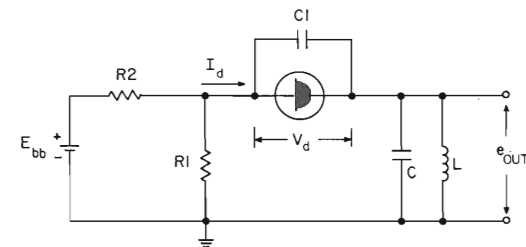


TUNNEL DIODE OSCILLATORS (1-18)

Tunnel Diode Oscillators are attractive because of their high-frequency capability, low power consumption, good frequency stability and extreme circuit simplicity. These advantages enable a designer to produce stable miniature oscillator circuits with a wide variety of uses. Figure 14.1 illustrates the *basic* "series-parallel" sinewave oscillator. Design equations are also given. Additional design information will be found by consulting the references at the end of this chapter.



$$R1 \leq \frac{|R_d|}{3}$$

where R_d is TD's negative resistance.

$$R2 = \frac{E_{bb} - V_d}{I_d + \frac{V_d}{R1}}$$

$$C1 = \sqrt{\frac{g_{d1} (1 - R_T g_{d1})}{R_T \omega^2}}$$

where g_{d1} is TD's initial negative conductance
 R_T is circuit's total dc resistance and

is equal to $\frac{R1 R2}{R1 + R2} + R_s + R_{DC(colt)}$

R_s is TD's total series resistance.

$$C + \frac{C1}{1 - R_T g_d} = \frac{1}{L \omega^2}$$

where g_d is TD's negative conductance.

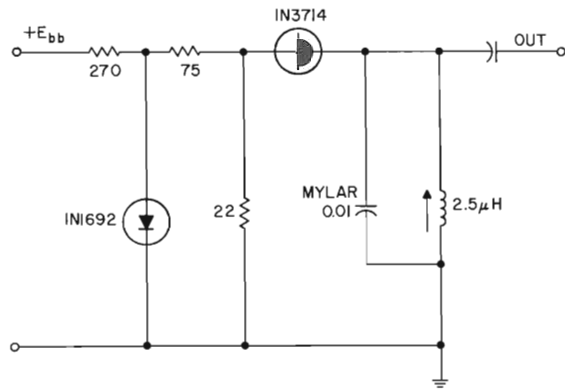
hence

$$L = \frac{1}{\omega^2 \left(C + \frac{C1}{1 - R_T g_d} \right)}$$

**BASIC TUNNEL DIODE SINEWAVE OSCILLATOR
AND DESIGN EQUATIONS**

Figure 14.1

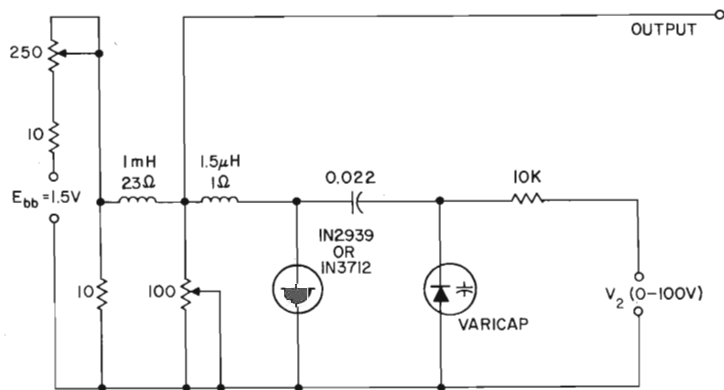
The circuits that follow illustrate the many applications and variety of tasks tunnel diode oscillators are capable of performing. Brief descriptions accompany some circuits. For more complete information readers should consult the specific reference as indicated. An extensive reference list appears at the end of this chapter.



This 1.1 mc oscillator senses temperature changes and translates them into frequency variations. The main temperature sensing element is a mylar capacitor whose characteristics yield a 0.5 kc/°C temperature coefficient.⁽¹⁾

TEMPERATURE SENSING OSCILLATOR

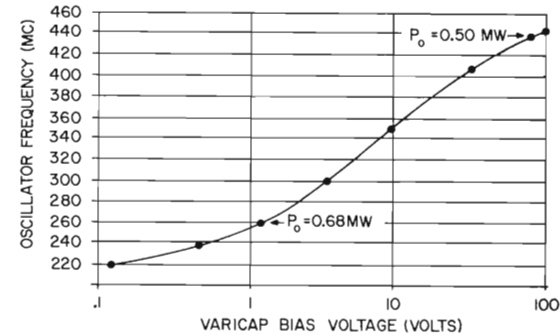
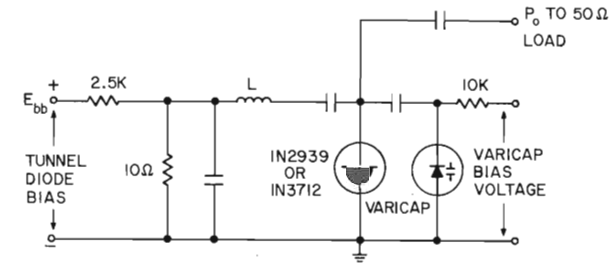
Figure 14.2



A voltage variable capacitor tunes this oscillator electronically over the 12-22 mc range.⁽¹⁾

VOLTAGE CONTROLLED OSCILLATOR

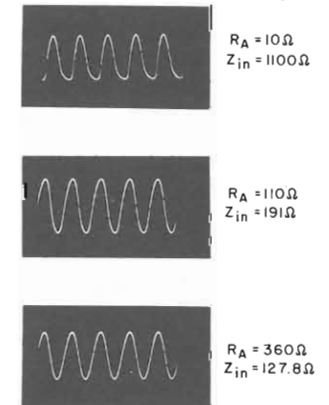
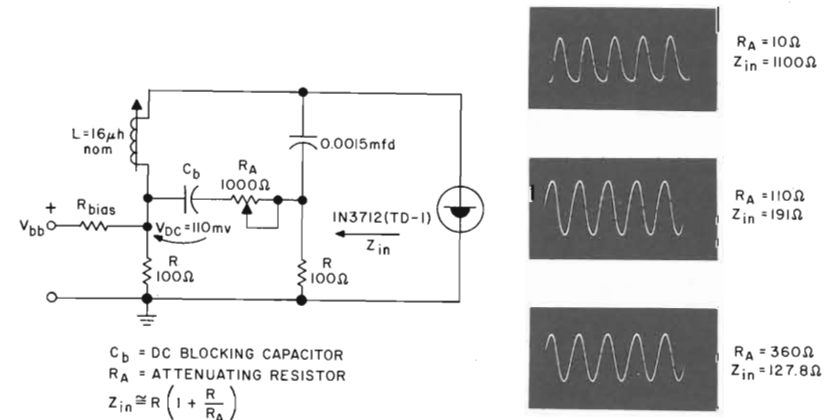
Figure 14.3



This VHF oscillator can be electronically tuned over the 200-400 mc range. Output power is over 0.5 milliwatts.⁽¹⁾

VOLTAGE CONTROLLED VHF OSCILLATOR

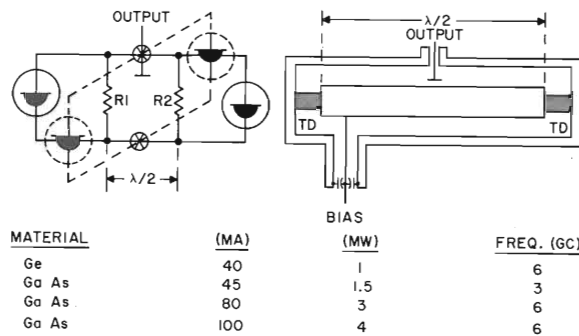
Figure 14.4



Resistor RA is an attenuating resistor which varies the magnitude of the oscillator swing. This enables the oscillator to operate over a limited, hence highly linear portion, of the diode's conductance curve. Note low distortion in the oscilloscope display at the bottom.⁽¹⁾

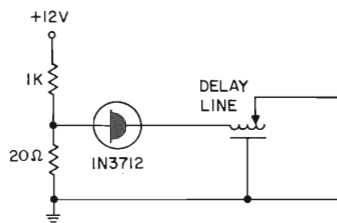
VARIABLE AMPLITUDE OSCILLATOR

Figure 14.5



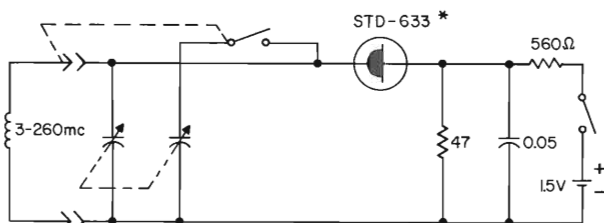
Two or more tunnel diodes placed in a half-wave cavity structure delivers 4 milliwatts at 6 kmc.⁽¹⁸⁾

MICROWAVE OSCILLATOR
Figure 14.6



Using a General Radio Delay-Line (Type 314-S86) this oscillator covers the 0.5-20 mc range. Output is in the square wave category.

