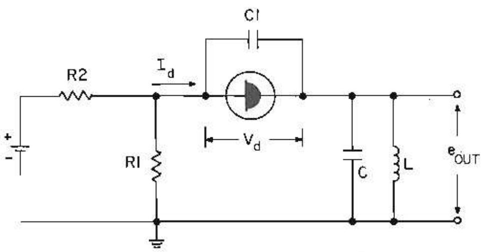
NOTES

CHAPTER 14

TUNNEL DIODE CIRCUITS

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.

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

$$C1 = \sqrt{\frac{g_{di}\,(1 - R_T\, g_{di})}{R_T\, \omega^2}}$$ where g_{di} is TD's initial negative conductance
R_T is circuit's total dc resistance and
is equal to $\frac{R1\ R2}{R1 + R2} + R_S + R_{DC\,(coil)}$
R_S is TD's total series resistance.

$$C + \frac{C_1}{1 - R_T\, g_d} = \frac{1}{L\, \omega^2}$$ where g_d is TD's negative conductance.

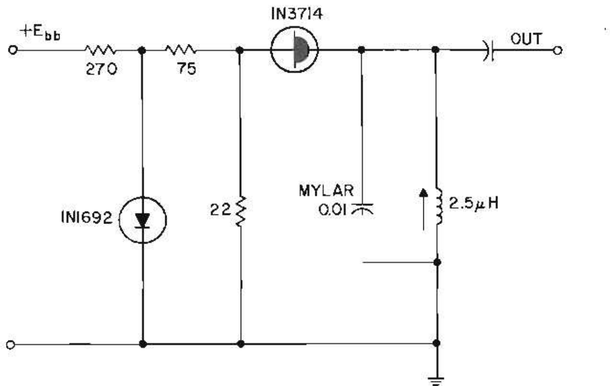
hence

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

BASIC TUNNEL DIODE SINEWAVE OSCILLATOR AND DESIGN EQUATIONS

Figure 14.1

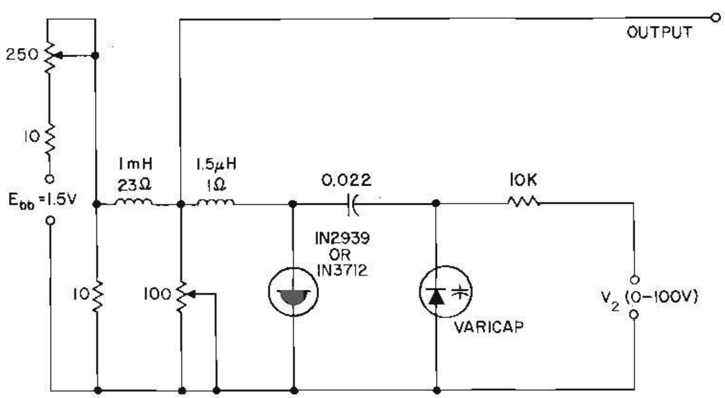
The circuits that follow illustrate the many applications and variety of tasks tunnel diode oscillators are capable of performing. Brief descriptions accompany some circuits. For more complete information readers should consult the specific reference as indicated. An extensive reference list appears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

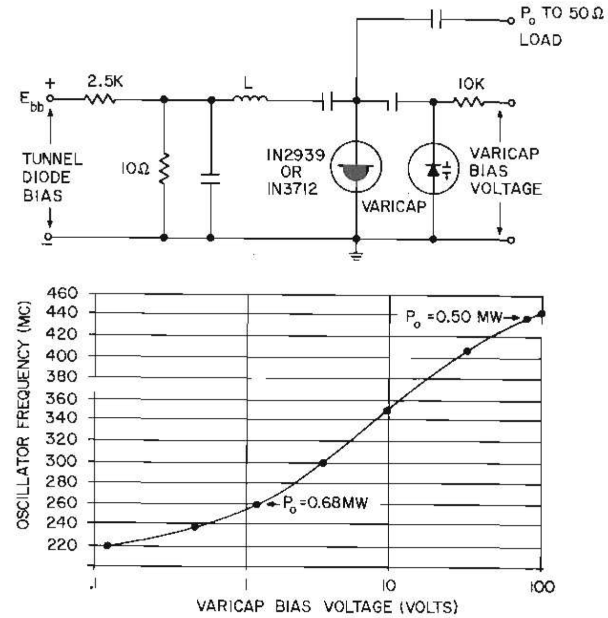
Figure 14.2



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

VOLTAGE CONTROLLED OSCILLATOR

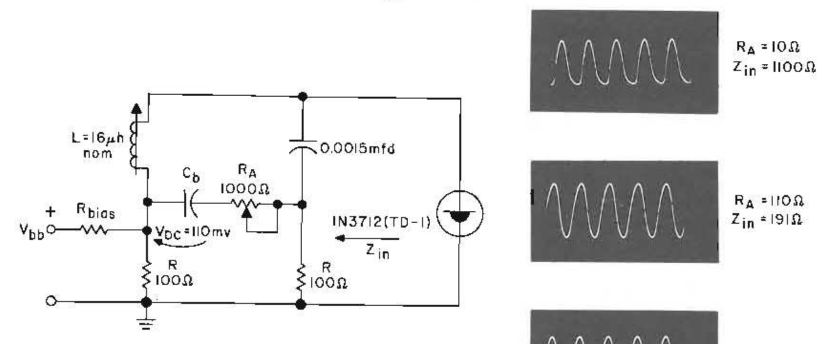
Figure 14.3



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

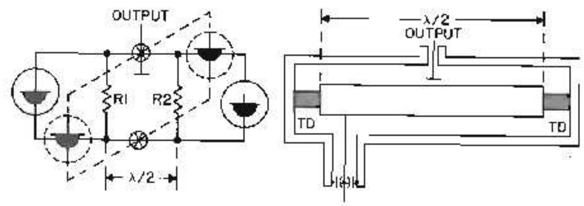


C_b = DC BLOCKING CAPACITOR
R_A = ATTENUATING RESISTOR
$Z_{in} \cong R\left(1 + \frac{R}{R_A}\right)$

Resistor R_A 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.[4]

