NORTHERN ALBERTA INSTITUTE OF TECHNOLOGY
EDMONTON ALBERTA

ELECTRONICS DEPARTMENT

Pulse Lab. - Job #7

TUNNEL DIODE MULTIVIBRATOR CIRCUITS

OBJECT: To examine switching characteristics of a typical tunnel diode.

THEORY: The tunnel diode may be used as a/an

1. astable
2. monostable
3. bistable multivibrator

These various forms are obtained by obtaining the proper load lines as shown in the following diagram:

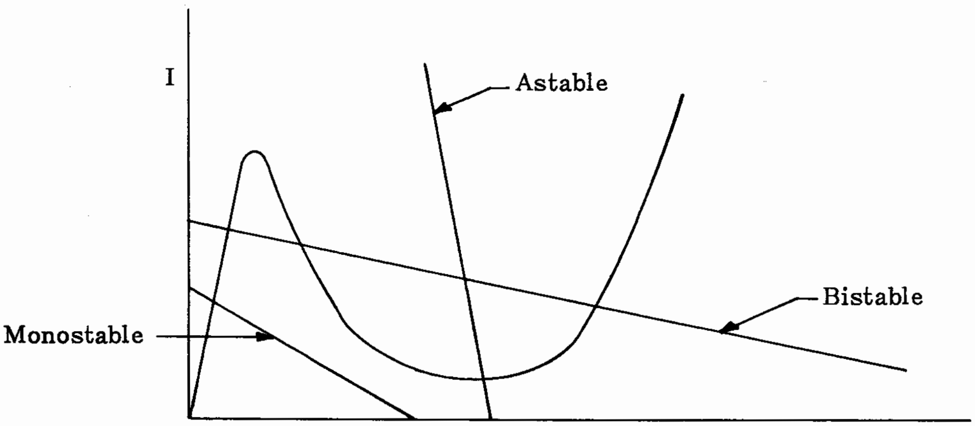


Fig. 1

1. The Astable Multivibrator

When a voltage is applied to the circuit shown in Figure 2, the current gradually increases due to the effect of the inductance. Just after the current reaches the peak point value, point "b" of Fig. 3, the resistance of the tunnel diode rapidly increases, and since the current cannot change instantaneously, the output voltage increases until a new equilibrium is obtained, point "c".

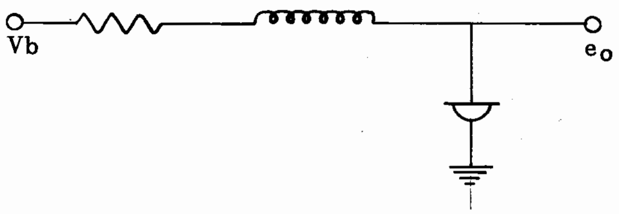


Fig. 2.

The current then decreases to the valley point current, point d, whereupon the resistance of the tunnel diode is quickly decreased and the new equilibrium point "a" is reached (the current through the inductor cannot change instantaneously). The cycle now repeats itself.

The output voltage will appear as follows:

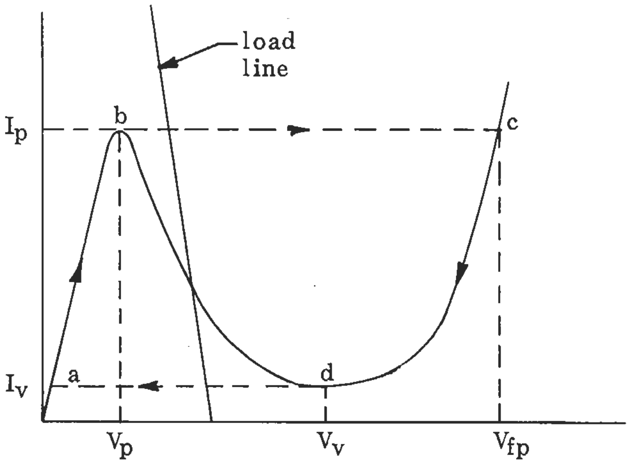


Fig. 3.

