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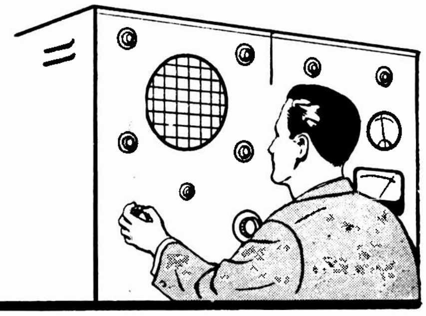

The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 33 NOS. 10-11-12 OCT. - NOV. - DEC., 1963 Subscription By Application Only

Capacitors in Tunnel Diode Circuits

The tunnel diode is no longer a new semiconductor device. It has already been applied to a number of experimental circuits in which it has done work previously expected of tubes or transistors, and it has been applied to a few commercial instruments. But its two-terminal simplicity (a publicized advantage) is perhaps the reason why the tunnel diode has not been used extensively in practical hardware; isolation of the input and output of such a device is not readily achieved. It seems reasonable to expect, however, that a respectable amount of circuitry will be redesigned in the future to exploit the simplicity, small size, high speed, low d-c requirement, excellent temperature characteristics, and resistance to nuclear radiation which characterize this diode.

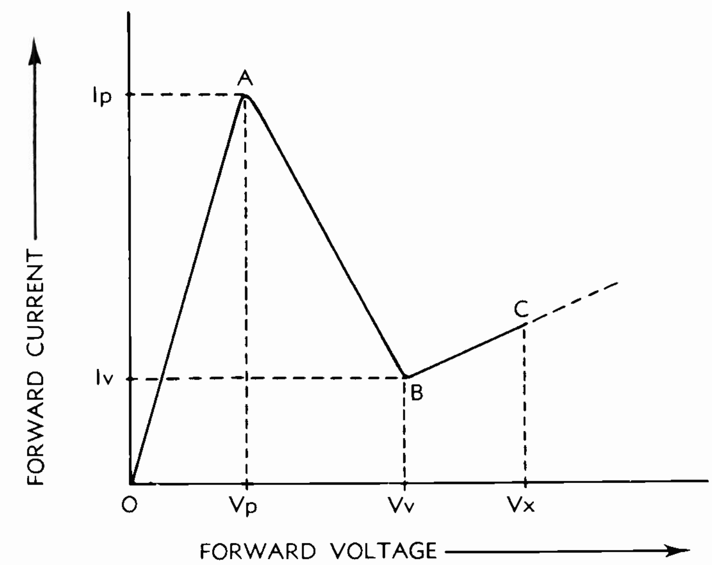

FIGURE 1. FORWARD D-C CHARACTERISTIC OF TUNNEL DIODE

Tunnel diode theory has been adequately covered in previous literature. We need call attention here only to the forward d-c volt-ampere curve which exhibits the useful characteristic of tunnel diode operation. From Figure 1, note that the forward current increases from zero to a peak point (Ip) as the forward voltage is increased from zero to Vp. As the voltage is further increased to V_V, the current then decreases to a valley point (I_V). And as the voltage is still further increased to V_X, the current again rises. The conduction curve thus shows two positive-resistance regions (OA and BC) and a negative-resistance region (AB). When the diode is biased into the negative-resistance region, it is capable of oscillation, amplification, bistable switching, or voltage threshold detection in a suitable circuit. Capacitance and capacitor requirements in such circuits are a matter of practical interest.

Printed by Aerovox Corporation, New Bedford, Mass., U. S. A.

INTERNAL CAPACITANCE

The internal capacitance of a tunnel diode, as a result of miniature construction, is largely the barrier capacitance of the intrinsic semiconductor diode. This varies with d-c ratings and is dc-variable: Maximum rated capacitance is between 5 pf at typical peak-point current of 1.0 ma, and 150 pf at 22 ma. Typical rated capacitance is between 4 pf at 1 ma and 60 pf at 22 ma.