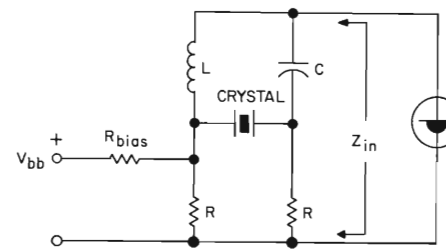
DELAY-LINE OSCILLATOR
Figure 14.7



* SELECTED DEVICE

SINEWAVE OSCILLATOR WITH "PLUG-IN" COILS
(Covers 3 to 260 mc range)

Figure 14.8



$$R < |R_{di}|$$

$$R = \sqrt{L/C}$$

$$Z_{in} = R \left(1 + \frac{R}{R_{CR}} \right)$$

WHERE R_{CR} IS THE SERIES RESISTANCE OF THE CRYSTAL AT RESONANCE.

FOR OSCILLATIONS:

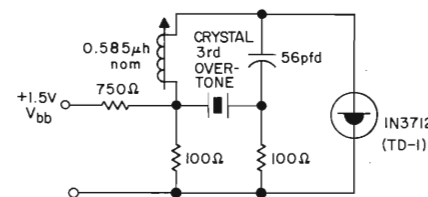
$$\left| R_e |Y_{in}| < |g_{di}| \right|$$

$$\left| I_m |Y_{in}| = 0 \right|$$

BASIC TUNNEL DIODE CRYSTAL CONTROLLED OSCILLATOR⁽⁷⁾

Figure 14.9

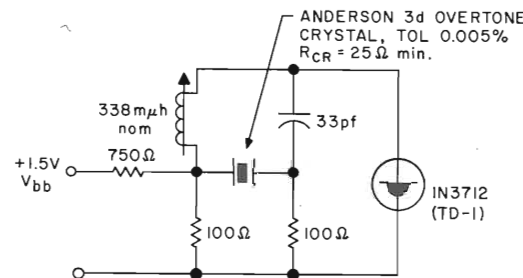
Figures 14.10 and 14.11 show crystal controlled Citizens Band and Fire Department oscillators. Both are useable in low power (microwatt) transmitters for short range communications.⁽⁷⁾



THE OSCILLATOR FREQUENCY OPERATES WITHIN THE TOLERANCE OF THE QUARTZ CRYSTAL OVER A TEMPERATURE RANGE OF FROM -55°C TO +85°C AND A BIAS RANGE OF FROM 110 TO 150mv.

CITIZENS BAND 27.255 MC CRYSTAL CONTROLLED OSCILLATOR

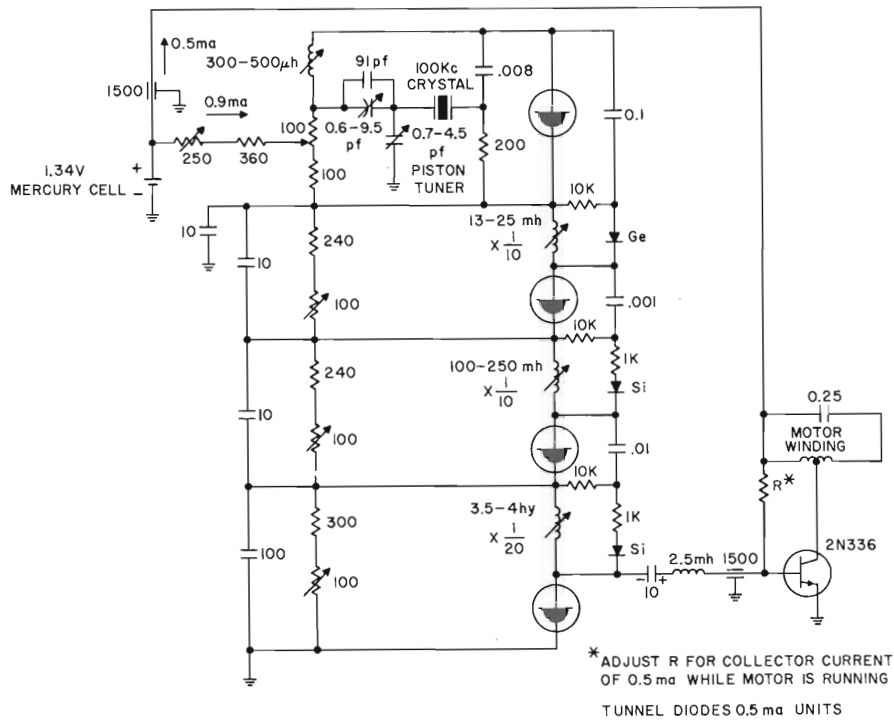
Figure 14.10



THE OSCILLATOR FREQUENCY OPERATES WITHIN THE QUARTZ CRYSTAL TOLERANCE OVER A TEMPERATURE RANGE OF FROM -55°C TO +85°C AND OVER A BIAS RANGE OF FROM 110 TO 150mv.

FIRE DEPARTMENT 47.100 MC CRYSTAL CONTROLLED OSCILLATOR

Figure 14.11



This circuit illustrates an application where the low power consumption, the low voltage requirements, and the excellent frequency stability of crystal controlled tunnel diode oscillators provides the circuit designer with an ideal device for his job. The complete circuit incorporates trimmers that can adjust the timing of the clock by a few seconds per year. Three tunnel diodes give overall division ratio of 2,000 to 1. Figure 14.13 pictures the finished chronometer.

CRYSTAL CONTROLLED CHRONOMETER⁽⁸⁾
Figure 14.12

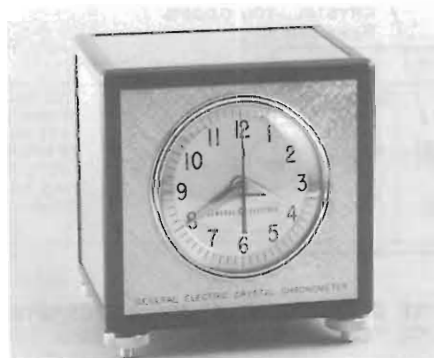


Figure 14.13 HIGH ACCURACY CHRONOMETER

TUNNEL DIODE MICRO-POWER TRANSMITTER (1,5)

Tunnel diode remote control transmitters have adequate range to remote control toys, garage doors, window displays, etc. Where voice modulated they can be used for short range communications, as in television studios, power plants, bowling alleys, shopping centers, etc. Circuits in Figures 14.15 and 14.16 can be built into miniature hand-held box chassis as shown below.

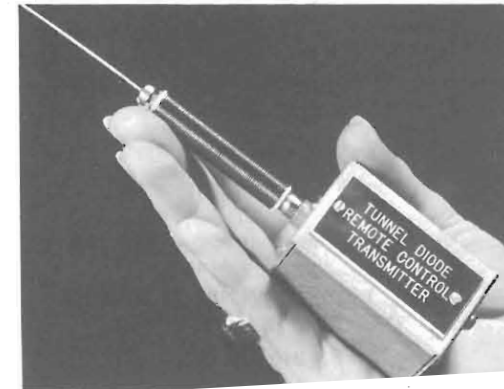
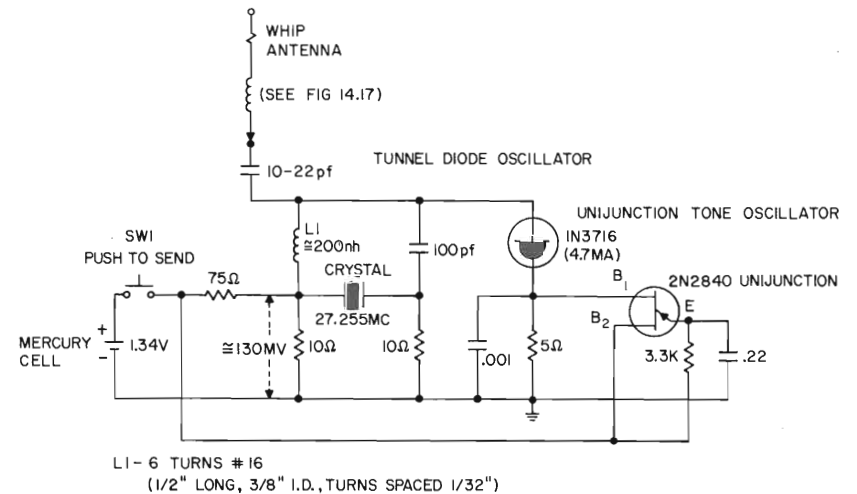
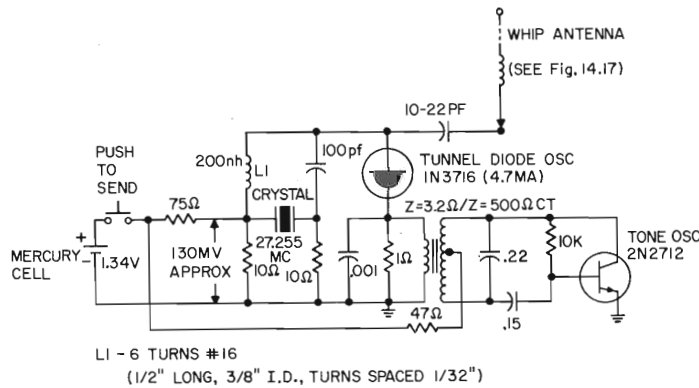


Figure 14.14



Unijunction tone oscillator modulates this miniature transmitter used to remotely control garage door.

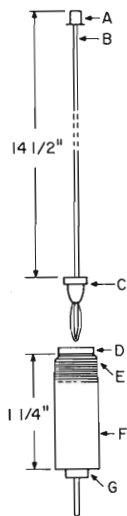
TUNNEL DIODE-UNI-JUNCTION REMOTE CONTROL TRANSMITTER
Figure 14.15



Hartley oscillator using silicon transistor modulates tunnel diode transmitter.