VARIABLE AMPLITUDE OSCILLATOR

Figure 14.5

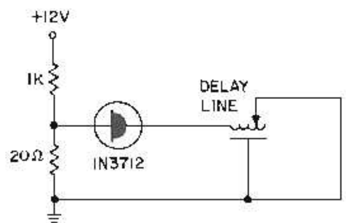


MATERIAL	(MA)	BIAS (MW)	FREQ. (GC)
Ge	40	1	6
Ga As	45	1.5	3
Ga As	80	3	6
Ga As	100	4	6

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

MICROWAVE OSCILLATOR

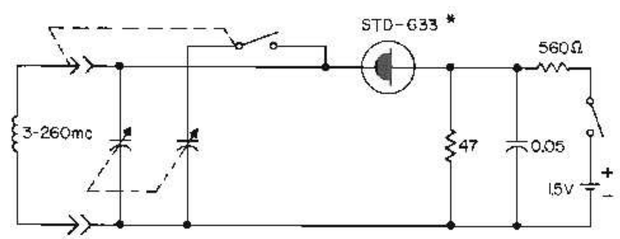
Figure 14.6



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

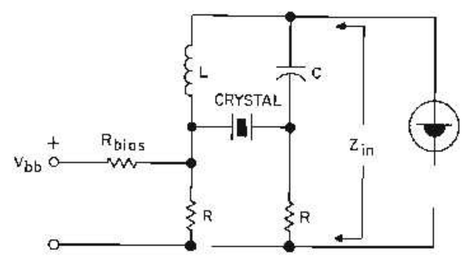


* SELECTED DEVICE

SINEWAVE OSCILLATOR WITH "PLUG-IN" COILS

(Covers 3 to 260 mc range)

Figure 14.8



$R < |R_{di}|$

$R = \sqrt{L/C}$

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

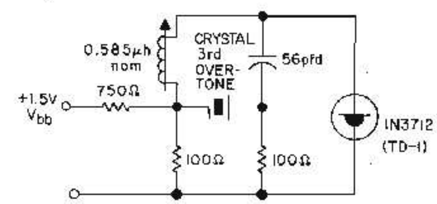
WHERE R_{CR} IS THE SERIES RESISTANCE OF THE CRYSTAL AT RESONANCE.

FOR OSCILLATIONS: $\left|\begin{array}{l} R_e\,|Y_{in}| < |g_{di}| \\ I_m\,|Y_{in}| = 0 \end{array}\right|$

BASIC TUNNEL DIODE CRYSTAL CONTROLLED OSCILLATOR[7]

Figure 14.9

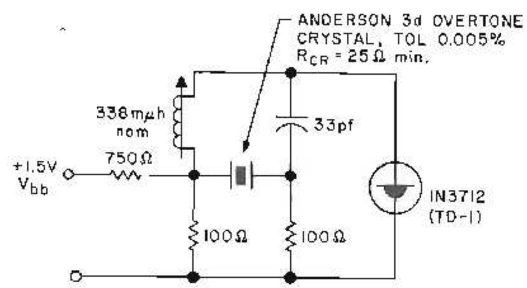
Figures 14.10 and 14.11 show crystal controlled Citizens Band and Fire Department oscillators. Both are useable in low power (microwatt) transmitters for short range communications.[7]



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

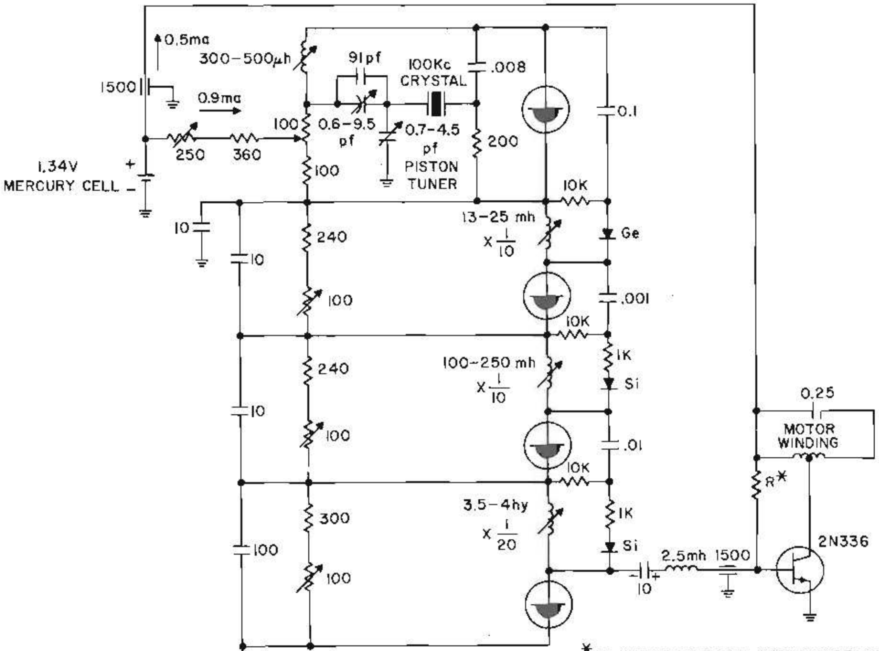
Figure 14.10



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



*ADJUST R FOR COLLECTOR CURRENT OF 0.5 ma WHILE MOTOR IS RUNNING

TUNNEL DIODES 0.5 ma UNITS

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[6]

Figure 14.12

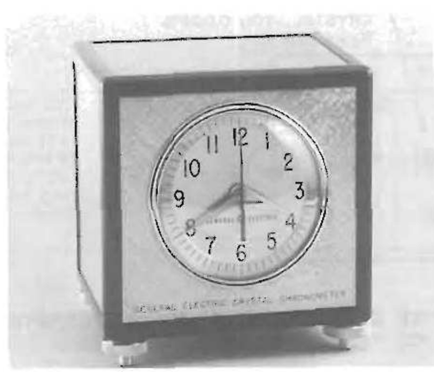


Figure 14.13 HIGH ACCURACY CHRONOMETER

TUNNEL DIODE MICRO-POWER TRANSMITTERS[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.