Internal capacitance is part of a "black-box" LCR network (see Figure 2) which includes inherent series inductance (L_S), inherent series resistance (R_S), and negative conductance (—G). This equivalent network assumes that the diode is biased along the AB slope of its characteristic (Figure 1). The relationship of capacitance C to self-resonant frequency f_r of the diode is complex:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{L_S C} - \frac{G^2}{C}}$$

This frequency is high, as attested by the rated maximum operating frequency of commercial tunnel diodes: Typical values are 1.3 kMc for 22-ma (I_p) diodes to 2.5 kMc for 2.2-ma diodes.

The internal capacitance can, and does, affect circuit behavior and must be taken into account when designing a circuit for the tunnel diode and when external capacitors are selected. The unwary designer who has grown indifferent to the less-than-1 pf capacitance of point-contact diodes may miss the fact that tunnel diode capacitance may be high enough that it cannot be neglected.

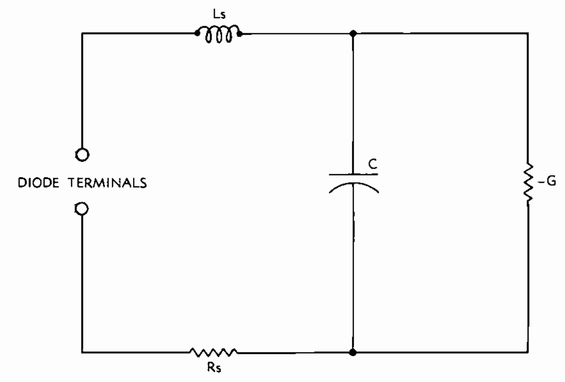

FIGURE 2. SMALL-SIGNAL EQUIVALENT CIRCUIT OF TUNNEL DIODE

SUSCEPTIBILITY TO EXTERNAL PARAMETERS

A negative-resistance device like the tunnel diode is a ready oscillator. A tunnel-diode amplifier or switching circuit consequently can self-oscillate whenever external circuit parameters provide the needed L or C for sinusoidal operation, or R and C for relaxation oscillations. Under similar circumstances, a tube or transistor often ignores these externals. Moreover, a tunnel diode oscillator may operate at a desired frequency determined by lumped C, L, and R components, and simultaneously at one or more other frequencies determined by diode internal capacitance, inductance, or negative resistance in combination with stray parameters of some other component. Thus, the internal inductance of a capacitor sometimes sets up a tuned circuit within the capacitor to support "parasitic" operation in a tunnel-diode oscillator. Tunnel-diode a-f amplifiers have been discovered to oscillate at very high frequencies.

Whenever possible, noninductive capacitors should be used in tunnel diode circuits.

POSITIONS OF CAPACITORS IN TD CIRCUITS

Some practical examples of capacitors in tunnel diode circuits may be given. Necessarily, only typical applications may be shown in this space.

Power Supply. A tunnel diode is dc-biased by means of batteries or an extremely well-filtered power supply. The output impedance of the supply, of whatever kind, must be as low as practicable. Because the forward bias voltage is low, a stiff voltage divider of some type is needed to reduce the supply voltage.