TUNNEL DIODE-TRANSISTOR REMOTE CONTROL TRANSMITTER

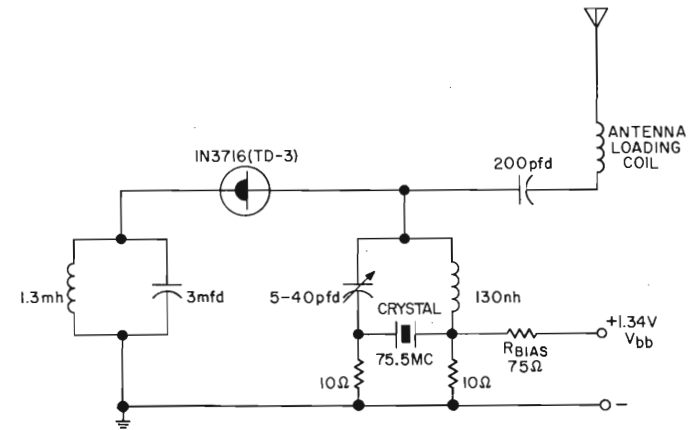
Figure 14.16



- A. SAFETY CAP SOLDERED TO ANTENNA TIP
- B. 14 1/2 INCH .052" PIANO WIRE SOLDERED OR BRAZED TO C
- C. BANANA PLUG (E.F. JOHNSON 108-771)
- D. BANANA JACK FORCED-TAPPED INTO 7/32" DRILLED HOLE (E.F. JOHNSON 108-760)
- E. 50 TURNS #24 FORMVAR OR ENAMEL COVERED WIRE ADJUSTED TO 27mc WITH GRID DIP METER
- F. 1/2" X 1 1/4" SOLID COIL FORM MADE FROM TEFLON OR POLYSTYRENE
- G. TIP PLUG FORCE TAPPED INTO 7/32" HOLE (E.F. JOHNSON 105-301)

Details of antenna and loading coil construction for Figures 14.5 and 14.6.

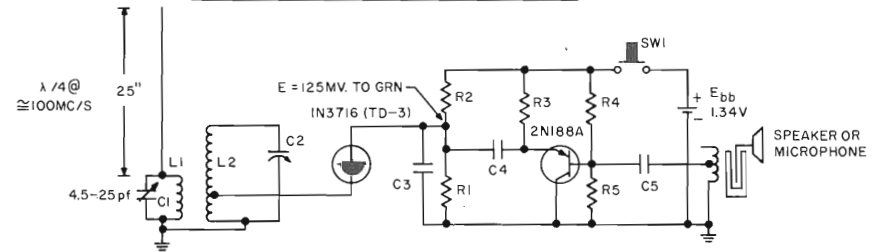
ANTENNA
Figure 14.17



73.5 MC CRYSTAL CONTROLLED SELF-MODULATED TRANSMITTER

Figure 14.18

FM TRANSMITTER 96 TO 110MC/S USING 4.7MA T.D.



- L1 2 TURNS #16 COPPER 3/8" I.D. SPACED 1/8" FROM GROUND END OF L2 (ADJUST FOR BEST STABILITY)
- L2 6 TURNS #16 COPPER 3/8" I.D. CLOSE-WOUND AND CONNECTED DIRECTLY TO C2, TAPPED 1 TURN FROM GROUND.
- C1 4.5-25μfd CERAMIC TRIMMER
- C2 1.5-5μfd VARIABLE
- C3 800μfd (VOLTAGE NOT IMPORTANT-SELECT FOR SMALL SIZE)
- C4 50μfd 6VDC ELECTROLYTIC (VOLTAGE NOT IMPORTANT-SELECT FOR SMALL SIZE)
- C5 1μfd 35VDC (VOLTAGE NOT IMPORTANT-SELECT FOR SMALL SIZE)
- R1 18Ω 1/2W 5%
- R2 150Ω 1/2W 5%
- R3 470Ω 1/4W
- R4 10KΩ 1/4W
- R5 10KΩ 1/4W
- E_{bb} MALLORY RM-12R MERCURY CELL 1.34VDC-3600 MAH
- SW1 NORMALLY OPEN SPST "PUSH-TO-TALK" SWITCH
- SPKR 2" PM SPEAKER
- IN3716 (TD-3) 4.7MA AXIAL TUNNEL DIODE

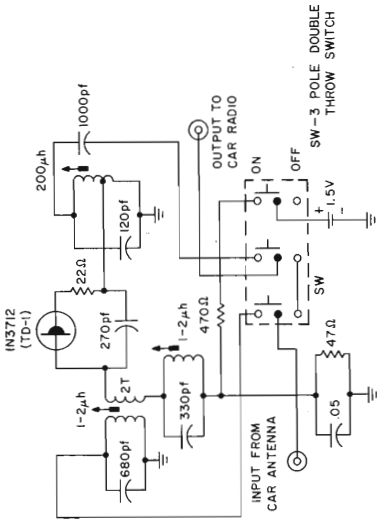
This circuit has a 200 yard range when used in conjunction with sensitive commercial receiver.

FM WIRELESS MICROPHONE
(96 to 110 mc)

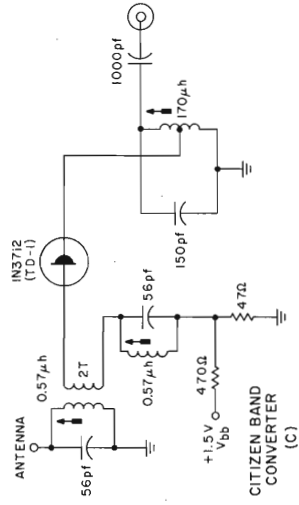
Figure 14.19

TUNNEL DIODE CONVERTERS (1, 2, 19-23)

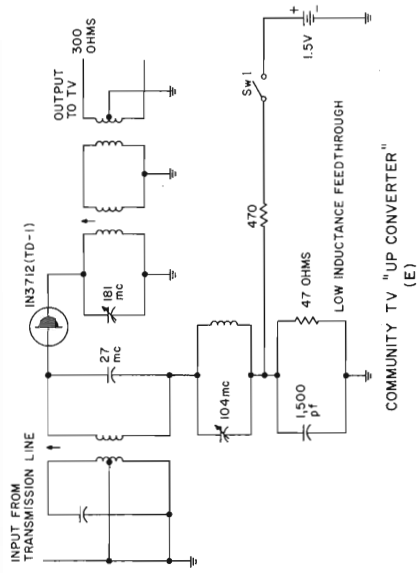
The tunnel diode oscillator can be used in the design of "self-oscillating" converters.



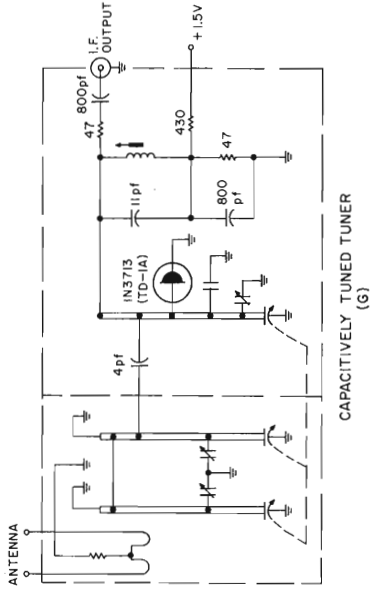
CIVIL AIR PATROL CONVERTER (A)



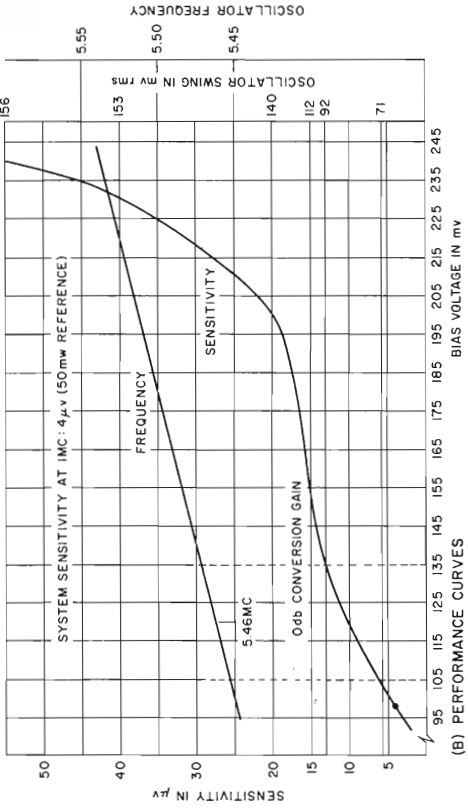
CITIZEN BAND CONVERTER (C)



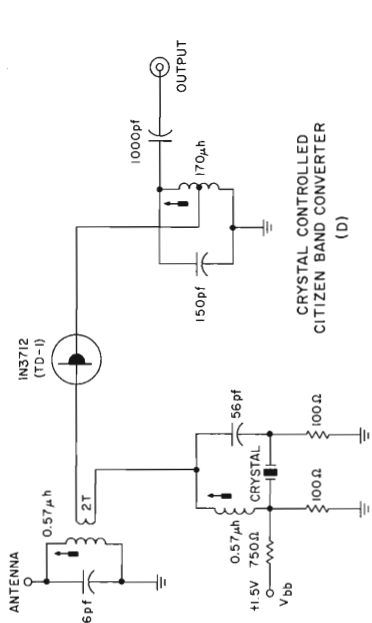
COMMUNITY TV "UP CONVERTER" (E)