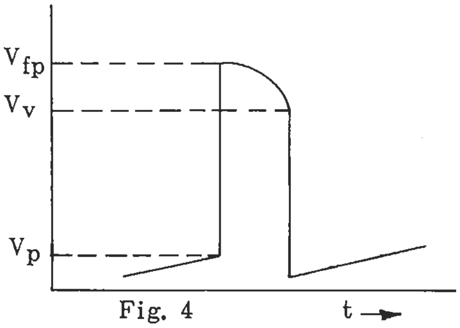


Fig. 4

2. The Monostable Multivibrator

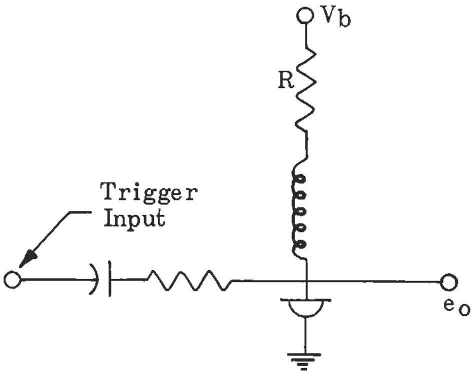


Fig. 5

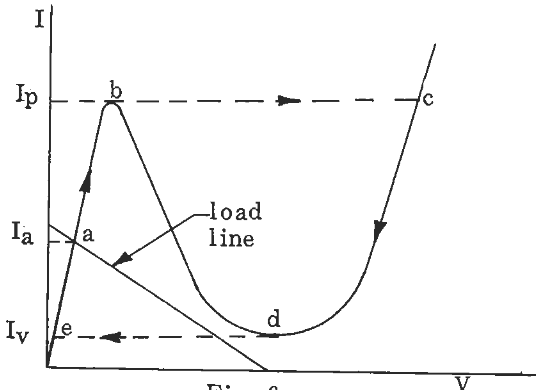


Fig. 6

In this case, point "a" is a stable operating point. With a sufficiently large triggering voltage, the current will reach Ip and because of instability the operating point will shift to point "c". Following similar reasoning as for the astable multivibrator, the operating point will move as shown on the characteristic curve.

3. The Bistable Multivibrator

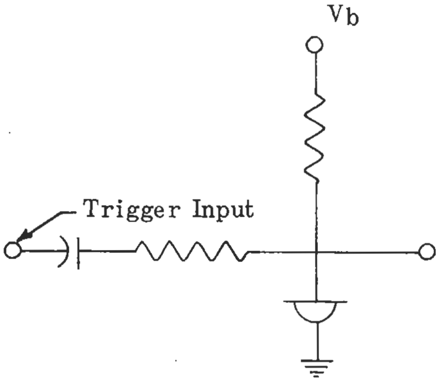


Fig. 7

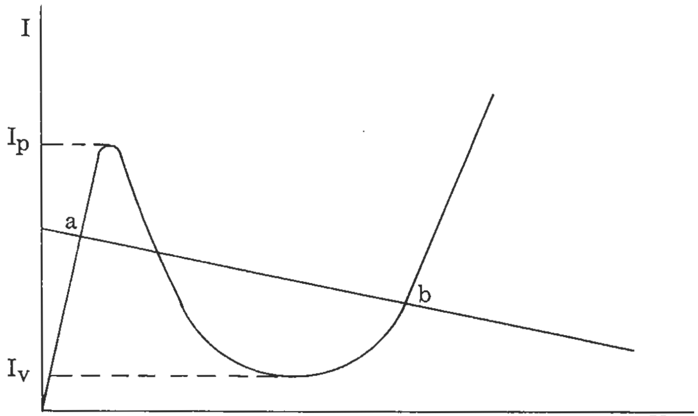


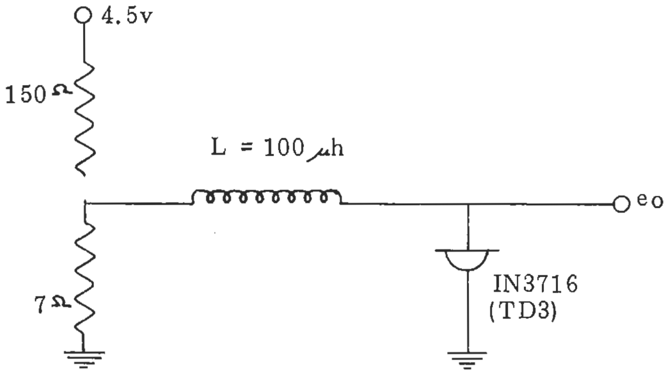
Fig. 8

Both points "a" and "b" are stable operating points. With a sufficiently large positive triggering voltage when operating at point "a", the current will reach Ip and because of instability, the operating point will switch to point "b" and remain there. The operating point can be switched back to point "a" by a sufficiently large negative pulse so that the current will reach Iv.