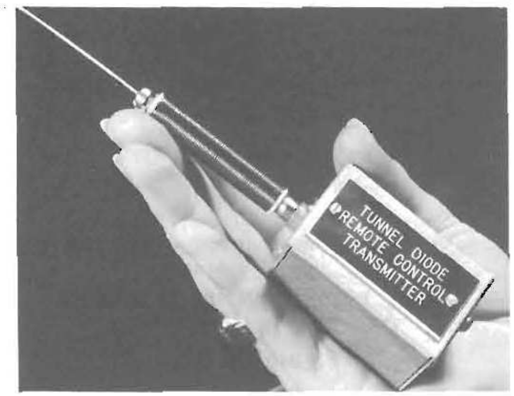
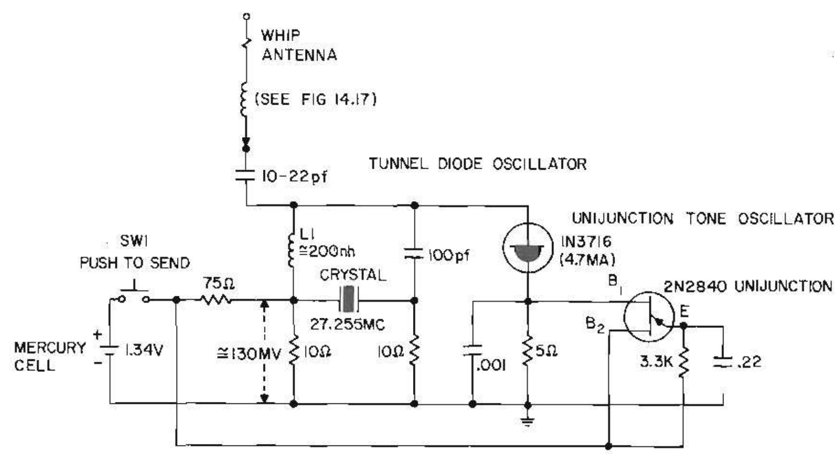


Figure 14.14

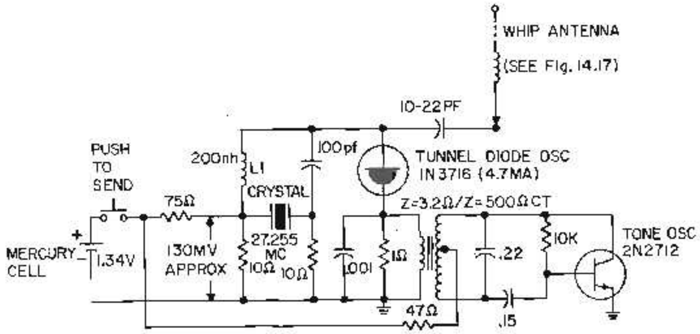


L1 - 6 TURNS #16
(1/2" LONG, 3/8" I.D., TURNS SPACED 1/32")

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

TUNNEL DIODE-UNIJUNCTION REMOTE CONTROL TRANSMITTER

Figure 14.15

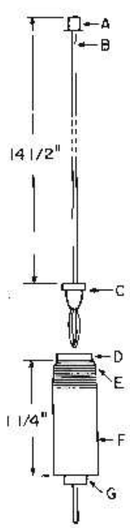


L1 - 6 TURNS #16
(1/2" LONG, 3/8" I.D., TURNS SPACED 1/32")

Hartley oscillator using silicon transistor modulates tunnel diode transmitter.

TUNNEL DIODE-TRANSISTOR REMOTE CONTROL TRANSMITTER

Figure 14.16

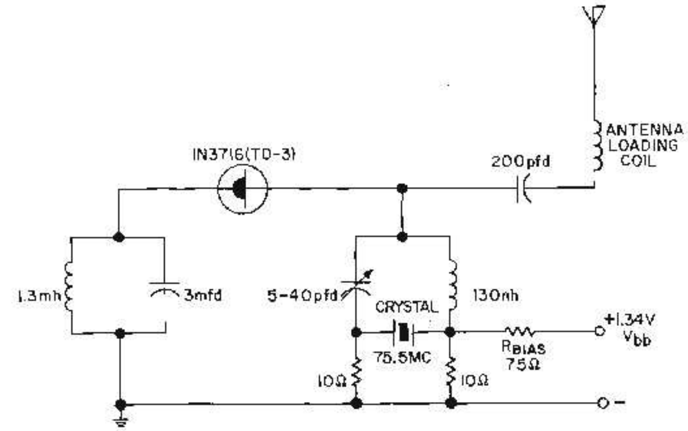


A. SAFETY CAP SOLDERED TO ANTENNA TIP
B. 14 1/2 INCH .052" PIANO WIRE SOLDERED OR BRAZED TO C
C. BANANA PLUG (E.F. JOHNSON 108-771)
D. BANANA JACK FORCED-TAPPED INTO 7/32" DRILLED HOLE (E.F. JOHNSON 108-760)
E. 50 TURNS # 24 FORMVAR OR ENAMEL COVERED WIRE ADJUSTED TO 27 mc WITH GRID DIP METER
F. 1/2"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

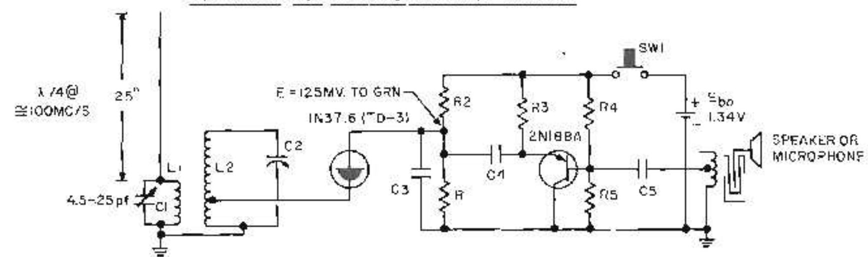
Figure 14.17



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"ID SPACED 1/8" FROM GROUND END OF L2 (ADJUST FOR BEST STABILITY)
L2 6 TURNS #16 COPPER 3/8"ID CLOSE-WOUND AND CONNECTED DIRECTLY TO C2, TAPPED 1 TURN FROM GROUND.
C1 4.5-25μμfd CERAMIC TRIMMER
C2 1.5-5μμfd VARIABLE
C3 800μμfd (VOLTAGE NOT IMPORTANT-SELECT FOR SMALL SIZE)
C4 50μfd 6 VDC ELECTROLYTIC (VOLTAGE NOT IMPORTANT-SELECT FOR SMALL SIZE)
C5 1μfd 35 VDC (VOLTAGE NOT IMPORTANT-SELECT FOR SMALL SIZE)
R1 18Ω 1/2 W 5%
R2 150Ω 1/2 W 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.