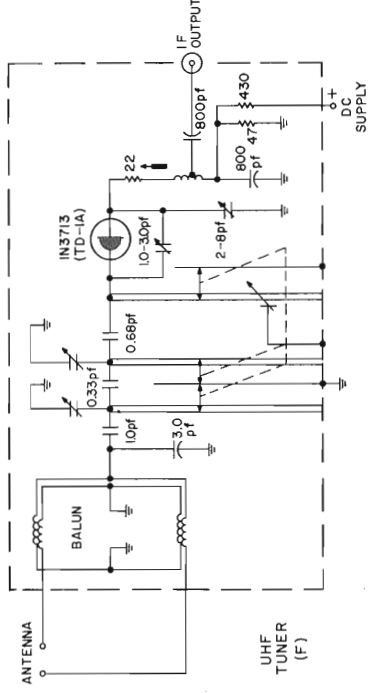
CAPACITIVELY TUNED TUNER (G)



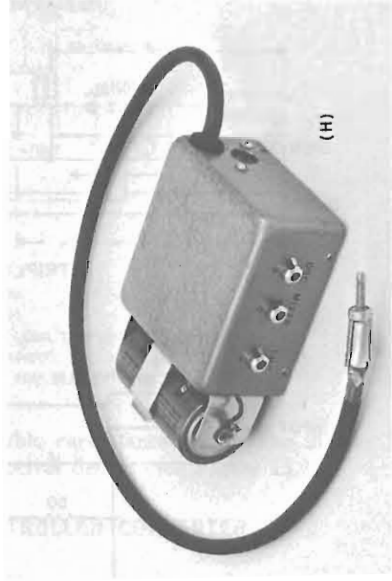
(B) PERFORMANCE CURVES



CRYSTAL CONTROLLED CITIZEN BAND CONVERTER (D)

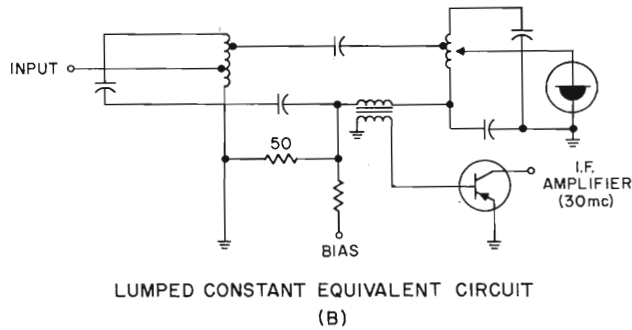
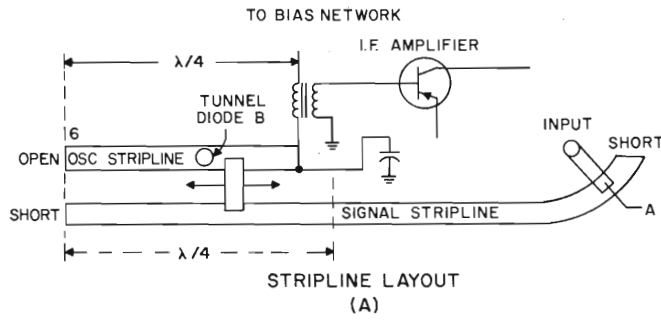


UHF TUNER (F)

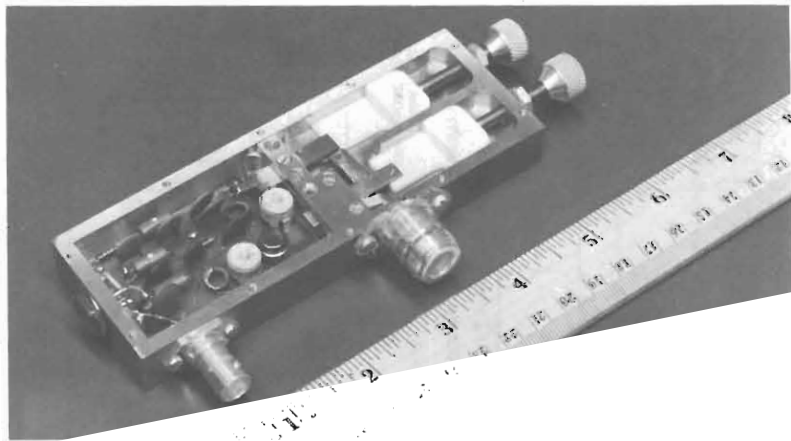


(H)

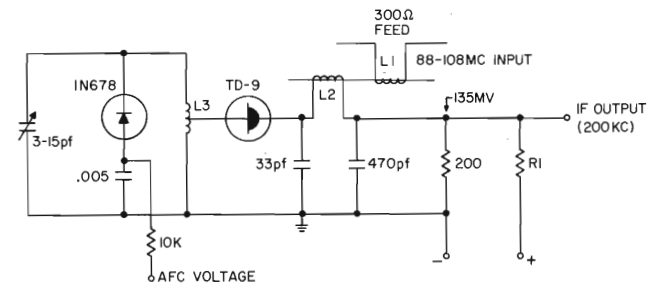
Figure 14.20 SELF-OSCILLATING TUNNEL DIODE CONVERTERS



L-BAND SELF-OSCILLATING CONVERTER
Figure 14.21



3 KMC L-BAND CONVERTER PACKAGE
Figure 14.22



L1 - 4 TURNS #18-3/8" ID, APPROX. 1/2" LONG
 L2 - 4 TURNS #18-3/8" ID, APPROX. 1/2" LONG
 L3 - 8 1/2" TURNS #18-3/8" ID, APPROX. 3/4" LONG TAPPED AT 5 TURNS
 L1L2 - COUPLED END TO END, SPACED ~ 1/8" APART
 R1 - DEPENDS ON SUPPLY VOLTAGE. SELECT FOR BIAS OF APPROX. 135MV ACROSS 200Ω RESISTOR.

This converter is AFC controlled by a variable capacitance diode. The 200 kc IF output is used here because of the type of receiver design (see Figure 15.21).

Figure 14.23 FM-AFC CONTROLLED CONVERTER

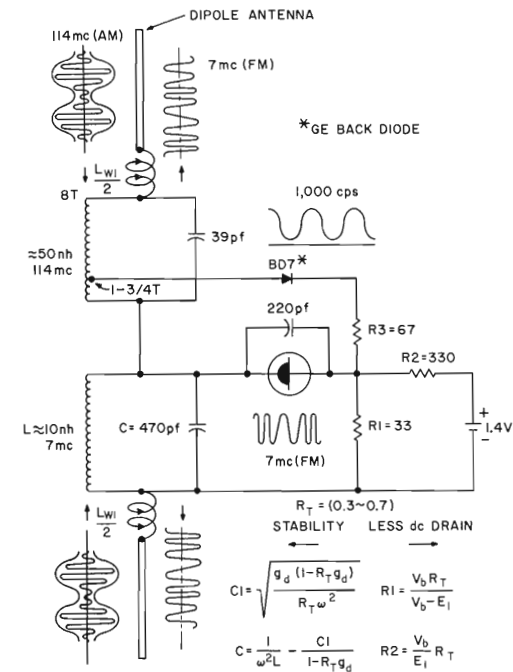
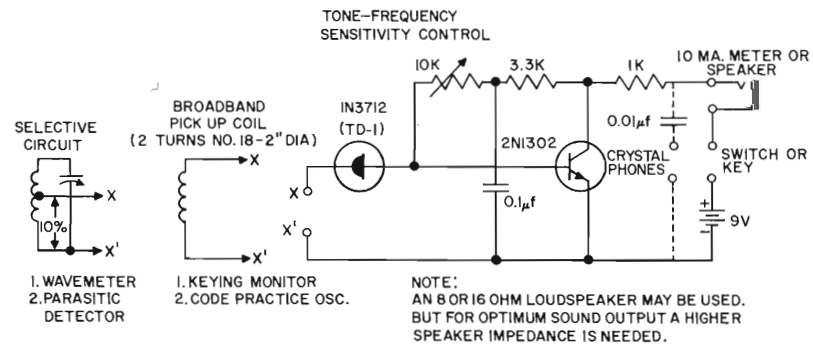


Figure 14.24 TUNNEL DIODE TRANSCEIVER⁽¹⁹⁾

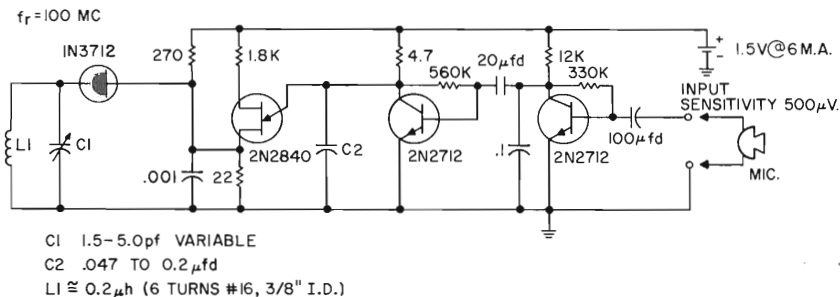
This transceiver is tuned for a 114 mc AM input signal and a 7 mc FM output signal. The 1N3714 (TD-2) tunnel diode acts as 7 mc RF oscillator and frequency modulator while the BD-7 back diode is the 114 mc detector.

