dissipation:		
At $T_a = 25°C$	80	mw
At $T_a = 55°C$	50	mw
At $T_a = 71°C$	35	mw
Ambient Temperature:		
Operating	71	°C
Storage	–65	to +85°C

Characteristics, at $T_a = 25°C$:

Common-Base Circuit, Emitter Input

DC Collector-to-Base Voltage	–12	volts
Current-Transfer Ratio (at 1 Kc):		
For $I_{E1} = 1$ ma, $I_{E2} = 0$	0.985	
For $I_{E1} = 0$, $I_{E2} = 1$ ma	0.985	
Alpha-Cutoff Frequency	40	Mc

Typical Operation:

In Mixer-Oscillator Circuit Shown in Fig. 2.
$f_o = 1$ Mc $T_a = 25°C$

Common-Base Circuit, Emitter Input

DC Collector-to-Base Voltage	–4.4	volts
DC Current in Emitter No. 1 (Signal Emitter)	1	ma
DC Current in Emitter No. 2 (Oscillator Emitter)	0.5	ma
Input Impedance (Signal Emitter)	25	ohms
Conversion Power Gain (1 Mc to 455 Kc) for emitter No. 1-to-collector load impedance of 300,000 ohms	26	db
Oscillator Voltage at Emitter No. 2	80	mv

Typical Operation:

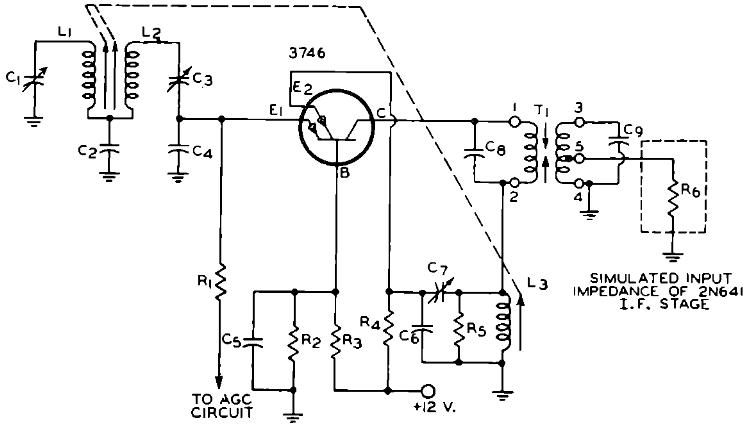
In Mixer-Oscillator Circuit Shown in Fig. 3.
$f_o = 1$ Mc $T_a = 25°C$

Common-Base Circuit, Emitter Input

DC Collector-to-Base Voltage	–10.5	volts
DC Current in Emitter No. 1 (Signal Emitter)	1.1	ma
DC Current in Emitter No. 2 (Oscillator Emitter)	0.42	ma
Input Impedance (Signal Emitter)	23	ohms
Conversion Power Gain (1 Mc to 262.5 Kc) for emitter No. 1-to-collector load impedance of 346,000 ohms	27	db
Oscillator Voltage at Emitter No. 2	145	mv

AGC Characteristic:

Automatic gain control for the 3746 in mixer-oscillator applications may be obtained by varia-



92CS-10794

C_1: Trimmer capacitor, 50 $\mu\mu$f approx.
C_2: 0.01 μf, paper, 15 v.
C_3: Trimmer capacitor, 110 $\mu\mu$f approx.
C_4: 0.005 μf, paper, 15 v.
C_5: 0.2 μf, paper, 15 v.
C_6: 0.0033 μf, paper, 15 v.
C_7: Padder capacitor, 550 $\mu\mu$f approx.
C_8: 47 $\mu\mu$f, silver mica, 500 v.
C_9: 50 $\mu\mu$f, silver mica, 500 v.

L_1, L_2: Antenna-transformer windings
L_3: Oscillator coil
R_1: 1500 ohms, 0.5 watt
R_2: 22000 ohms, 0.5 watt
R_3: 5600 ohms, 0.5 watt
R_4: 4700 ohms, 0.5 watt
R_5: 3300 ohms, 0.5 watt
R_6: 1400 ohms
T_1: Intermediate-frequency transformer

Fig. 3 — Inductance-Tuned Oscillator-Mixer Stage Utilizing Type 3746.

tion of the current in the signal emitter (emitter No. 1). The agc characteristic of the 3746 as a function of emitter No. 1 current is shown in Fig. 4.

