

Think Tank

Tunnel Diodes and Other Goodies

ALEX BIE

One type of diode that was widely used in the 1960s in many applications where transistors did not operate well was the tunnel diode. Its mode of operation enabled it to be used at frequencies in excess of those that could be achieved by many other semiconductor devices.

Although tunnel diodes are not nearly as widely used today, they are still mentioned; and it's well worth investigating how they work. Sometimes they are encountered today, and their mode of operation is very interesting.

Background

The diode was discovered in 1958 by a Ph.D. research student named Leo Esaki. He was investigating the properties of heavily doped germanium PN junctions for applications associated with high-speed bipolar transistors. In this application a narrow, but heavily doped PN junction was required. Subsequently the tunnel diode, also referred to as the "Esaki diode," was demonstrated in a number of other materials including gallium arsenide. In 1973, Esaki was awarded the Nobel Prize for Physics for his pioneering work with the tunnel diode.

The tunnel diode (like the Gunn diode—see *Think Tank*, December 1998) has no rectifying properties. The diode's unusual characteristic, as a negative resistance device, proved that it could be useful commercially as a microwave oscillator, since it was smaller than the tubes or transistors of the time.

Tunnel-Diode Structures

The tunnel diode is similar to a standard PN junction, except that the doping or impurity levels are very high; and the depletion region (or the area between the P-type and N-type materials) is infinitesimally thin, typically in

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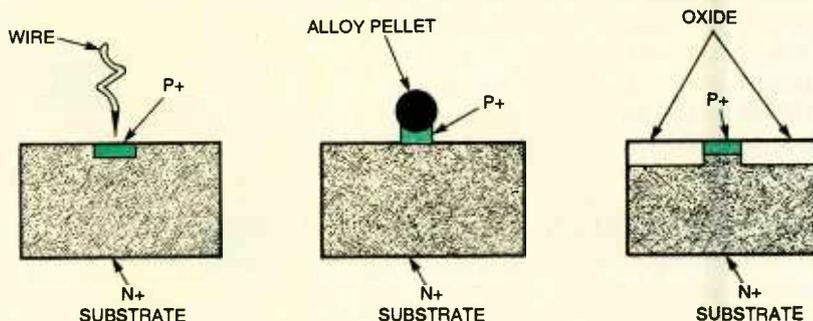


Fig. 1. Here we see several structures of tunnel diodes. In (A) we illustrate the pulse-bonded process, in (B) the ball-alloy structure is seen, while the fabrication shown in (C) uses normal planar technology to produce the required PN junction.

the range five to ten nanometers (or 50 to 100 angstroms). This very narrow depletion region width indicates that the capacitance of the diode is high. That means that when the diode is to be used for high-frequency operation, where a low value of capacitance is required, the diode area must be made very small. (Recall that the capacitance for a parallel-plate capacitor varies inversely with the thickness of the structure but directly with the area of the plates.)

There are a number of methods that can be used to fabricate a tunnel diode. These are shown in Fig. 1. The first structure, Fig. 1A, is made with the pulse-bonded method. Here a heavily doped substrate is taken, and a wire coated with the dopants is pressed against it. A voltage pulse is then applied, which causes local alloying; and a small junction is formed. As can be seen, this method is not very controllable, but it produces a very small junction suitable for RF applications.

The second structure is known as the ball-alloy structure. Here an alloy containing the required dopants is brought into contact with a heavily doped substrate. The structure is heated to a temperature of around 500° C. At this point, the alloy melts and the dopants diffuse into the substrate. The area around the alloy is then etched to reduce the size of the junction, as shown in Fig. 1B.

The third structure uses normal pla-

nar technology (shown in Fig. 1C). A small area of a heavily doped substrate is left exposed; and the area is exposed to diffusion, epitaxial growth, or alloying to give the required PN junction

Characteristic Curves

The combined current-voltage curve for a tunnel diode is shown in Fig. 2, superimposed with similar characteristic curves for its component elements; namely normal diode current and tunnel current. The composite curve for the tunnel diode can be seen to rise at first and “peak,” then fall back to a “valley,” and then start to rise again. The reason for this “peak” and “valley” effect is that there are a number of different components needed to form the overall curve.

The two main components are the normal diode current across the junction and the current arising from the tunneling effect. It is this last component that is of interest in a tunnel diode. The phenomenon of “tunneling” is a complicated mechanism resulting from a quantum mechanical effect. It occurs when electrons pass through a potential barrier in a way that can be visualized as tunneling. It has been found that the tunneling current peaks at a certain voltage and then falls away giving a negative resistance. This effect can be used in a variety of ways, which permits the tunnel diode to be used as an amplifier and also an oscillator—depending upon the diode's bias and input-source characteristics.