VARIOUS INDUSTRIAL SPECIAL USES OF TUNNEL DIODES (34-41)



SENSITIVE BROADBAND CW KEYING MONITOR-CODE PRACTICE OSCILLATOR-SENSITIVE AURAL/VISUAL PARASITIC DETECTOR OR WAVEMETER

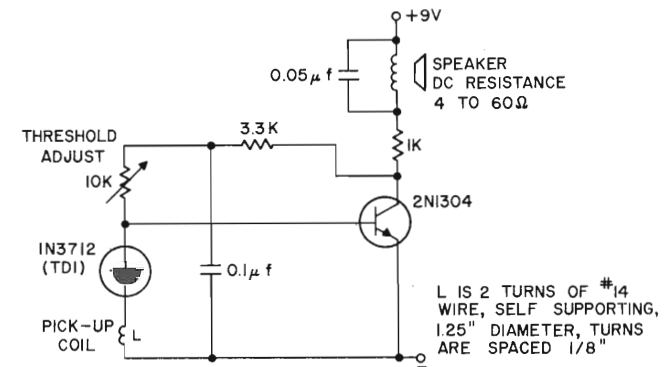
Figure 14.25



100 mc wireless telemetry link transmitter. The microphone picks up signal which is amplified by 2N2712; second 2N2712 inhibiting C1 turns off allowing C1 to charge up and fire 2N2840 unijunction oscillator. Unijunction pulse modulates a tunnel diode transmitter.

WIRELESS PULSE MONITOR

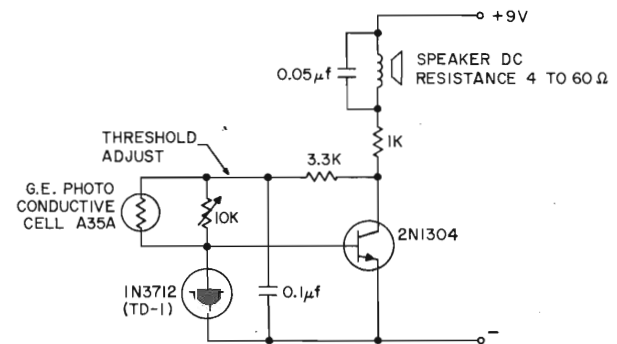
Figure 14.26



This circuit illustrates a 200 mc, RF radiation detector giving audible (1800 cps) alarm oscillations. A small slot antenna or a pick-up coil can be used as sensors.

RF RADIATION DETECTOR (41)

Figure 14.27



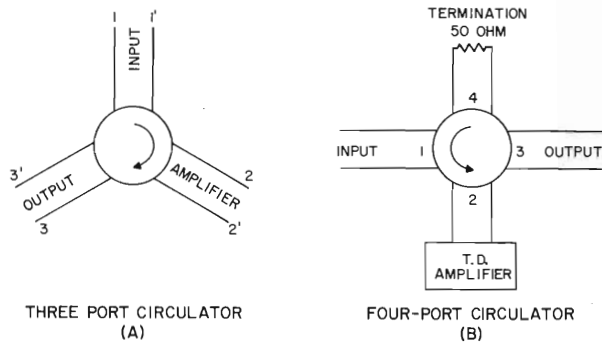
This is a variation of the circuit shown in Figure 14.27. Here the sensor is a photoconductive cell giving alarm at below 0.1 foot candles of illumination near 5500 angstroms.

LIGHT DETECTOR

Figure 14.28

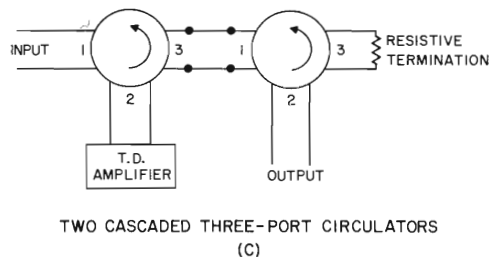
TUNNEL DIODE AMPLIFIERS (1, 2, 42-45)

The performance of tunnel diodes in low noise amplifiers is especially attractive at UHF and microwave frequencies where ferrite isolators, circulators, and/or hybrid-couplers can be used to unilaterize the signal flow. At frequencies where these devices are not available, stable gain is difficult to achieve. Tunnel diodes have been used at L, S, C, and X band with excellent stability and low noise performance.



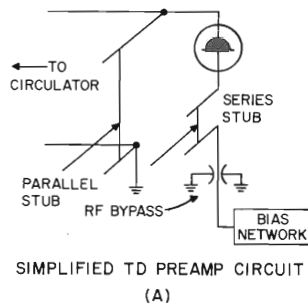
THREE PORT CIRCULATOR (A)

FOUR-PORT CIRCULATOR (B)

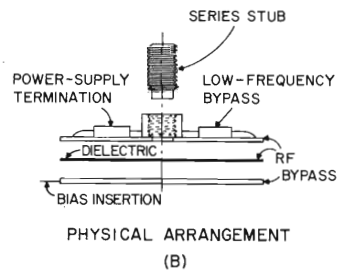


TWO CASCADED THREE-PORT CIRCULATORS (C)

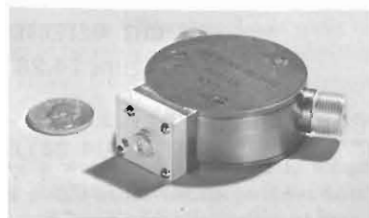
TUNNEL DIODE UHF CIRCULATORS
Figure 14.29



SIMPLIFIED TD PREAMP CIRCUIT (A)



PHYSICAL ARRANGEMENT (B)



THREE-PORT CIRCULATOR COUPLED L-BAND AMPLIFIER (C)

UHF PREAMPLIFIERS
Figure 14.30

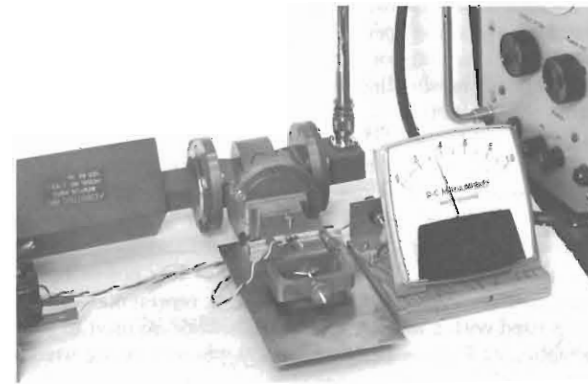
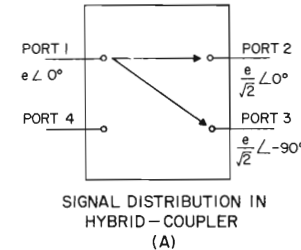
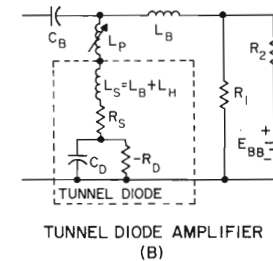


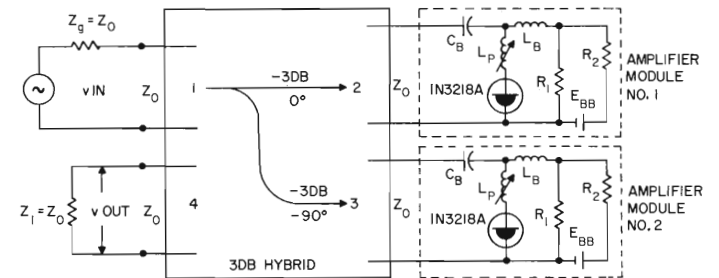
Figure 14.31 TUNNEL DIODE SIX-GIGACYCLE WAVEGUIDE AMPLIFIER



SIGNAL DISTRIBUTION IN HYBRID-COUPLER (A)



TUNNEL DIODE AMPLIFIER (B)



$$r^2 = \frac{\left[\frac{f_0^2}{f_1^2} - 1 + \frac{Z_0 + R_s}{-R_d} \right]^2 + \frac{f_0^2}{f_1^2} \left[\frac{Z + Z_0/|-R_d|}{|-R_d|} - \frac{R_s/|-R_d|}{Z/|-R_d|} \right]^2}{\left[\frac{f_0^2}{f_1^2} - 1 + \frac{Z_0 + R_s}{-R_d} \right]^2 + \frac{f_0^2}{f_1^2} \left[\frac{Z - Z_0/|-R_d|}{|-R_d|} - \frac{R_s/|-R_d|}{Z/|-R_d|} \right]^2}$$

$Z_0 = \text{CHARACTERISTIC IMPEDANCE}$ $f_1 = \frac{1}{2\pi\sqrt{LC}}$

$Z = \sqrt{L/C}$ $|-R_d| = \text{NEGATIVE RESISTANCE OF THE DIODE}$

Figure 14.32

HYBRID-COUPLED TUNNEL DIODE AMPLIFIER AND GAIN EQUATION (C)

The tunnel diode is a very useful device in switching circuits because of its

1. Very high switching speed capabilities
2. Low power consumption
3. Well defined thresholding properties
4. Stable characteristics
5. Radiation resistance

It is the fastest switching device known, with transition times as low as 27 picoseconds (27×10^{-12} second or the time it takes light to travel 0.3 inches). The speed of most high speed circuits is limited by the circuit and package inductance and capacitance and not by the tunnel diode.