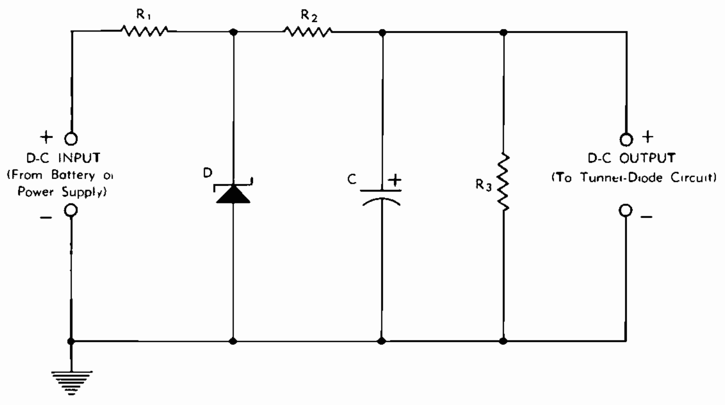

FIGURE 3. TYPICAL BIAS SUPPLY FOR TUNNEL DIODE

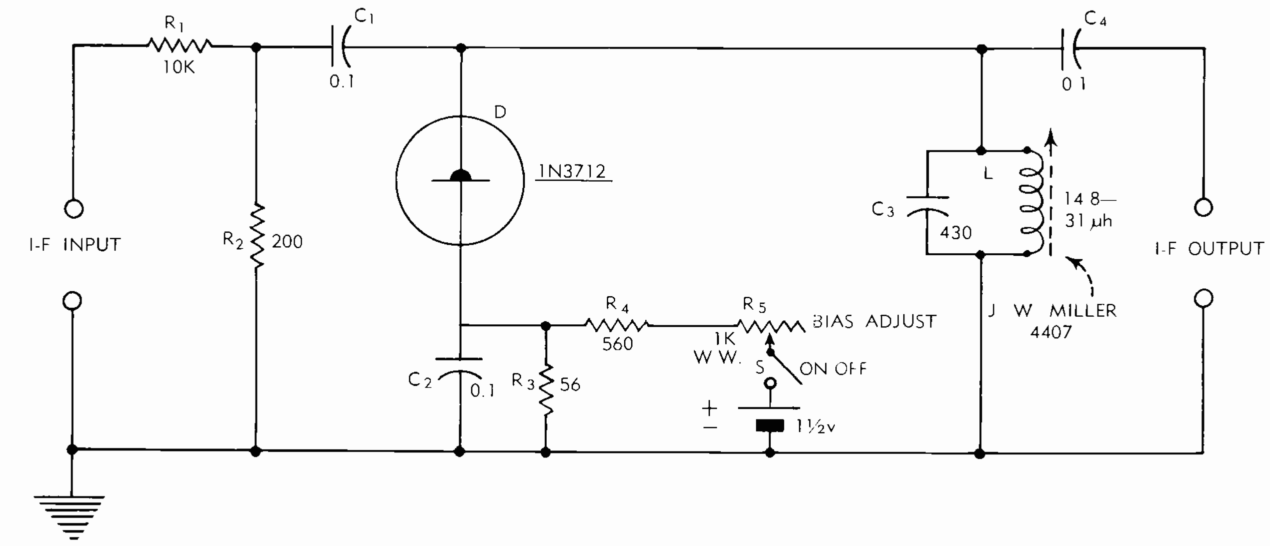

FIGURE 7. I-F AMPLIFIER

I-F Amplifier. Figure 7 shows a 1500-kc intermediate-frequency amplifier which provides a gain of 30 db. It has approximately 200 ohms input and output impedance.

In this circuit, the input and output coupling capacitors (C and C) and bias bypass capacitor (C) are 0.1 ufd noninductive plastic or wax units. Tuned-circuit capacitor C is mica.

SUMMARY AND CONCLUSION

Experience shows that noninductive capacitors are essential in tunnel-diode circuits if spurious oscillation is to be avoided. The following chart shows capacitor types which have been found most suitable in the circuit functions of coupling, power supply bypass, signal circuit bypass, and circuit tuning.

COUPLING
A-F Mica, ceramic, plastic, oil, wax
R-F Mica, high-quality ceramic

POWER SUPPLY BYPASS
Electrolytic, plastic, oil, wax

SIGNAL-CIRCUIT BYPASS
UHF Feed-through mica or ceramic
R-F Mica, ceramic
A-F Electrolytic, plastic, oil, wax