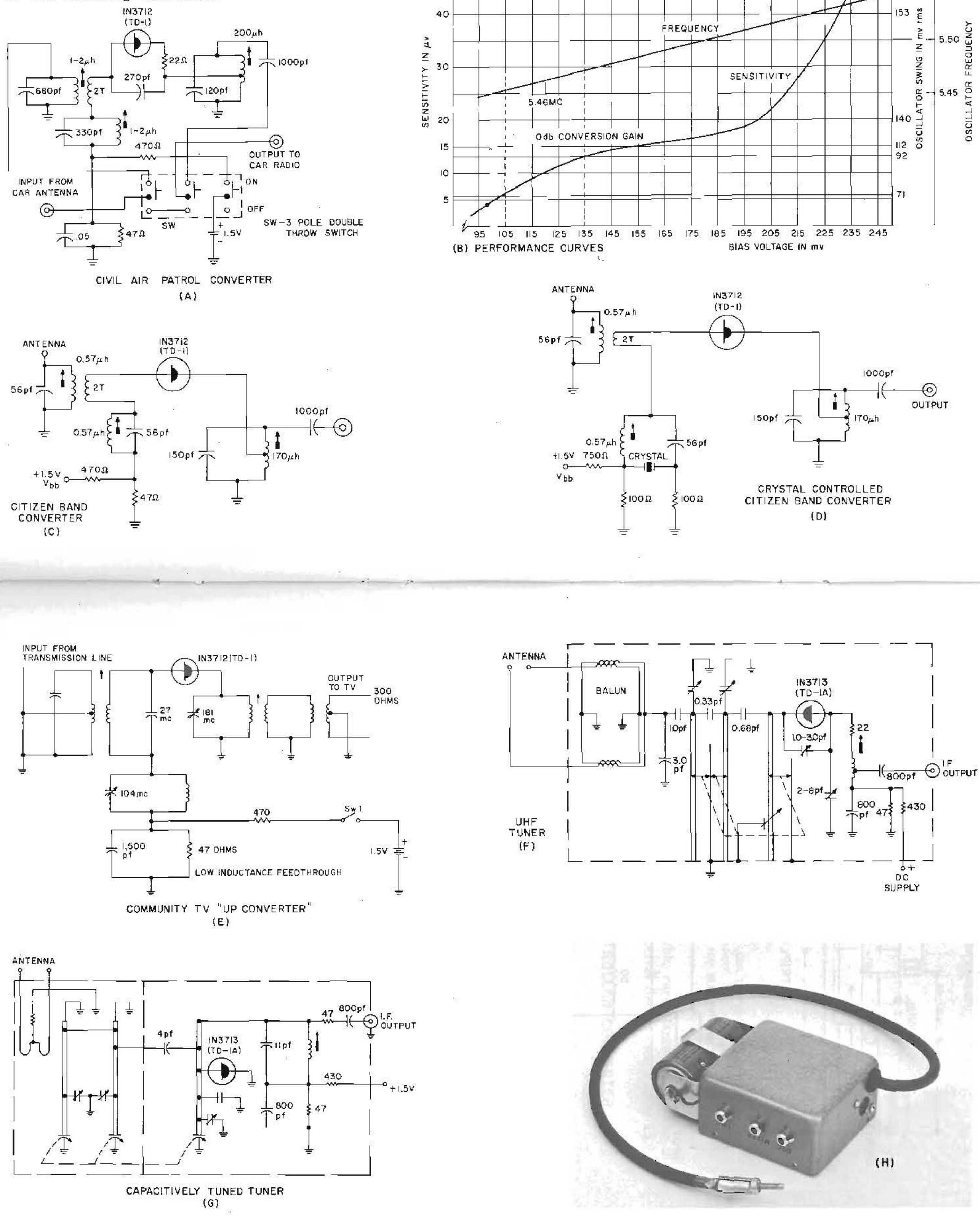
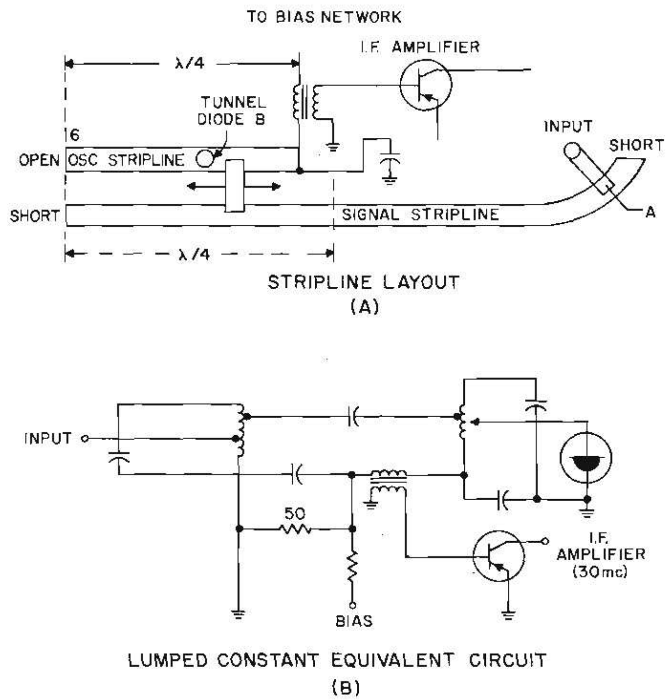
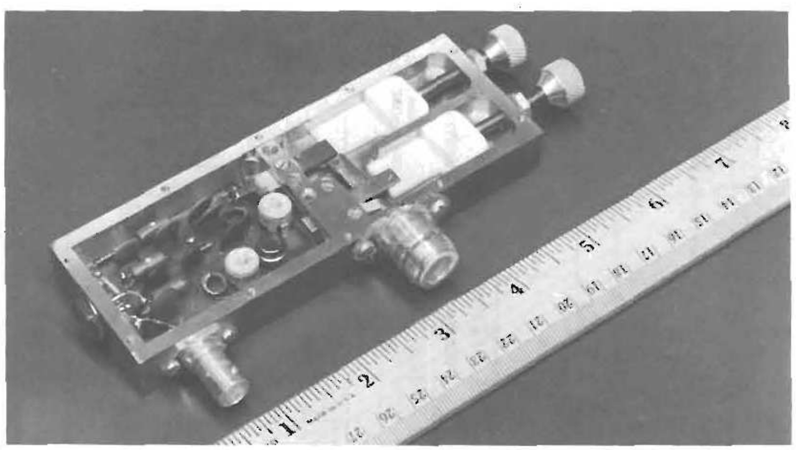