Figures 14.33 through 14.35 show various types of low power consumption tunnel diode multivibrators. Figure 14.36 through 14.41 is representative of circuits where the tunnel diode is used with a transistor. The transistors are used to provide amplification with the exception of Figures 14.38 and 14.39 where they are used as a shorting - resetting element.

Figure 14.42 shows a selection of some high speed logic circuits developed to take advantage of the tunnel diodes ultra-high-speed switching capabilities.

TUNNEL DIODE MULTIVIBRATORS⁽²⁾

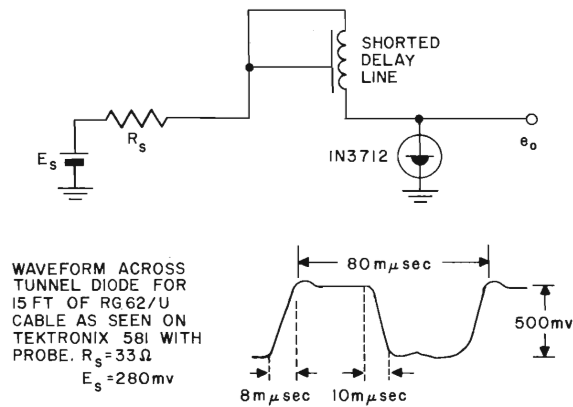


Figure 14.33 RELAXATION OSCILLATOR USING A SHORTED DELAY LINE

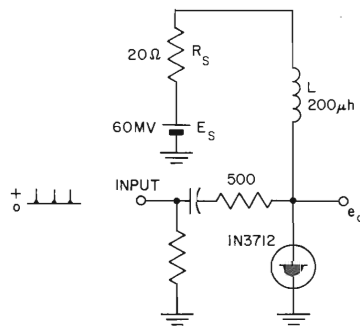
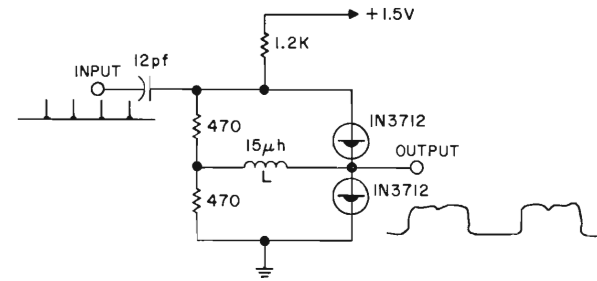


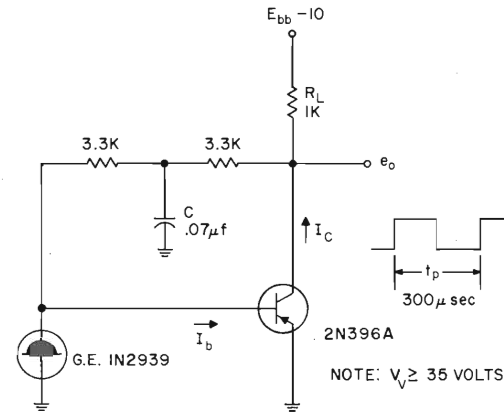
Figure 14.34 TUNNEL DIODE MONOSTABLE OSCILLATOR



TUNNEL DIODE FLIP-FLOP

Figure 14.35

HYBRID (TRANSISTOR-TUNNEL DIODE) MULTIVIBRATORS⁽²⁾

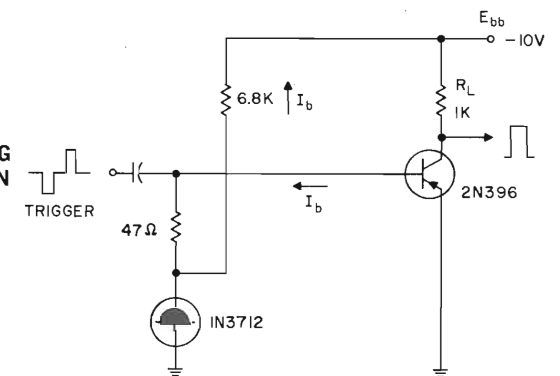


ASTABLE HYBRID OSCILLATOR

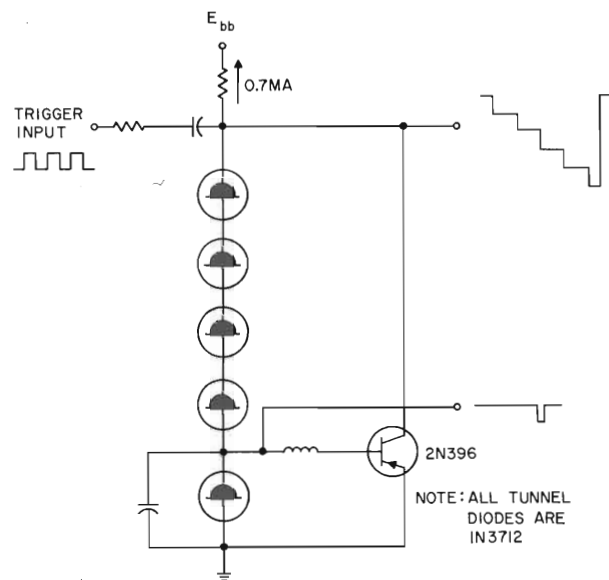
FIGURE 14.36

BISTABLE CIRCUIT USING TUNNEL DIODE AND NPN GERMANIUM ALLOY TRANSISTOR

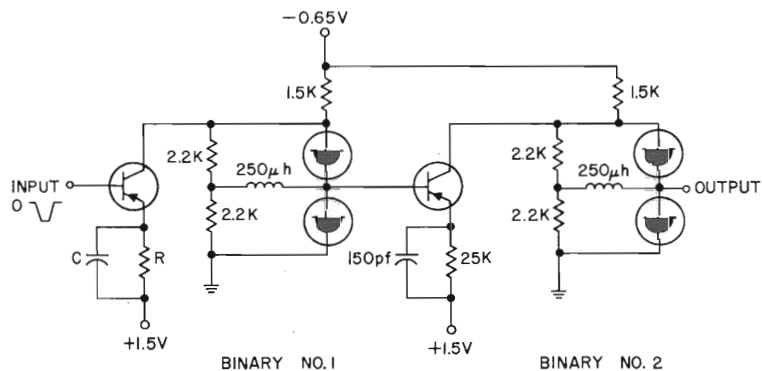
Figure 14.37



TUNNEL DIODE COUNTERS (1, 2)

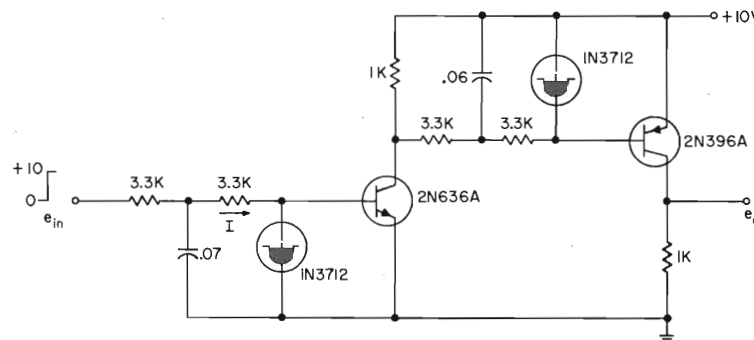


SERIES CONNECTED TUNNEL DIODES USED FOR 5:1 PULSE FREQUENCY DIVIDER OR STAIRCASE WAVE GENERATOR
Figure 14.38

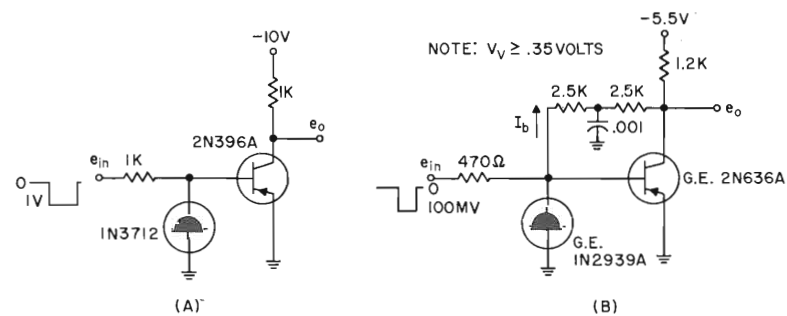


LOW LEVEL TUNNEL DIODE COUNTER
Figure 14.39

MISCELLANEOUS TUNNEL DIODE CIRCUITS (2)