CIRCUIT TUNING
Mica

ALL SHOULD BE NONINDUCTIVE

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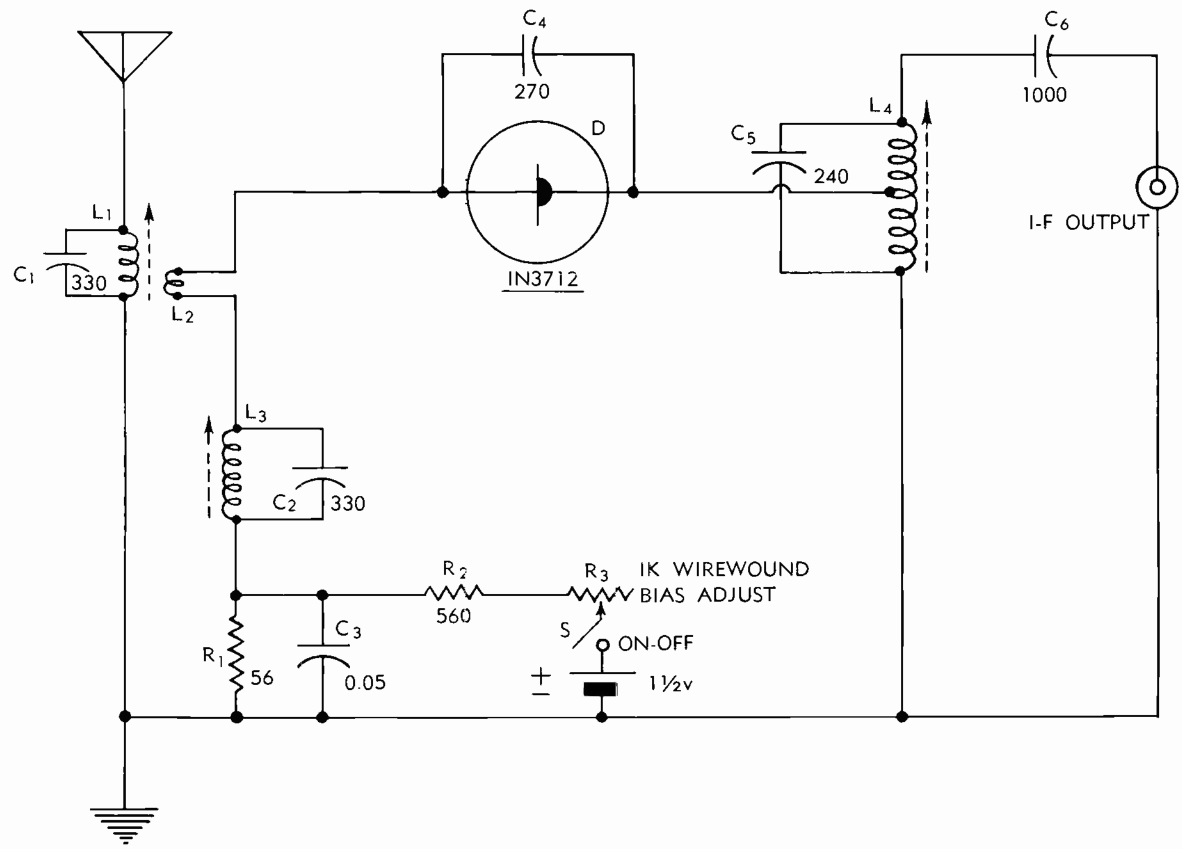

FIGURE 6. SUPERHET-TYPE CONVERTER

The capacitance of this capacitor usually runs from 1 pf to 0.1 μfd in practical circuits, depending upon frequency. It often is omitted in high-frequency r-f oscillators. The capacitance of C_3 will depend upon desired operating frequency and inductance L. Depending upon the magnitude of inductance L, either a high-quality mica, plastic or oil-filled unit is required for audio frequencies; or mica or air for radio frequencies. The inductance must be chosen such that C_3 exceeds by the highest obtainable ratio combined stray and inherent diode capacitances. An electrolytic capacitor should not be used in this position. Output coupling capacitor C_4 will have a C value between 3.3 pf at radio frequencies to 0.0001 to 0.01 μfd at audio frequencies.

[1] Davidsohn, U.; Y. Hwang; and G. Ober; "Designing with Tunnel Diodes," *Electronic Design*, Feb. 3 and 17, 1960.

[2] *General Electric Tunnel Diode Manual*, 1st Ed., pp. 33-37.

Converter. Figure 6 shows the circuit of a single-stage superheterodyne converter of the type used to adapt a broadcast receiver for short-wave reception. It is based on a G. E. 1N3712 tunnel diode, D. Intermediate-frequency output is at whatever frequency the receiver is set to, usually 1500-1600 kc.