PROBLEM #1 The Astable Multivibrator

PART A: Theoretical

(a) Draw the output voltage for the following circuit, giving all maximum and minimum amplitudes.



PART B: Laboratory

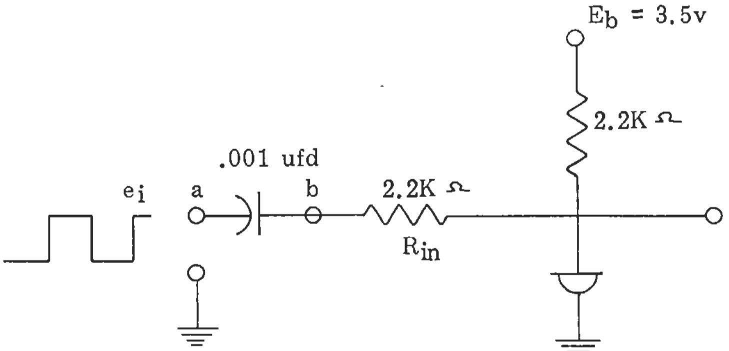
(a) Construct the above circuit and observe and record the results. Increase the 7Ω to 15Ω and notice the effect. Explain.

PROBLEM #2 The Bistable Multivibrator

PART A: Theoretical

(a) From the manufacturer's data sheets, sketch the characteristic curve and insert the D.C. load line. What are the stable operating points, voltages, and currents?

(b) Determine the diode current required to cause the tunnel diode to switch, and from this calculate the amplitude of input voltage required. ($i_D \simeq e_{in}/R_{in}$) since the diode resistance is small compared to 2.2K.



(c) Determine the amplitude of the output waveform.

PART B: Laboratory

(a) Apply a 2 KHz square wave to the diode as shown, having an amplitude appropriate to produce switching. Observe the waveforms at a, b, and c, giving particular attention to the rise and fall times.

(b) Decrease the amplitude of the applied signal and observe the effect.

(c) Increase R_{in} to 4.7 K and observe the effect. Explain.

DISCUSSION:

(a) What type of waveform was obtained at point "b"?
Give the name of this waveform and relate it to the waveform obtained at point "c".

(b) Discuss the problem of measuring the switching speed of the tunnel diode.

TUNNEL DIODES-

The tunnel diode has been around for about fifteen
plications for it. Even so, it is seldom men-
manual. Here are experiments and some practical

by STEPHEN DANIELS

IN THE MAD RUSH TOWARD INTEGRATED circuitry of the past 15 years, the tunnel diode has been shunted aside by multi-element packages. It's still very much around though and it may one day enjoy a resurgence as a component of some of those same chips that have replaced it.

The unusual properties of the tunnel diode lend themselves to some simple solutions of complex problems. Circuit design is inherently easy and TD's will amplify and oscillate at frequencies at which most other solid-state devices fall flat. In this article, we'll examine the negative-resistance phenomenon that the tunnel diode produces and show some possible audio and rf applications.

Experimental layout

Everything except the really high-frequency circuits can be assembled on a phenolic breadboard. The board, required brackets and hardware can be found at any well-stocked parts house.

Once you have the breadboard put together, set up the basic voltage divider biasing circuit diagrammed in Fig. 1. Watch the polarity carefully on the tunnel diode and batteries and also on C1 and M1. M1 reads the current through TD1 and can be rated from 5 to 15 mA. I used the low-current scale of my vom. BATT1 and BATT2, like any batteries used in tunnel diode circuits, *must* be mercury types. Zinc-carbons have a high internal resistance which tends to cancel the negative-resistance effect of the tunnel diode.