TUNNEL DIODE TIME DELAY CIRCUIT WITH TWO CASCADED COMPLIMENTARY STAGES
Figure 14.40



HYBRID LEVEL DETECTOR CIRCUITS
Figure 14.41

TUNNEL DIODE COMPUTER CIRCUITS⁽¹⁾

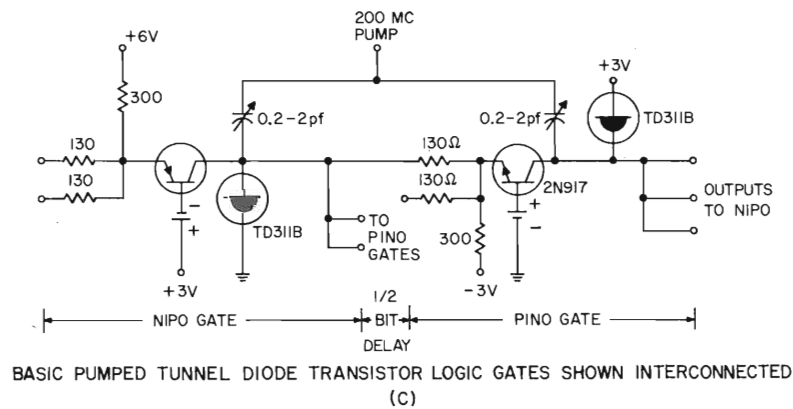
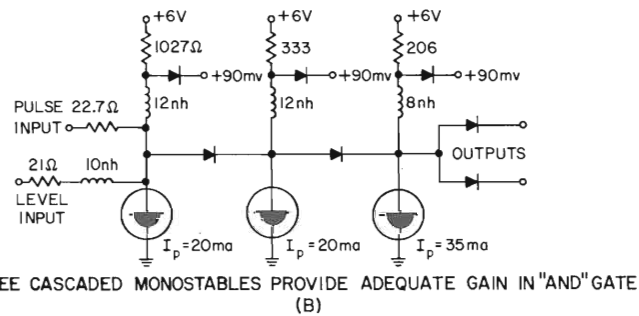
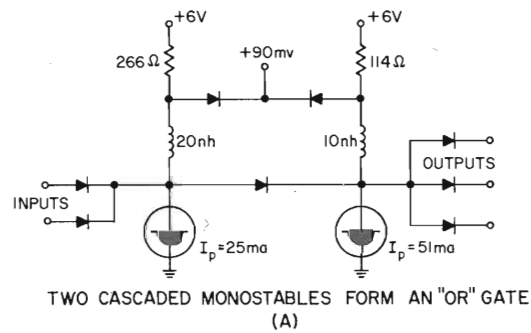
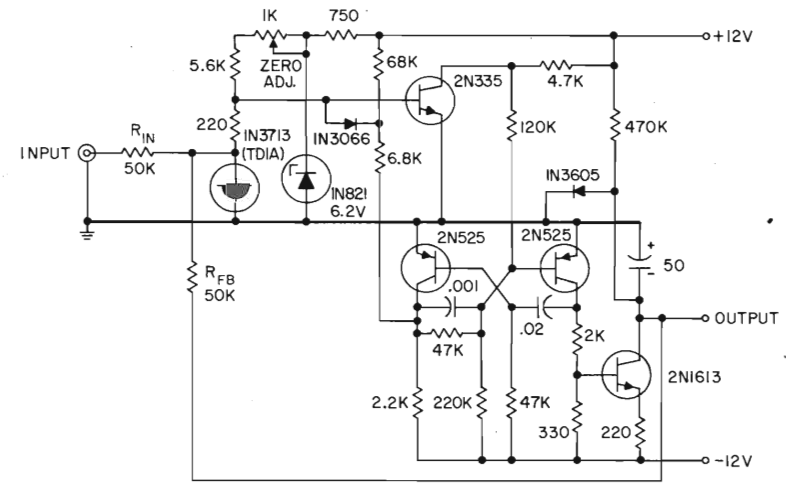
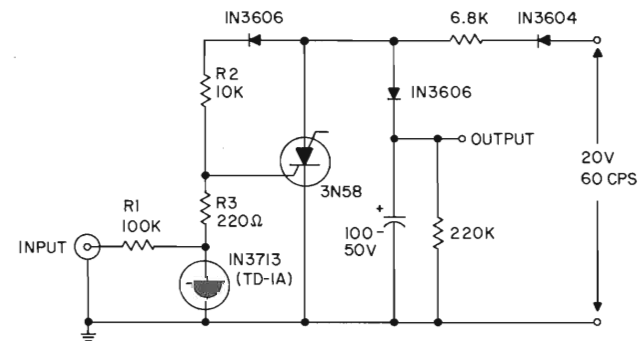


Figure 14.42



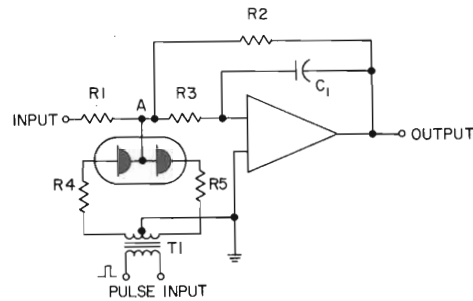
This circuit operates as a slideback sensing circuit⁽⁵⁰⁾ to give a dc output which is proportional to the positive peak of a repetitive input signal. With proper choice of the tunnel diode and the input circuit layout it is possible to measure the peak amplitude of pulses as narrow as one nanosecond. The circuit is similar to an operational amplifier with a voltage gain determined by the ratio R_{FB}/R_{IX} .

TUNNEL DIODE PEAK SENSING OPERATIONAL AMPLIFIER
Figure 14.43



A simple peak reading voltmeter circuit using a tunnel diode together with a silicon controlled switch to give a dc output proportional to the positive peak of the input signal. Voltage gain is equal to $(R_2 + R_3)/R_1$.

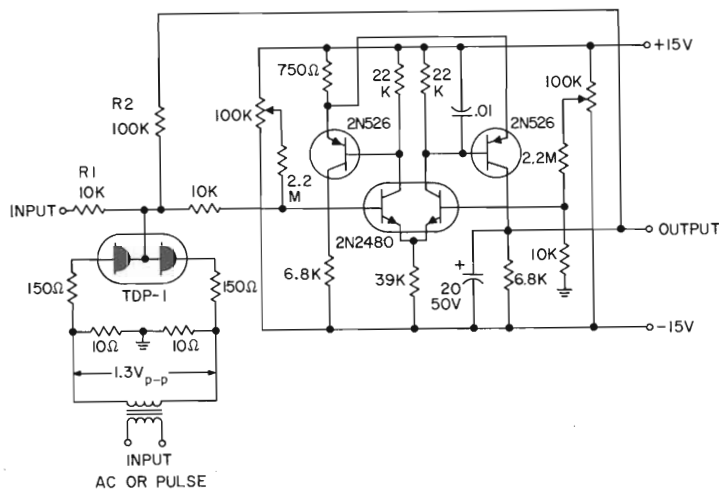
AC OPERATED PEAK READING VOLTMETER
Figure 14.44



A tunnel diode pair used in conjunction with an operational amplifier which functions as a sampling circuit with the output proportional to the input signal at the instant corresponding to the leading edge of the sampling pulse. Effective rise-time can be in the nanosecond range depending on the tunnel diodes used, the rise-time of the sampling pulse and the construction of the input circuitry. Voltage gain is determined by the ratio $R2/R1$.

OPERATIONAL SAMPLING CIRCUIT USING TUNNEL DIODE PAIR

Figure 14.45



A practical version of an operational sampling circuit using the principles shown in Figure 14.45. Voltage gain of the circuit is 100. Pulse synchronizing and pulse generating circuit details are not shown. This circuit can also be used to measure the differential peak point current of tunnel diode pairs.