The r-f circuits are fixed-tuned for the desired signal by adjustment of the slugs of L_1, L_3, and L_4. The tank capacitors (C_1, C_2, and C_5), diode capacitor C_4, and output coupling capacitor C_6 are high-quality mica units. Power supply bypass capacitor C_3 is noninductive plastic or wax type. Input coil L_1 is chosen in inductance to resonate, with C_1, at the signal frequency; oscillator coil L_3 is chosen in inductance to resonate, with C_2 at the difference between signal and desired intermediate frequencies (i-f usually is 1500-1600 kc); and L_4 to resonate, with C_5, at the output (intermediate frequency. L_2 is a 1— or 2—turn link-coupling coil.

Figure 3 shows a typical supply using a zener diode (D) for voltage regulation. Resistor R_1 is essentially the current limiter for the diode. Resistors R_2 and R_3 provide the necessary division of the zener voltage to the required bias level of the tunnel diode. R_3 is chosen to be 10 to 20 percent of the negative resistance of the tunnel diode, and generally is 10 to 22 ohms. C is a high-capacitance, low-voltage electrolytic (100 to 500 μfd) which must itself sometimes be bypassed with a lower-capacitance (100 to 1000 pf) mica or ceramic unit when the tunnel diode circuit is operated at high radio frequencies. It should be noted that electrolytic capacitor C is operated far below its maximum DCWV rating, often at only 50 to 150 millivolts, and may undergo capacitance change as a result. Leakage is not an extreme concern, however, since the heavy shunting effect of R_3 negates the effects of ordinary leakage.

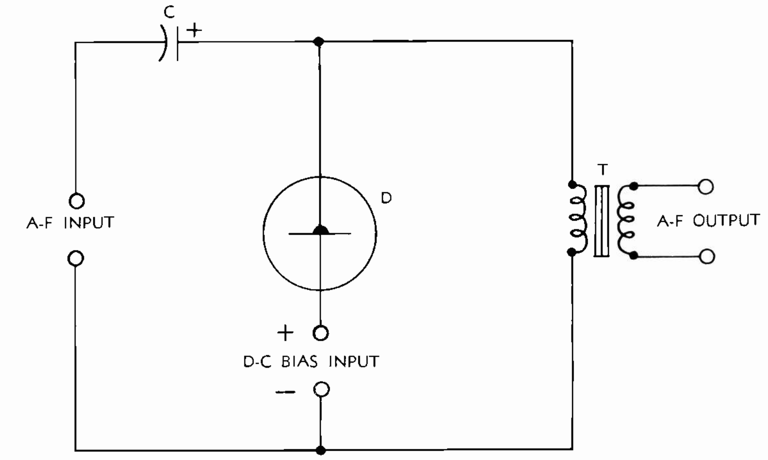

FIGURE 4. BASIC A-F AMPLIFIER

A-F Amplifier. Like the transistor, the tunnel diode is a low-impedance device. In order to obtain good response at low audio frequencies, high input coupling capacitance therefore is required in simple RC-coupled a-f circuits. In Figure 4, for example, coupling capacitance C operates into a circuit having 100 ohms or less impedance, therefore must be 100 to 1000 μfd for acceptable response at 20 cps. The resulting time constant is long: 10 msec with 100 μfd, and 100 msec with 1000 μfd.

Oscillator. Figure 5 shows a typical series-tunnel-diode sine-wave oscillator circuit. This arrangement may be used at either audio or radio frequencies by suitable choice of C_3 and L. The circuit is biased by a battery or well-filtered power supply through voltage divider R_1-R_2. The lower resistor of this divider is bypassed by high capacitance C_1 (see "Power Supply").