The tunnel diode can be placed in a circuit like that shown in Fig. 3. The steady DC voltage supplies the bias voltage for the diode. In this simple gain circuit, the output signal is an amplified form of the changing input signal.

Advantages and Disadvantages

The success of the tunnel diode resulted not only from its negative resistance but also its high speed of operation. This results from the fact that it only uses majority carriers; *i.e.*, holes in a P-type material and electrons in an N-type material. The tunneling effect is inherently fast, while many other devices are slowed down by their minority carriers (*i.e.*, holes in an N-type material and electrons in a P-type material).

However, there are a number of disadvantages, and these have meant that in recent years tunnel diodes have not been as widely used. In the first instance, they only have a low tunneling current; and this implies an oscillator generating low-output power (under 10 mW). Secondly, they are only two-terminal devices, and they do not provide sufficient isolation between the input and output stages. The third drawback results from the manufacturing problems in reproducibility, especially in integrated circuits.

Uses

Although tunnel diodes are not widely used today, they had found widespread use in the late 1960s in UHF and microwave amplifiers and oscillators. In these applications, they were able to offer good high-frequency performance coupled with low levels of noise. Today they are still occasionally used in low-noise amplifiers.

In next month's column, we will continue looking at unusual semiconductor devices as we examine the laser diode, which is used in various commercial applications ranging from CD drives, copy machines, *etc.* to specialized optical communications. But enough theory, let's look at a couple of interesting reader circuits.

SELECTABLE PULSE-WIDTH GENERATOR

Our first entry, see Fig. 4, is a pulse-generator circuit that can be programmed for a number of different outputs by closing one or a combination of ten switches. The output of the 4093 IC oscillator circuit clocks the input of a 4017 CMOS IC. The 4017 CMOS IC is a divide-by-ten counter with ten individual outputs. With each input clock pulse, the 4017 steps one position and brings that output high. The next pulse steps the next output high while return-

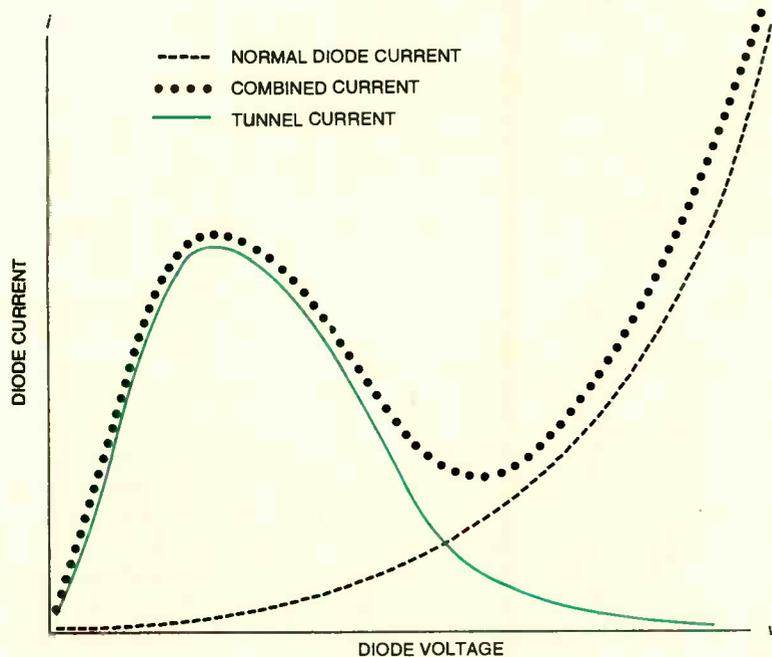


Fig. 2. These curves illustrate the various currents present in a tunnel diode. The combined current (dotted) is shown as the superposition of normal diode current (dashed) and tunnel current (solid).

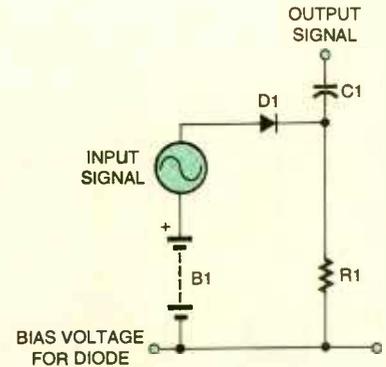


Fig. 3. A basic circuit for an amplifier using a tunnel diode (D1).

ing the previous output back low. This process continues for a count of ten in a sequential manner. Each output occurs only one time in ten input pulses. So to obtain a 100-Hz output, the clock oscillator would operate at 1000 Hz, or ten times the single output frequency.