OPERATING CONSIDERATIONS

The flexible leads of this transistor are usually soldered to the circuit elements. Soldering of the leads may be made close to the glass stem provided care is taken to conduct excessive heat away from the lead seal. Otherwise, the heat of the soldering operation may crack the glass seals of the leads and damage the transistor.

It is recommended that this transistor not be connected into or disconnected from circuits with the power on because high transient currents may cause permanent damage to the transistor.

When dip soldering is employed in the assembly of printed circuitry using this transistor, the temperature of the solder should not exceed 255°C for a maximum immersion period of 10 seconds.

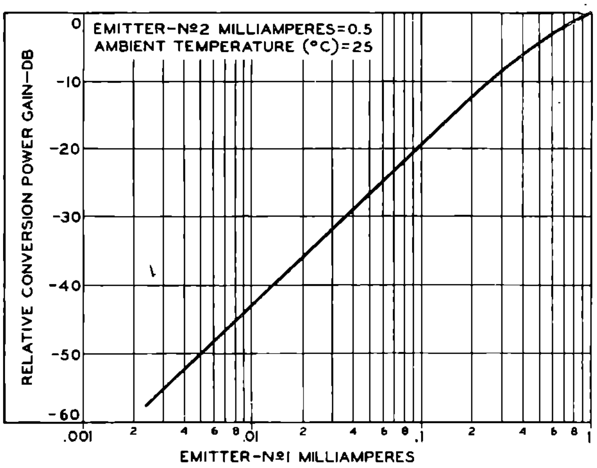


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Fig. 4 — Performance Characteristic of Type 3746.

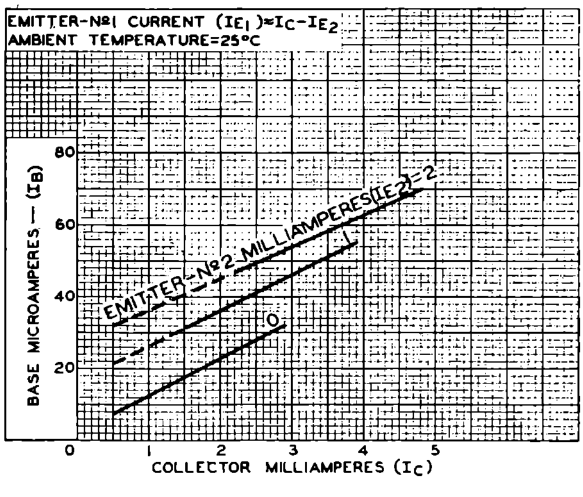


Fig. 5 — Typical Characteristics of Type 3746.

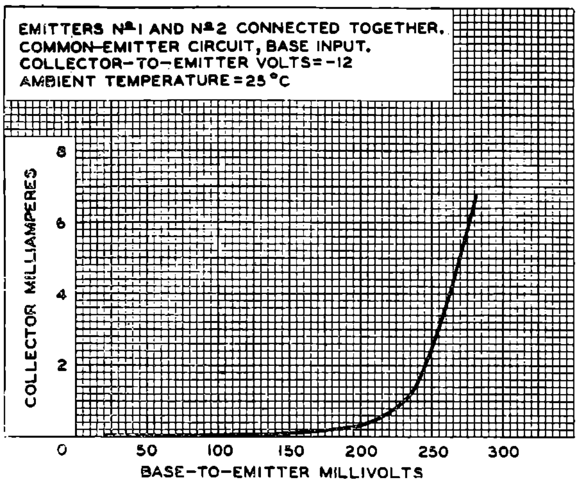


Fig. 6 — Typical Characteristic of Type 3746.