Figure 14.20 SELF-OSCILLATING TUNNEL DIODE CONVERTERS



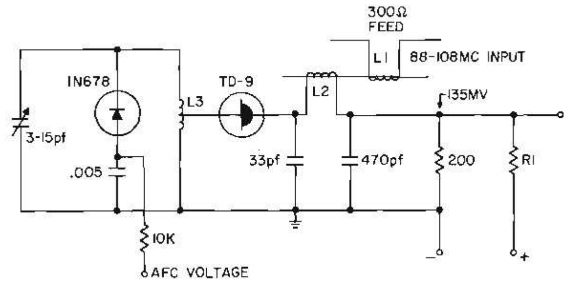
L-BAND SELF-OSCILLATING CONVERTER

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

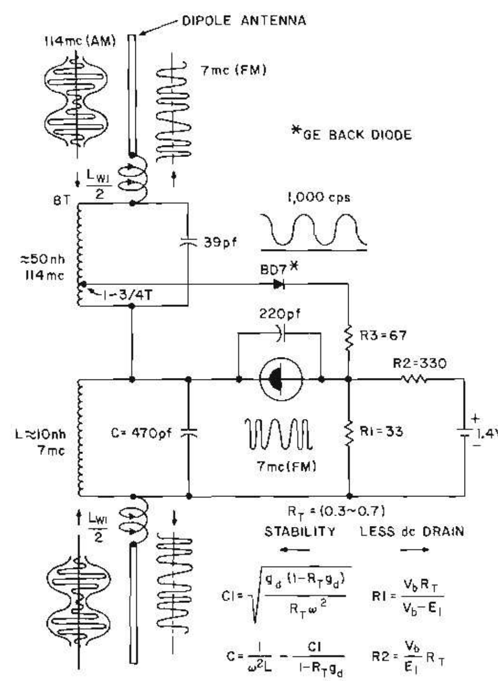
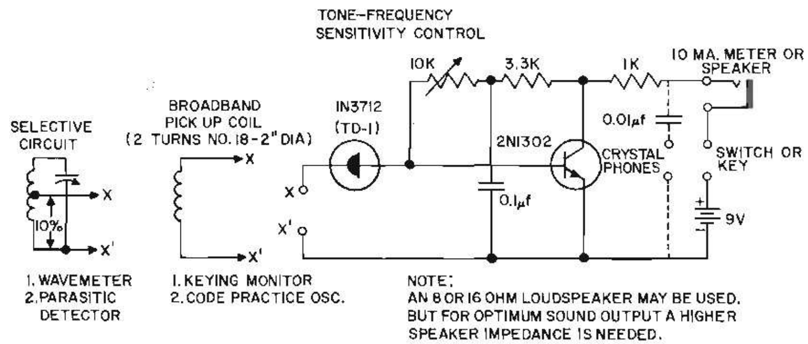


Figure 14.24 TUNNEL DIODE TRANSCEIVER[19]

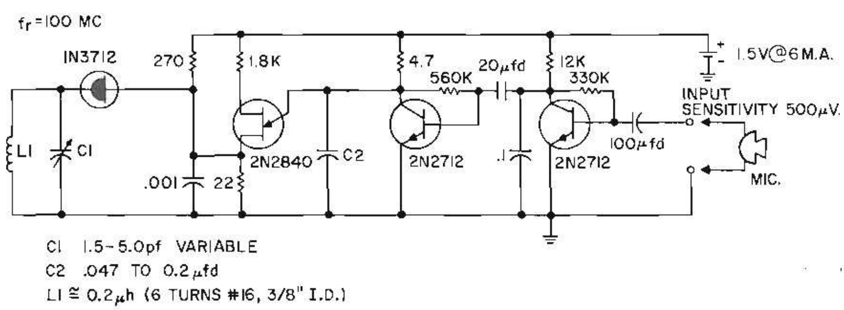
This transceiver is tuned for a 114 mc AM input signal and a 7 mc FM output signal. The 1N3714 (TD-2) tunnel diode acts as 7 mc RF oscillator and frequency modulator while the BD-7 back diode is the 114 mc detector.

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

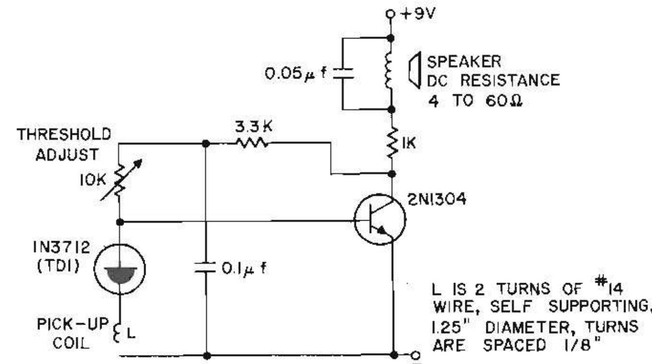


C1 1.5-5.0pf VARIABLE
C2 .047 TO 0.2μfd
L1 ≅ 0.2μh (6 TURNS #16, 3/8" I.D.)

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

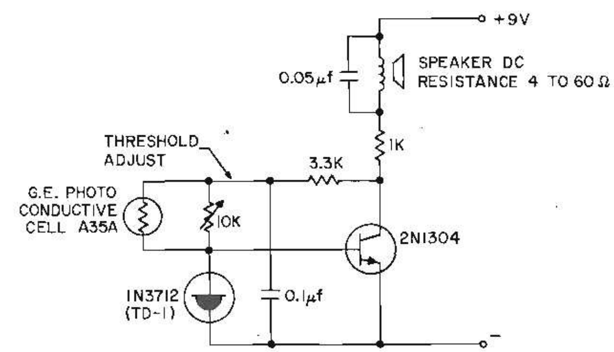
Figure 14.26



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



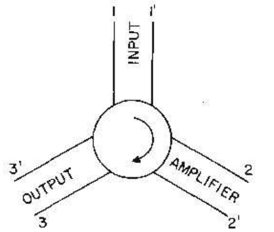
This is a variation of the circuit shown in Figure 14.27. Here the sensor is a photoconductive cell giving alarm at below 0.1 foot candles of illumination near 5500 angstroms.