Capacitor C_2 must be noninductive and high-Q. Its capacitance [1, 2] may be determined from:

$$(2)\quad C_2 = \sqrt{\frac{G\ (1-R_t\ G)}{R_t}}$$

Where G is the diode conductance, and

$R_t = (R_1 R_2) / (R_1 + R_2)$

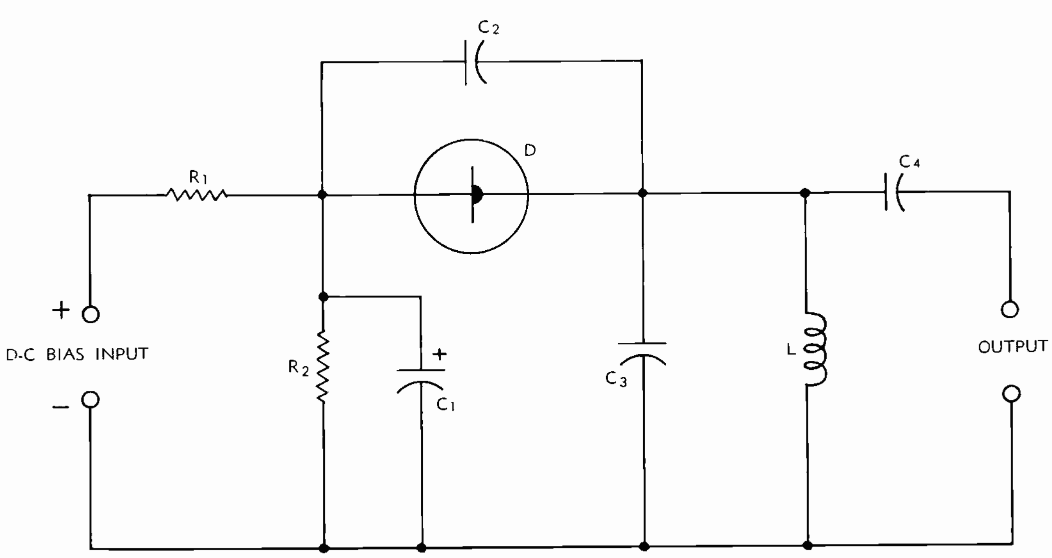

FIGURE 5. OSCILLATOR

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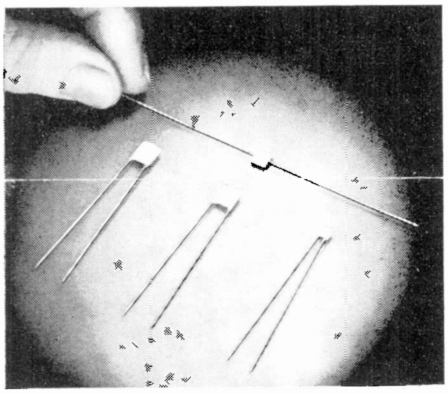

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Voltage, VDCW @ 85°C (Derated 50% @ 125°C)	50	50	50
Power Factor, Maximum @ 1 KC.	.1%	.6%	2%
Temperature Coefficient with 0 Voltage, −55°C to +125°C	0±30PPM/°C	+5%, −8%	+10%, −30%
Temperature Coefficient with rated Voltage applied, −55°C to +125°C.	0±30PPM/°C	+5%, −10%	+10%, −40%
Capacity Tolerance, as low as	±5%	±10%	±20%

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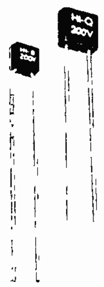

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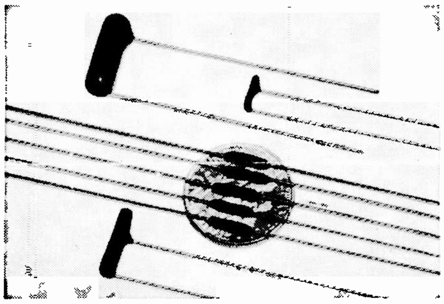

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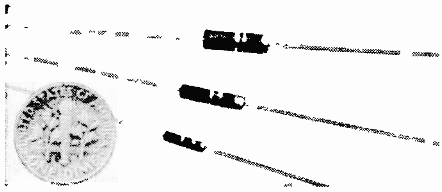
ELECTRICAL SPECIFICATIONS
VOLTAGE – 100 VDCW; 300 VDCT.
TEMPERATURE COEFFICIENT (−55°C to +85°C).
No voltage +10% to −15%.
100 volts applied +10% to −35%.
OPERATING TEMPERATURE –
−55°C to 85°C at 100 volts
−55°C to 125°C at 50 volts



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