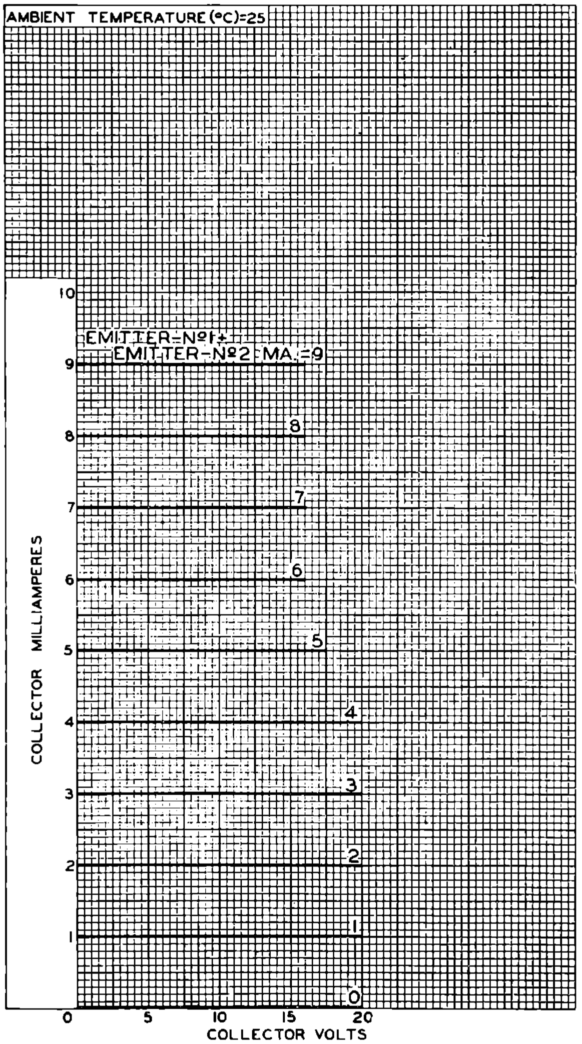
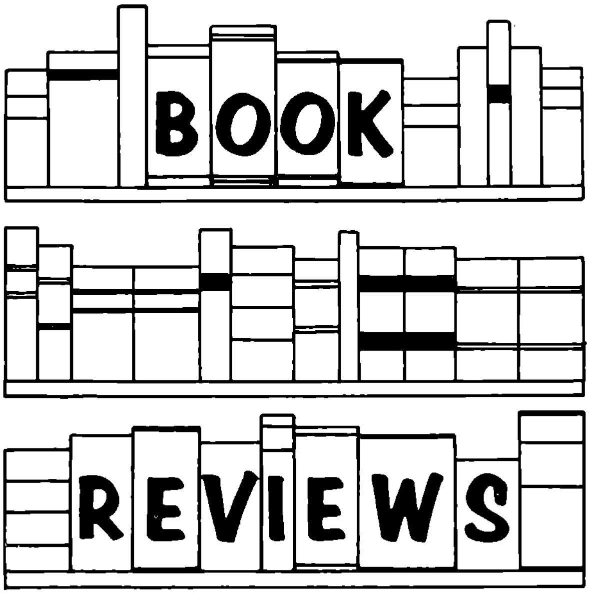


Fig. 7 — Output Characteristics of Type 3746 in Common-Base Circuit.



"Getting the Most out of Vacuum Tubes", Robert B. Tomer, Howard W. Sams & Co. Inc., 5½" x 8¾". 160 pages. 25 diagrams.

It has been said that about 80% of all electronic equipment failures result directly or indirectly from valve failures; yet it is an acknowledged fact that the valve manufacturer today possesses skills and manufacturing "know-how" which result in the production of a very high-grade item. There is a paradox here, and to solve it we can quote from the preface of this book.

Mr. J. M. Bridges, Director of Electronics in the U.S. Defence Department has stated "It has been demonstrated by service tests that the average number of tube failures per operating hour in two equipments of equal complexity — can differ by as much as a factor of ten, due entirely to differences in the thoroughness and completeness of engineering design." Aeronautical Radio's General Report No. 2, 1957 states "The influence of maintenance personnel is one of the dominant causes of unreliability in military equipment." The report goes on to state a conclusion that one out of every three valves removed from military equipment was, in fact, a "good tube."