With R1 set at maximum resistance, apply power and *slowly* bring the resistance down, thus raising the voltage at the anode of TD1. As you would expect, the current through the tunnel diode increases . . . until you get to just over 4 mA. The point at which things begin to get peculiar will vary from diode to diode, but at about 4 mA the current will suddenly *dip* even though you've been increasing the voltage steadily. Increase the voltage some more and the current continues to dip and then starts to rise again. Confused? OK, let's turn to Ohm's law to straighten things out.

If we write Ohm's law as I = E/R, a little figuring will tell you that the only way E can get larger while I gets smaller is if R is some *negative* value. Yup, what you saw in that demonstration was the tunnel diode behaving as a *negative resistance*. As we'll see later, the unusual doping of the TD's pn junction is responsible for this effect. What can it be used for? You know that all that keeps a tuned circuit from oscillating spontaneously is the resistance

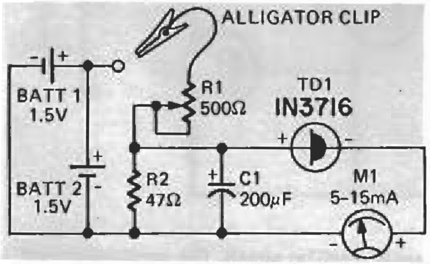


FIG. 1—THE DC PARAMETERS of the tunnel diode can be studied using this simple circuit. The batteries must be mercury types.

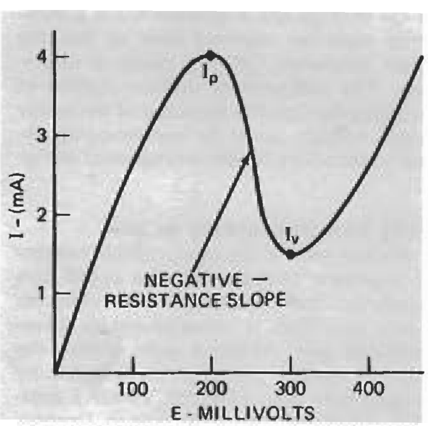


FIG. 2—VOLTAGE CURRENT CURVE of a tunnel diode. Note the negative-resistance slope.

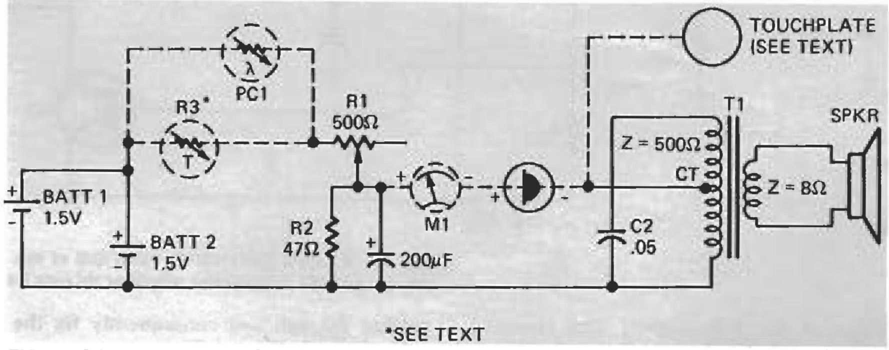


FIG. 3—BASIC TUNNEL-DIODE SINEWAVE OSCILLATOR operates at a frequency determined by the inductance of the transformer primary and the lumped and stray capacitances. It can be controlled by the touchplate, thermistor or photoresistive cell. Photocell PC1 is a CdS type such as the Clairex CL-504L. The value and type of thermistor depend on the application.

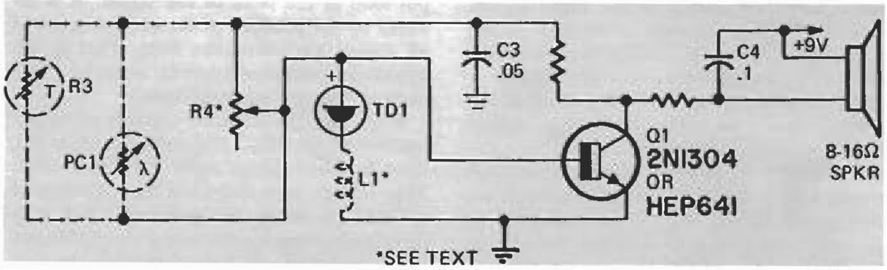


FIG. 4—SENSITIVE ALARM CIRCUIT can be used to detect changes in temperature or light and the presence of signals from a rf transmitter type electronic bug. The two unmarked resistors should be selected so 1.5 volt is delivered to the top end of bias control R4. It can be used as a basic radio-control receiver.

theory and circuits

years and there are a number of practical ap-
tioned except on a few pages in a transistor
applications to help you learn about this device.