PRACTICAL EXAMPLE OF OPERATIONAL SAMPLING CIRCUIT USING TUNNEL DIODE PAIR

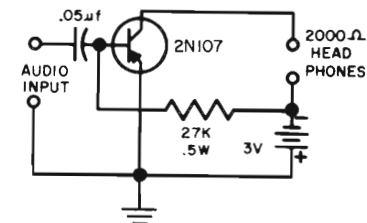
Figure 14.46

REFERENCES

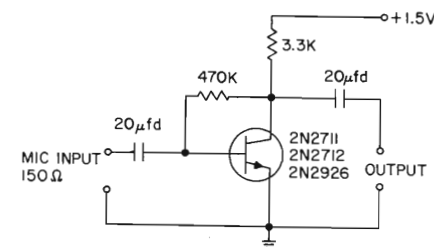
- (1) Gottlieb, E., Giorgis, J., "Tunnel Diodes - A Four Part Series," General Electric Application Note 90.48. (Reprinted from June 14, 21, 28 and July 5, 1963 issues of *Electronics*.)
- (2) "Tunnel Diode Manual." Chapter 4, General Electric Company, Semiconductor Products Department, Syracuse, New York 13201.
- (3) Burrus, C.A., "Millimeter Wave Esaki Diode Oscillators," *Proceedings of the IRE*, p. 2024, December 1960.
- (4) Gottlieb, E., "Tunnel Diode Oscillators - Don't Sell Them Short," *Electronic Design*, March 1963.
- (5) Gottlieb, E., Cleary, J.F., "Tunnel Diode Remote Control Transmitters," *Radio Electronics*, June 1963.
- (6) Nagle, J.J., "Crystal-Stabilized Tunnel Diode Oscillators," *Electronics*, p. 40, September 1, 1961.
- (7) Watters, R.L., "A Quartz Crystal Controlled Tunnel Diode Oscillator," General Electric Research Lab Memo Report p. 203.
- (8) Watters, R.L., "A Quartz Crystal Chronometer," *Electronics*, p. 129, September 29, 1961.
- (9) Ishii, K., Hoffins, C.C., "Extending Tunnel Diode Operating Frequency," *Electronics*, p. 43, June 1, 1962.
- (10) Pulfer, J.K., "Voltage Tuning in Tunnel Diode Oscillators," *Proceedings of the IRE*, p. 1155, June 1960.
- (11) Haneman, F.G., Thomson, G.W., "Varactor-Tuned Tunnel Diode Oscillator Now Practical," *Electronics*, p. 50, September 21, 1962.
- (12) Hauer, W.B., "A 4 Mw, 6 Kmc Tunnel Diode Oscillator," *Digest of Technical Papers - 1962 International Solid-State Circuits Conference*, p. 68.
- (13) Ishii, K., Hoffins, C.C., "Microwave Tunnel Diode Operation Beyond Cutoff Frequency," *Proceedings of the IRE, (Correspondence)*, p. 370, February 1963.
- (14) Bammel, S.E., "Tunnel Diode Radio Frequency Generator," *Popular Electronics*, p. 44, February 1963.
- (15) Kim, C.S., Hopkins, J.B., "High Frequency and High Power Operation of Tunnel Diodes," *Digest of Technical Papers - 1961 International Solid State Circuits Conference*, p. 22.
- (16) Trambarulo, R., Burrus, C.A., "Esaki Diode Oscillators from 3-40 Kmc." *Proceedings of the IRE (Correspondence)*, p. 1776, October 1960.
- (17) Sterzer, F., Nelson, D.E., "Tunnel Diode Microwave Oscillators," *Proceedings of the IRE*, p. 744, April 1961.
- (18) Gottlieb, E., "Tunnel Diode Sinewave Oscillators," *Electronic Design*, August 2 and August 16, 1961.
- (19) Iizuka, K., "Leadless Transceiver Probe Works Underwater," *Electronics*, pp. 56-59, July 19, 1963.
- (20) Kim, C.S., "Tunnel Diode Converter Analysis," *IRE Transactions on Electron Devices*, p. 394, September 1961.
- (21) Christensen, B., "Measurement of Tunnel Diode Conductance Parameters," *Proceedings of the IRE, (Correspondence)* p. 1581, October 1961.
- (22) Semiannual Report of Advanced Equipment Studies, WDL Technical Report TR 1481 Contract AF04(647)-532.
- (23) Sterzer, F., Presser, A., "Stable Low Noise Tunnel Diode Frequency Converters" *RCA Review*, p. 3, March 1962.
- (24) Pucel, R.A., "Measurement of the Conversion Conductances of Esaki Mixer Diodes," *IRE Transactions on Microwave Theory and Techniques*, MTT-9, 6, November 1961.
- (25) Pucel, R.A., "Theory of the Esaki Diode Frequency Converter," *Solid State Electronics*, p. 167, Pergamon Press 1961, Printed in Great Britain.
- (26) Gottlieb, E., "Practical Tunnel Diode Converter Circuit Considerations," *Solid State Design*, p. 31, September 1962.
- (27) Hubbard, D., "Pulse Counter FM Discriminator Design," *Electronic Equipment Engineering*, p. 44, July 1962.
- (28) Gottlieb, E., and Wolfram, A., "Design of Tunnel Diode UHF-TV Tuners," *Semiconductor Products Magazine*, p. 36A, March 1962.
- (29) Reindel, J., "A Compact Tunable Tunnel Diode S-Band Receiver," *The Microwave Journal*, p. 92, December 1961.
- (30) Chang, K.K.N., Heilmeier, G.H., Prager, H.J., "Low Noise Tunnel-Diode Down Converter Having Conversion Gain," *Proceedings of the IRE*, 48, p. 854, May 1960.
- (31) Dickens, L.E., Gneiting, G.R., "A Tunnel Diode Amplifying Converter," *IRE Transactions on Microwave Theory and Techniques*, p. 99, January 1961.
- (32) Eng, S.T., "Low Noise Properties of Microwave Backward Diodes," *IRE Transactions on Microwave Theory and Techniques*, p. 419, September 1961.
- (33) Follmer, W.C., "Low Frequency Noise in Backward Diodes," *Proceedings of the IRE*, p. 1939, December 1961.
- (34) "Tunnel Detector Models A and B," Reindel Microwave Engineering, San Diego, Calif.
- (35) Barnes, F.S., Morris, L., "A Tunnel Diode Frequency Multiplier with Gain," *Proceedings of the IRE*, p. 1940, December 1961.
- (36) Stockman, H.E., "Tunnel Diode Super Regenerative Parametric Motor," *Proceedings of the IRE*, p. 1586, October 1961.
- (37) Sikorski, M.E., "Sensitive Tunnel Diode Pressure Transducers," *Digest of Technical Papers - 1962 International Solid State Circuits Conference*, p. 74 and 106, February 15.
- (38) Mason, W.P., "Semiconductor Devices as Pressure Transducers," *Electronics*, p. 35, February 23, 1962.

- (30) Miller, S.L., Nathan, M.I., and Smith, A.C., "Pressure Dependence of the Current-Voltage Characteristics of Esaki Diodes," *Physical Review*, Letters p. 60, 4 No. 2, January 15, 1960.
- (40) Rogers, E.X., "Experimental Tunnel Diode Electromechanical Transducer Elements and Their Use in Tunnel Diode Microphones," *Journal Acoustical Society of America*, p. 888, 34, No. 7, July 1962.
- (41) Phelps, J.H., "A Tunnel Diode RF Radiation Detector," General Electric Application Note 90.43, April 1962.
- (42) MacGlashan, D.W., "New Tunnel Diode Preamplifier Improves Phased Array Radar," *Electronics* p. 57, September 28, 1962.
- (43) Sie, J.J., "Absolutely Stable Hybrid-Coupled Tunnel Diode Amplifier," *Proceedings of the IRE*, p. 1321, July 1960.
- (44) Fleri, D., Boyet, H., "Investigation of Traveling Wave Parametric and Hybrid Coupled Tunnel Diode Amplifier," Technical Note RADC-TR-61-231.
- (45) Yariv, A., Cook, J.S., "A Noise Investigation of Tunnel Diode Microwave Amplifiers," *Proceedings of the IRE*, pp. 739-743, April 1961.
- (46) Goto, E., et al., "Esaki Diode High Speed Logical Circuits," *IRE Transactions on Electronic Computers*, EC-9, p. 25, 1, March 1960.
- (47) Herzog, G.B., "Tunnel-Diode Balanced-Pair Switching Analysis," *RCA Review*, p. 187, XXIII, No. 2, June 1962.
- (48) Gibson, J.J., "An Analysis of the Effects of Reactances on the Performance of the Tunnel-Diode Balanced-Pair Logic Circuit," *RCA Review*, p. 457, XXIII, No. 4, December 1962.
- (49) Miller, H.S., and Powlus, R.A., "An Evaluation of Tunnel Diode Balanced Pair Logic Systems," *RCA Review*, p. 489, XXIII, No. 4, December 1962.
- (50) Axelrod, M.S., et al., "Some New High-Speed Tunnel-Diode Logic Circuits," *IBM Journal*, p. 158, 6, No. 2, April 1962.
- (51) Bergman, R.H., et al., "High Speed Logic Circuits Using Tunnel Diodes," *RCA Review*, page 152, XXIII, No. 2, June 1962.
- (52) Hwang, Y.C., et al., "Analysis of a Pumped Tunnel Diode Logic Circuit," *IRE Transactions on Circuit Theory*, p. 233, Volume CT-9, No. 3, September 1962.
- (53) Sear, B., et al., "The Enhanced Tunnel Diode Logic Circuit," *Digest of Technical Papers - 1963 International Solid States Circuits Conference*.
- (54) Berry, D.L., and Fisch, E.A., "High Speed Tunnel Diode Memory," *Digest of Technical Papers - 1961 International Solid States Circuits Conference*, p. 112.
- (55) Chaplin, G.B., and Thompson, P.M., "A Fast-Word Organized Tunnel-Diode Memory Using Voltage-Mode Selection," *Digest of Technical Papers - 1961 International Solid States Circuits Conference*, p. 40.
- (56) Cole, A.J., et al., "The Engineering of a Fast Word Organized Tunnel Diode Store," *Digest of Technical Papers - 1962 International Solid States Circuits Conference*, p. 40.
- (57) Schindler, H.R., "UHF Analog Digital Converter," *Digest of Technical Papers - 1963 International Solid States Circuits Conference*.
- (58) Bush, E.G., "A Tunnel Diode Counter for Satellite Applications," NASA Technical Note D-1337, June 1962.
- (59) Sylvan, T.P., "Tunnel Diode Slide-Back Sensing Circuits," *Electronic Equipment Engineering*, p. 60-64, September 1963.

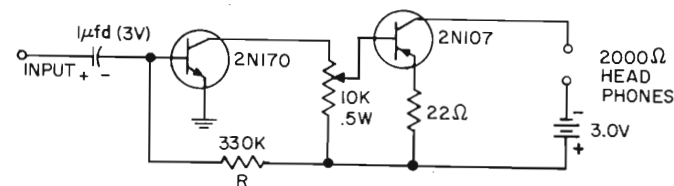
NOTES



SIMPLE AUDIO AMPLIFIER
Figure 15.1



LOW IMPEDANCE MICROPHONE PREAMPLIFIER
Figure 15.2



NOTE: ADJUST R FOR OPTIMUM RESULTS

DIRECT COUPLED "BATTERY SAVER" AMPLIFIER
Figure 15.3