LIGHT DETECTOR

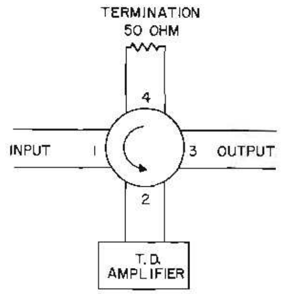
Figure 14.28

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

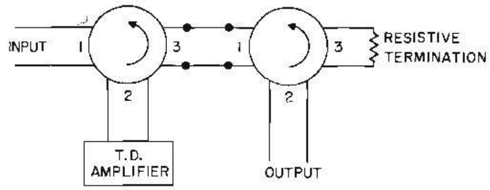
The performance of tunnel diodes in low noise amplifiers is especially attractive at UHF and microwave frequencies where ferrite isolators, circulators, and/or hybrid-couplers can be used to unilateralize the signal flow. At frequencies where these devices are not available, stable gain is difficult 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)

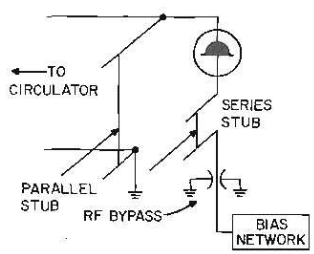


FOUR-PORT CIRCULATOR
(B)

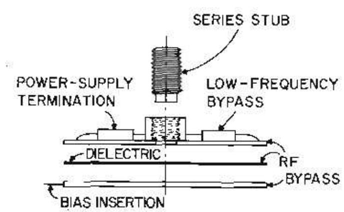


TWO CASCADED THREE-PORT CIRCULATORS
(C)

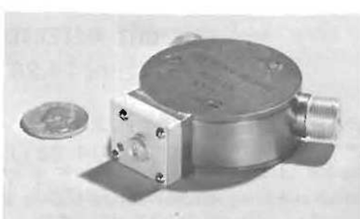
TUNNEL DIODE UHF CIRCULATORS
Figure 14.29



SIMPLIFIED TD PREAMP CIRCUIT
(A)



PHYSICAL ARRANGEMENT
(B)



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

UHF PREAMPLIFIERS
Figure 14.30

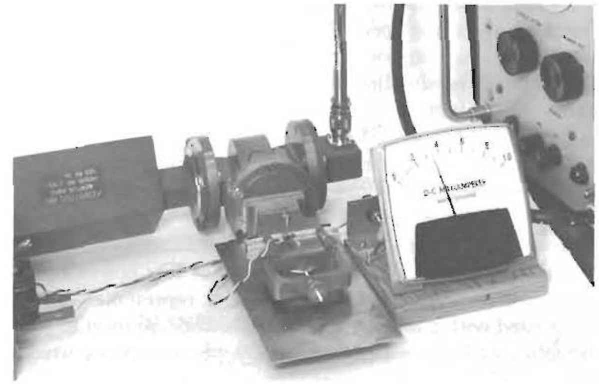
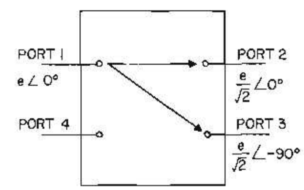
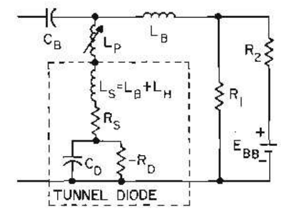


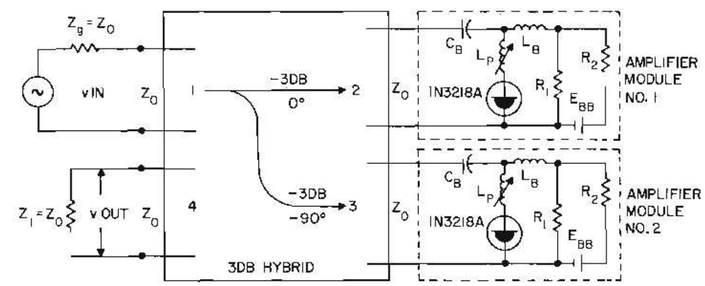
Figure 14.31 TUNNEL DIODE SIX-GIGACYCLE WAVEGUIDE AMPLIFIER



SIGNAL DISTRIBUTION IN
HYBRID-COUPLER
(A)



TUNNEL DIODE AMPLIFIER
(B)



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

Z_0 = CHARACTERISTIC IMPEDANCE $\qquad f_1 = \dfrac{1}{2\pi\sqrt{LC}}$

$Z = \sqrt{L/C}$ $\qquad |-R_d|$ = 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 transistion times as low as 27 pico-seconds (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]

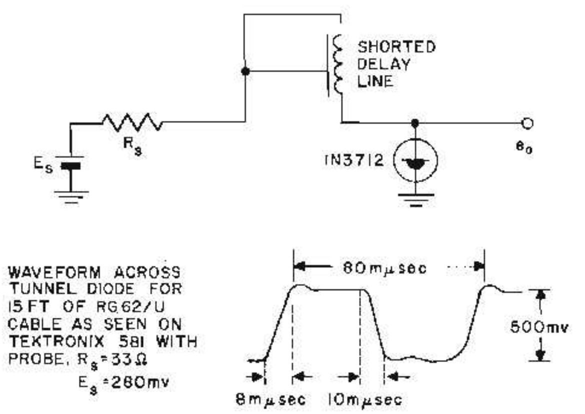


Figure 14.33 RELAXATION OSCILLATOR USING A SHORTED DELAY LINE

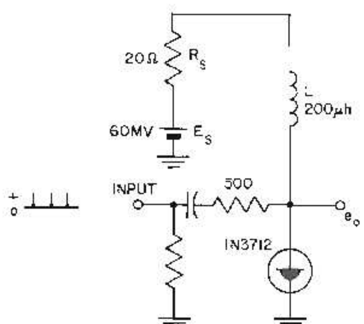
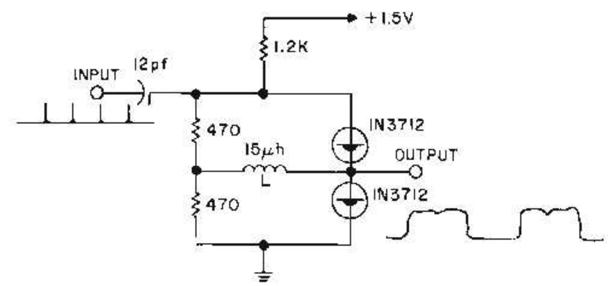


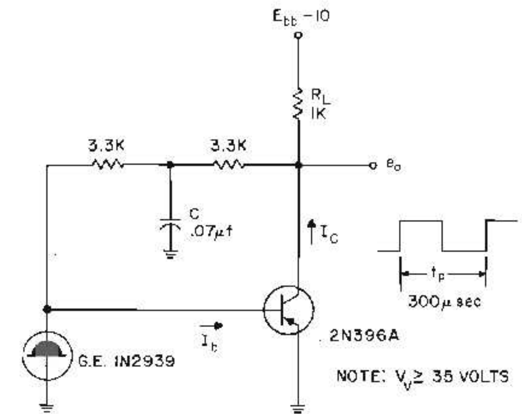
Figure 14.34 TUNNEL DIODE MONOSTABLE OSCILLATOR