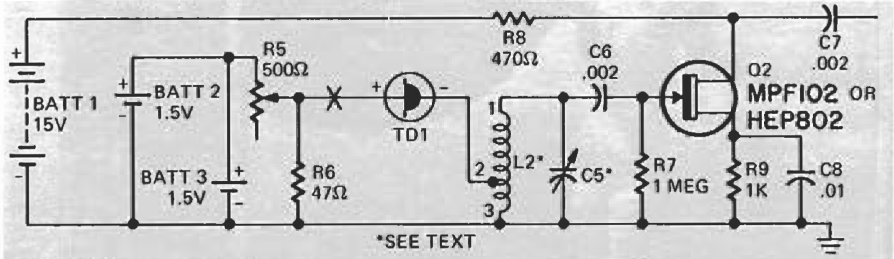
losses in the coil. The tunnel diode can, as we will see, be used to cancel the *positive* resistance in the tuned circuit with its own *negative* resistance and thus start and sustain oscillation.

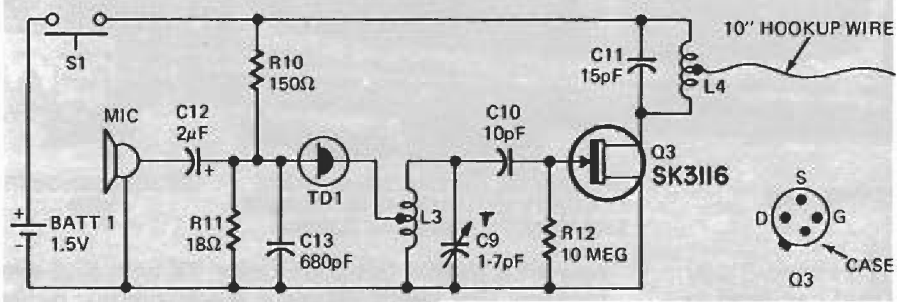
History and basic physics

The tunnel diode is also referred to as the Esaki diode, named after the Japanese physicist, Dr. Leo Esaki, who developed its basic principles. Esaki was working as a physicist for Sony in the late '50's when he showed that a heavily doped pn junction could exhibit negative resistance. General Electric researchers came up with the first practical units based on Dr. Esaki's work.

Any pn diode has a region of relatively few current carriers right at the junction which is referred to as the *depletion region*. A normal diode is doped only lightly to give relatively few free charge carriers. The depletion region in this diode is effectively wide and a relatively large voltage will be required to get a current going, i.e. to move current carriers across the depletion region. In a tunnel diode, the semiconductor material is heavily doped to give a large number of current carriers in the depletion region and thus effectively narrow it. In a TD, even a tiny voltage will allow current carriers to "tunnel" across that narrow depletion region, hence the name of the device. With a slightly greater bias, however, quantum physics gets into the act.

One of the laws of quantum physics says that electrons can only exist at certain defined energy levels within an atom and not in between. It's a bit like the way fixed resistors are made in standard values; you can buy a 2700 or 3300, but not a 2900. Electron energy levels work similarly.





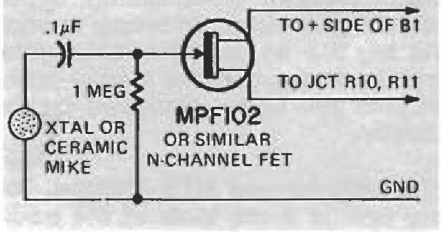


FIG. 5 (top)—SIMPLE RF SIGNAL GENERATOR can be both amplitude and frequency modulated by audio from a low-impedance source. FIG. 6-a (above)—FM WIRELESS MIKE. Coil L3 is 6 turns of No. 16 enameled wire closewound, ⅜ inch diameter with tap 1 turn from ground. L4 is 3 turns of No. 22 wire with the 10-inch antenna wire soldered to the midpoint. FIG. 6-b (left)—PREAMP for hi-Z mike. Remove the speaker and C12 and connect preamp as indicated.