The waveform chart in Fig. 5 shows the output for each switch closure. As shown, any combination of switch closures can be used to create a desired output waveform. Closing S2, S3, S6, and S7 produces the bottom waveform.—C. Rakes, Bentonville, AR

This is a fine circuit to experiment with at home or in the lab. By selecting any one or more of the SPST switches, you can create many different outputs. By the way, good substitutes for the 4093 Schmitt trigger IC are NTE4093B or Thomson SK4093B; the 4017 decade counter/divider IC can be replaced with an NTE4017B or SK4017B unit.

AN AUDIO Q-MULTIPLIER

It's a busy night on the 80-meter band. You're trying to listen to a CW message in an extremely crowded spot on the dial, but the constant grind of QRN and QRM (atmospheric noise and signal interference, respectively) makes you just about climb the wall. Before you swing a baseball bat at the receiver, consider building this audio Q-multiplier. Connecting it to your receiver's output jack will give you interference-free CW reception of the quality you would expect from a high-priced receiver.

Instead of requiring an internal receiver connection, as does the usual IF (Intermediate Frequency) Q-multiplier, this audio Q-multiplier connects to your receiver's speaker or headphone output jack. Just as the IF Q-multiplier narrows the bandpass of the IF amplifier

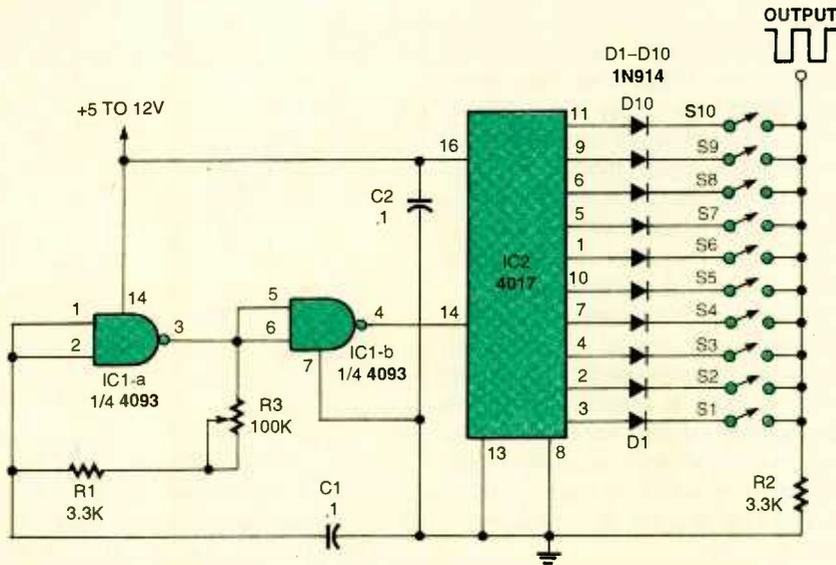


Fig. 4. Want to experiment with pulse-generator circuits? This design uses ten SPST switches to select output pulse timing and pulse width. Potentiometer R2 in the 4093 IC oscillator section sets the base frequency of operation.

by putting the stage on the verge of oscillation, this audio Q-multiplier increases the Q (or selectivity) of an external audio stage, by setting it at the point of oscillation. The result is that the Q-multiplier's output amplifier, which follows its tuned audio stage, receives primarily the desired tone frequency—all other background noise is sharply attenuated.

The heart of the device is Q1, an N-channel dual-gate MOSFET that provides a slight amount of AF amplification via its input gate G2 and output drain D. The signal at the drain is divided as it passes through capacitor C3. It is then applied to both IC1, an LF351 op-amp IC (which is used as a buffer), and to the parallel-T filter network—consisting of capacitors C4, C5, C6, and C7, and resistors R5, R6, R7, and R8. The values of parts used in the parallel-T have been chosen to provide a voltage across potentiometer R8, which is in phase (positive with respect to G2's gate-input signal) at one specific frequency. The positive feedback is applied via R8's wiper to Q1's other gate, G1, where it combines in the drain circuit with the input signal, (if too much feedback is applied through R8, the stage will break into oscillation).