TUNNEL DIODE FLIP-FLOP

Figure 14.35

HYBRID (TRANSISTOR-TUNNEL DIODE) MULTIVIBRATORS[2]

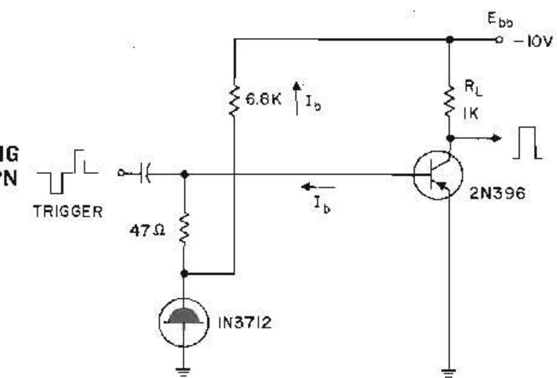


ASTABLE HYBRID OSCILLATOR

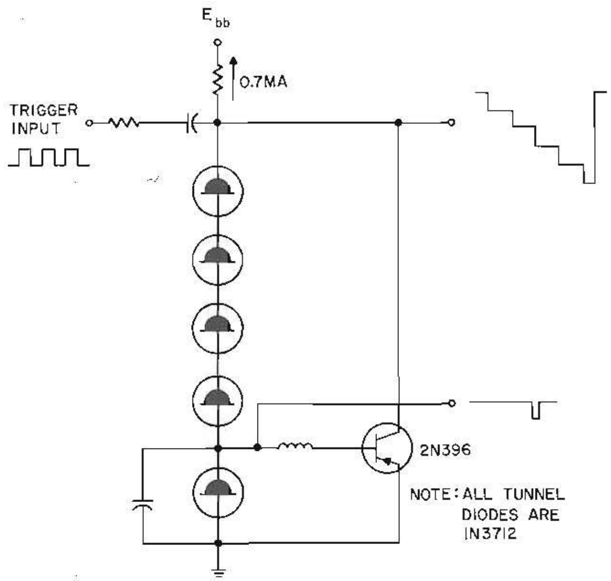
FIGURE 14.36

BISTABLE CIRCUIT USING TUNNEL DIODE AND NPN GERMANIUM ALLOY TRANSISTOR

Figure 14.37

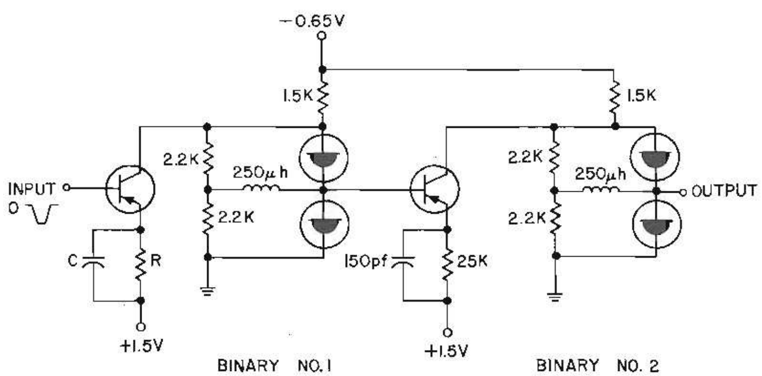


TUNNEL DIODE COUNTERS[1, 2]



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

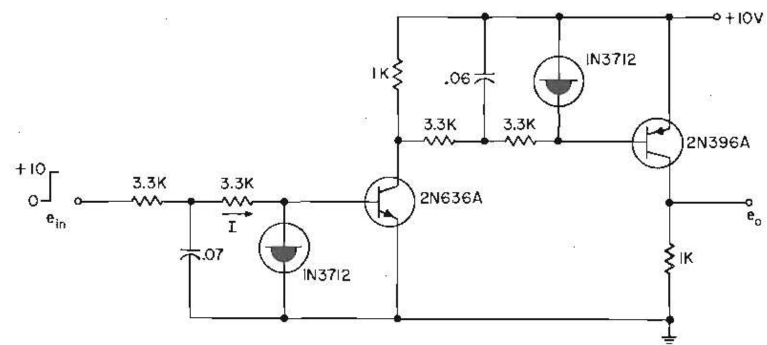
Figure 14.38



LOW LEVEL TUNNEL DIODE COUNTER

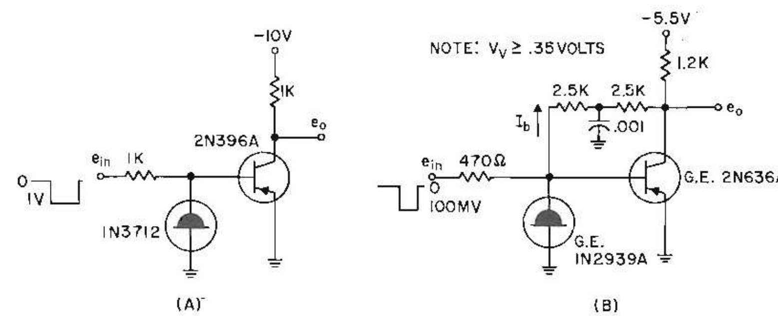
Figure 14.39

MISCELLANEOUS TUNNEL DIODE CIRCUITS[2]



TUNNEL DIODE TIME DELAY CIRCUIT WITH TWO CASCADED COMPLIMENTARY STAGES

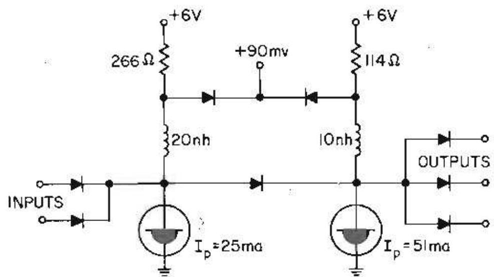
Figure 14.40



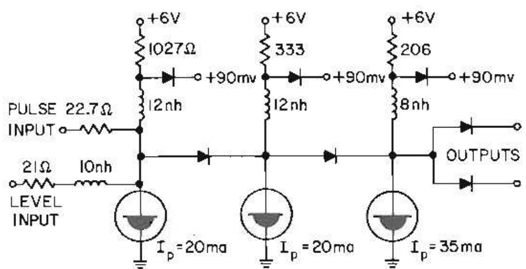
HYBRID LEVEL DETECTOR CIRCUITS

Figure 14.41

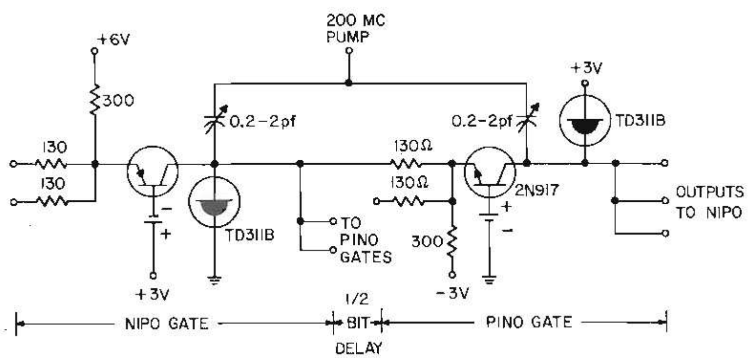
TUNNEL DIODE COMPUTER CIRCUITS[1]