Thus an electron that wants to go from the n-type to the p-type region must have enough voltage behind it to get it up to a permissible energy "slot" in the p-type section. When the voltage across the tunnel diode is great enough to produce many electrons with "forbidden" energy levels, i.e. too much energy for a low level and not enough for a higher one, the result is a *decrease* in current. Here is the negative resistance phenomenon. The current will now keep decreasing as more electrons are brought to forbidden energy levels. Current will eventually increase again if the voltage is raised enough to bring some of the electrons to higher energy slots.

The graph (Fig. 2) shows the dc characteristics of the tunnel diode. Current rises to the point I_p, called the peak-point current. Now comes the drop into the negative resistance slope. I_v, the valley current, is the bottom of the slope and the point where normal current flow resumes.

Audio applications

Now that you know how the tunnel diode works, we'll get into some circuitry. Figure 3 shows a basic sinewave audio oscillator whose principle of operation stems directly from our theoretical digression. With TD1 electronically removing all resistance from the tuned circuit consisting of C2 and the primary of T1, the tuned circuit oscillates at its resonant frequency. Set up the circuit as shown in Fig. 3 and, with R1 at maximum resistance, apply power. Lower R1 very slowly and the speaker will suddenly break into a tone at some point. If you reconnect M1 as shown, you'll find, as you would expect, that the onset of oscillation coincides exactly with the beginning of the negative resistance slope. This unusually simple oscillator can be used anywhere that a tone source is required. It will be most stable if working into a relatively high impedance load.

Staying with this circuit for a minute,

I'm going to throw you a curve. Get R1 back to maximum resistance and remove C2 from the tuned circuit. Now apply power and look for the negative resistance point again. Surprised that you get a tone without a complete tuned circuit? What's happened here is that the distributed capacitance of the transformer's turns in combination with the half of the primary still in the circuit still acts like a parallel resonant circuit. This self-resonant effect is used to advantage in microwave tunnel diode oscillators where the TD is linked to a resonant cavity. The cavity doesn't have a capacitor physically present any more than this circuit, but a TD will produce oscillation in anything that *looks* to it like a tuned circuit and has the proper impedance.

Several possible modifications of this circuit are in dotted lines in Fig. 3. Adding photocell PC1 will give you a daylight alarm or "electronic rooster." By adjusting R1 carefully so that the circuit doesn't quite oscillate, you can make it sensitive to any small change in light intensity. Similarly, a thermistor (R3) connected in this position gives a temperature sensor. This could be used as a warning indicator or as part of a control circuit to maintain temperature within a certain range. Select R3 to satisfy the needs of the application.

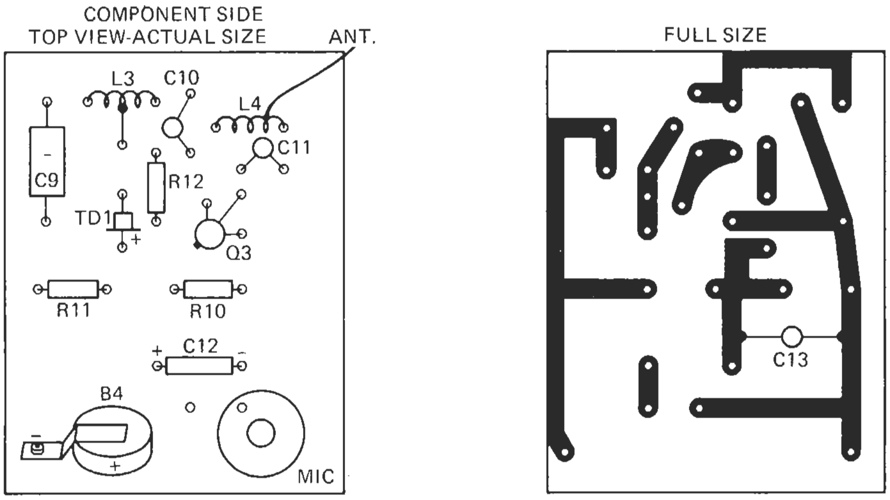


FIG. 7—WIRELESS MICROPHONE PC PATTERN and parts layout shown full-size. A similar layout using perforated board will work if you keep the rf circuit leads short.