This book is unusual in its field, interesting and authoritative. It has been written to point up those engineering practices leading to premature valve failure, and maintenance practices leading to additional failures. This book should be read by every user of valves, but particularly by those responsible for the design and maintenance of the more complex equipments.

Next page please.

"Basic Mathematics for Electronics", N. M. Cooke, McGraw-Hill Book Company Inc. Size 9" x 6". 679 pages.

This is the second edition of a book which originally appeared under the title "Mathematics for Electricians and Servicemen." The book has been considerably expanded and rewritten under the new title, but its purpose remains the same. The book is intended to provide students of electronics and electrical subjects with a sound background in basic mathematics. It does this very well, and in a surprisingly "readable" way. This results from the fact that problems are approached from the practical viewpoint rather than as hypothetical cases written around undefined situations.

The study of mathematics is a fascinating one, founded as it is on sound logic and orderly reasoning. It thus offers a student not only the ability to gain a better understanding and knowledge of his chosen subjects, but, by increasing his mental capacity, enables him to deal more effectively with all the problems he meets through life. There must be many thousands of people who have gained a practical knowledge of electronics by a "rule of thumb" method, and who would benefit to an untold extent by a sincere study of a book such as this.

NEW RELEASES

6166-A/7007

The 6166-A/7007 is a forced-air-cooled beam power valve featuring ceramic-metal construction. The 6166-A/7007 supersedes and replaces type 6166-A and is a direct replacement for types 7007 and 6166.

The 6166-A is intended for vhf service in television and cw applications as an rf power amplifier. The 6166-A/7007 can deliver a synchronizing-level power output of 14 kilowatts in broadband television service at 216 Mc; a carrier-power output of 6 Kw in plate modulated telephony service using conventional grid-drive circuits operating at 60 Mc; and a power output of 12 kilowatts in class C telegraphy service using grid-drive circuits operating at 216 Mc.

7295-A

The 7295-A is a new 4½" image orthicon camera tube. This new tube is a companion to, and interchangeable with, the 7389-A, and provides superior outdoor or studio pickup for black-and-white TV under conditions where scene contrast cannot conveniently be limited. Thus the 7295-A adds operational range to 4½" cameras designed to provide outstanding pictures. The 7295-A is unilaterally interchangeable with the 7295.

7389

The 7389 is a new 4½-inch image orthicon from EEV, featuring a target capacitance between that of the P812 and of the 7295(P811). It has an improved signal-to-noise ratio, and reduced edge and halo effects when compared with the 7295. The 7389 is primarily intended for studio use where some measure of control over scene illumination is possible, so enabling the full benefits inherent in this tube to be realised. Its sensitivity however is adequate for outside broadcasts under normal conditions. The operational sensitivity is in the region of f/5.6 at 50 foot-lamberts scene illuminance and with the lens adjusted to half a stop above the "knee" of the transfer characteristic. The photocathode has a spectral response closely approaching that of the eye, permitting the portrayal of colours by their true monochrome equivalents.

7764, 7767

Two new ¾-inch diameter multiplier phototubes, 7764 and 7767, are intended especially for applications involving low-light levels and space restrictions requiring small tube size. The 7764 is a six-stage, head-on type having an overall length of approximately 2-¾ inches, and the 7767 is a ten-stage, head-on type having an overall length of approximately 4 inches. The short length and small diameter of these new types recommend their use in underground geological exploration, biological tracer studies, industrial computers, punched-tape and punched-card applications. Both the 7764 and the 7767 feature a flat faceplate, a curved semi-transparent photocathode having a minimum diameter of 0.5 inch, and electrostatically-focused in-line dynode stages. The 7767 has flexible leads which may be soldered directly into the associated circuit. The spectral response of these types covers the range from about 3000 to 6500 angstroms. Maximum response occurs in the blue region at approximately 4400 angstroms. When operated at a supply voltage of 1200 volts, the 7764 has a median luminous sensitivity of 0.3 ampere per lumen and a current amplification of 5,000. When the 7767 is operated at a supply voltage of 1250 volts, it has a median luminous sensitivity of 7.5 amperes per lumen and a current amplification of 125,000.


AWV