TWO CASCADED MONOSTABLES FORM AN "OR" GATE
(A)

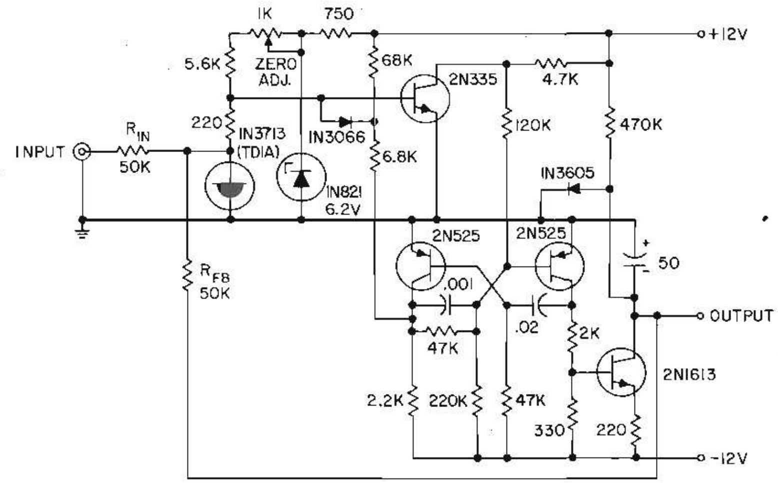


THREE CASCADED MONOSTABLES PROVIDE ADEQUATE GAIN IN "AND" GATE
(B)



BASIC PUMPED TUNNEL DIODE TRANSISTOR LOGIC GATES SHOWN INTERCONNECTED
(C)

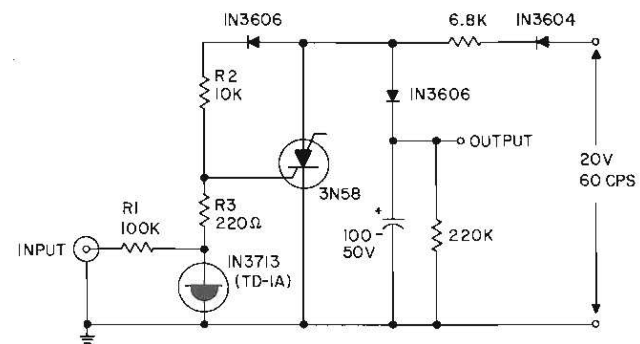
Figure 14.42



This circuit operates as a slideback sensing circuit[58] 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_{IN}.

TUNNEL DIODE PEAK SENSING OPERATIONAL AMPLIFIER

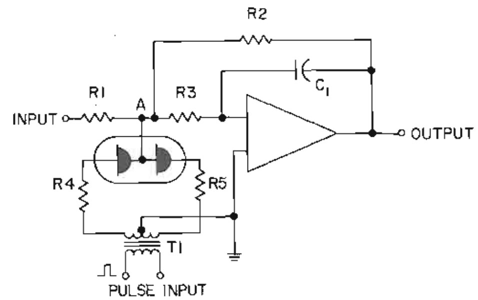
Figure 14.43



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 (R2 + R3)/R1.

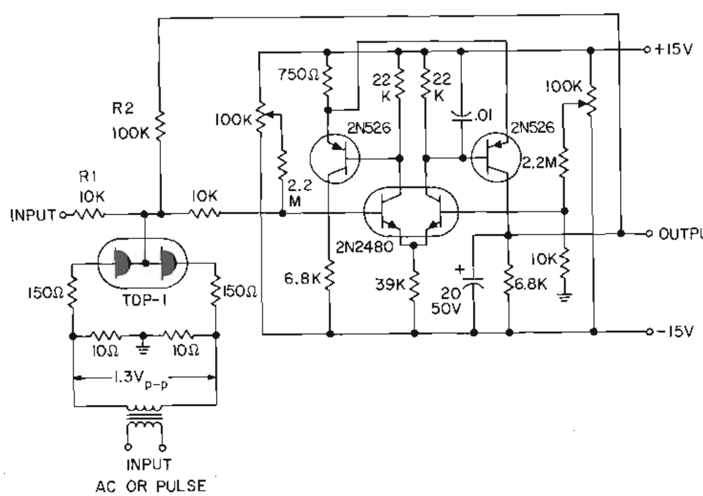
AC OPERATED PEAK READING VOLTMETER

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

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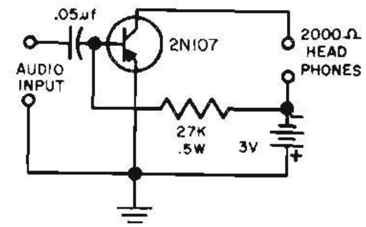
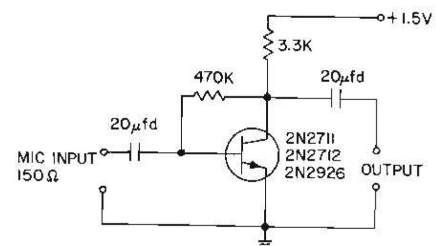
NOTES

EXPERIMENTERS CIRCUITS

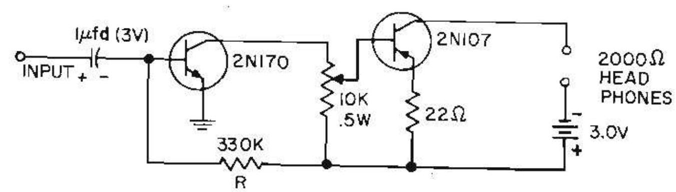
CHAPTER 15



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