If the bias is adjusted carefully, it is possible for an external signal to "shock excite" the tunnel diode into its negative-resistance region. The basic sinewave oscillator can work as a "touch switch" on this principle. Disconnect C2 from the circuit and connect a 2-inch diameter circle of sheet metal to the point shown in the schematic via a short piece of hookup wire. If you now adjust R1 to a point just before the circuit oscillates by itself, you'll find that the touch of a finger on the plate will start things up. The external signal that gets things going is the 60-Hz noise that your body is always picking up off the power lines. The adjustment of R1 is quite critical in this application, and a few trials may be required for best results.

Using a junction transistor in combination with a tunnel diode can produce a level sensor of much greater sensitivity than the basic oscillator. Figure 4 shows this circuit, which is capable of responding to .1 foot-candle or less when used as a light detector. In operation, C3 provides a feedback path for signal from the collector of Q1 to the cathode of TD1. The tunnel diode feeds the signal back to the base when the resistance of the sensor is low enough to get it into negative resistance. L1 is 2 turns of No. 14 wire, 1 in. diameter, turns spaced ⅛ in.

In these security-conscious times, the idea of a personal "bug detector" isn't such a far out idea. With a suitable pickup coil (L1) connected at the points shown, the small rf signal from a concealed transmitter is sufficient to shock excite the tunnel diode into negative resistance as in the touch switch described previously. R4 is the threshold/sensitivity control. When the circuit is used with a photocell or thermistor, it should be 10 K to 25 K ohms; 2 K or so when used as a bug detector. In operation, it is set just below the point of oscillation.

Rf applications

It is as a high-frequency amplifier and oscillator that the tunnel diode really comes into its own as the following circuits show. The basic sinewave oscillator circuit will crank out rf very nicely with just a change in tuned circuits.

Figure 5 shows an rf signal generator suitable for testing and alignment purposes from 1 to 40 MHz. The FET buffer stage prevents loading of the tuned circuit and resulting instability and loss of Q. Applying an audio signal from a low impedance source at the junction of R5 and R6 will give a combination of amplitude and frequency modulation at the output if desired. The FM component results because changes in the bias on the tunnel diode (from the modulating signal) vary its negative resistance operating point. This tends to "pull" the resonant frequency of the tuned circuit up and down in step with the input signal amplitude. L2 may be a BC band Loopstick with C5 200—400 pF to cover the AM broadcast band. For the 27-MHz Citizens band, C5 is 20 pF and L2 is 11 turns of No. 22 enameled wire on a ⅜ in. slug tuned form. Tap at 3 turns.

Initial adjustment is easy. Break the circuit at the point marked "x" in the schematic and hook up the milliammeter as for the first experiment. Apply power and adjust R5 for a stable point in the middle of the negative resistance slope. R5 can be sealed in this spot if desired with a few drops of clear nail polish. It is also possible to measure the resistance of the Trimpot with an accurate bridge or ohmmeter and substitute a fixed 5% resistor of the nearest standard value.

Printed circuit construction or tight point-to-point wiring on Perfboard is a must for this circuit and the one following if reasonable stability is to be obtained.

One possible vhf application for a tunnel diode, a complete FM wireless mike, is shown in Fig. 6-a. Operation is the same as that of the rf signal generator, but the resonant frequency of the tank circuit has been altered. Again, a FET is employed as a buffer to reduce the instability that is usually a drawback of these circuits. A small speaker is used as a microphone to modulate the transmitter. If operation from a high-impedance source is desired, add the matching circuit of Fig. 6-b.

The author's model was constructed on a PC board as shown in the photograph and the etching pattern is given in Fig. 7. A stiff guitar pick makes a good, cheap tool for tuning C9 to a quiet spot on the FM band.

I hope you've enjoyed experimenting with these circuits; the basic principles can easily be adapted to your own special ideas and design problems. **R-E**