The total signal at the drain is therefore peaked at the resonant frequency of parallel-T network, around 1.5 kHz. Because control R7 is variable, the network tunes a range of approximately 800 Hz to 2 kHz. Capacitors C6 and C7 can be replaced by a single 0.003- μ F capacitor. However, we have illustrated two standard capacitor values in parallel to allow for trimming to the desired value. If you prefer your CW tones at a lower center frequency of 600 Hz, use C4 = C5 = 0.0013 μ F and C6 = C7 = 0.003 μ F (or replace with a single 0.006- μ F capacitor). For a higher center frequency, around 2.5 kHz, use C4 = C5 = 330 pF and C6 = C7 = 750 pF (or replace with a single 1500-pF capacitor).

In addition to suppressing tones other than the one peaked, background noise is sharply reduced because of the narrow audio bandpass. Signal diodes D1 and D2, which provide overload protection for Q1, also act as an audio-noise limiter to further reduce the background impulse noise.

In this circuit the output amplifier, IC2, a LM386 low-power amplifier, has a maximum power of about 500 mW;

4017
OUTPUTS

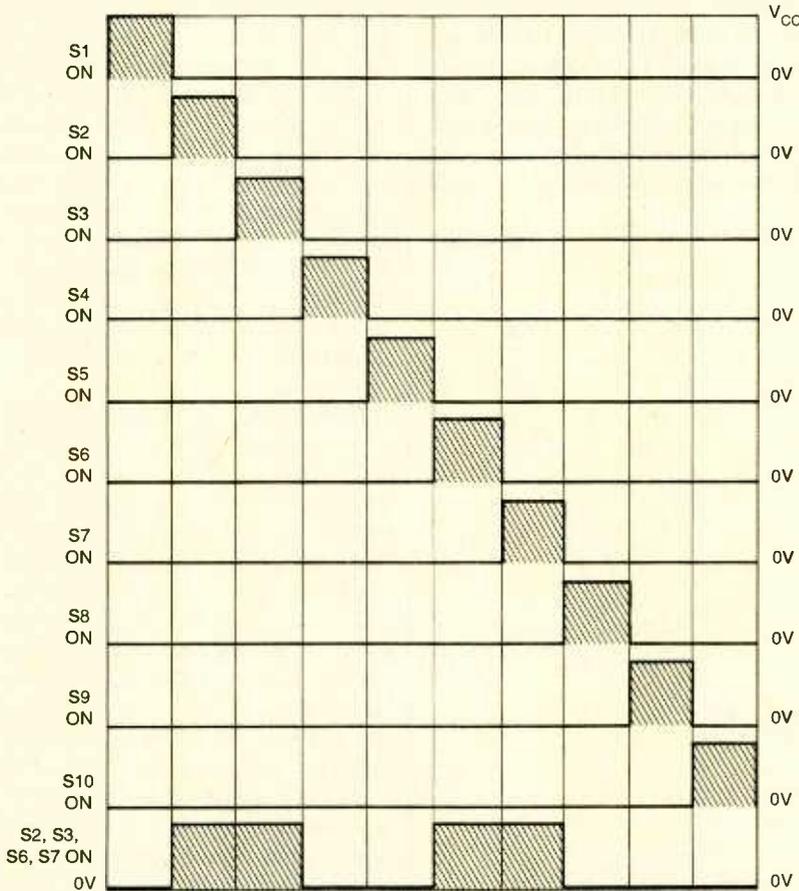


Fig. 5. This chart illustrates the different outputs obtainable with the ten SPST switches. Combinations of two or more switches increase the corresponding pulse widths.

but while this audio output may be sufficient for headphones, it may be too low to adequately drive an 8-ohm speaker. While the amplifier can be overdriven to a higher volume (by removing diodes D1 and D2), transistor Q1 may be damaged. Therefore, do not attempt to get more volume output by eliminating these diodes. If you want more audio, then adjust trimmer potentiometer R14.

The MOSFET is very sensitive to a static discharge, and if its leads are not kept shorted during installation it can be instantly destroyed by the charge from the tip of a soldering iron. Transistor Q1 is supplied with its leads in conductive *Styrofoam*. Before removing the *Styrofoam*, wrap several turns of bus wire around Q1's leads just below the case. Then remove the *Styrofoam* and fan out the leads so you are certain they all touch the bus wire. Keep this wire on until the project is completed.

This prototype was constructed inside a *RadioShack* 270-274 cabinet. The circuit was assembled on a piece of 2 1/2" x 5 1/2"-inch perforated board. Push-in terminals were used for tie points.

Keep the components about 1/2-inch back from the front edge of the perf-board so they will not interfere with mounting of the cabinet parts. Solder all the components in before installing Q1. To avoid the possibility of heat damage from soldering, Q1 must be the last part installed.

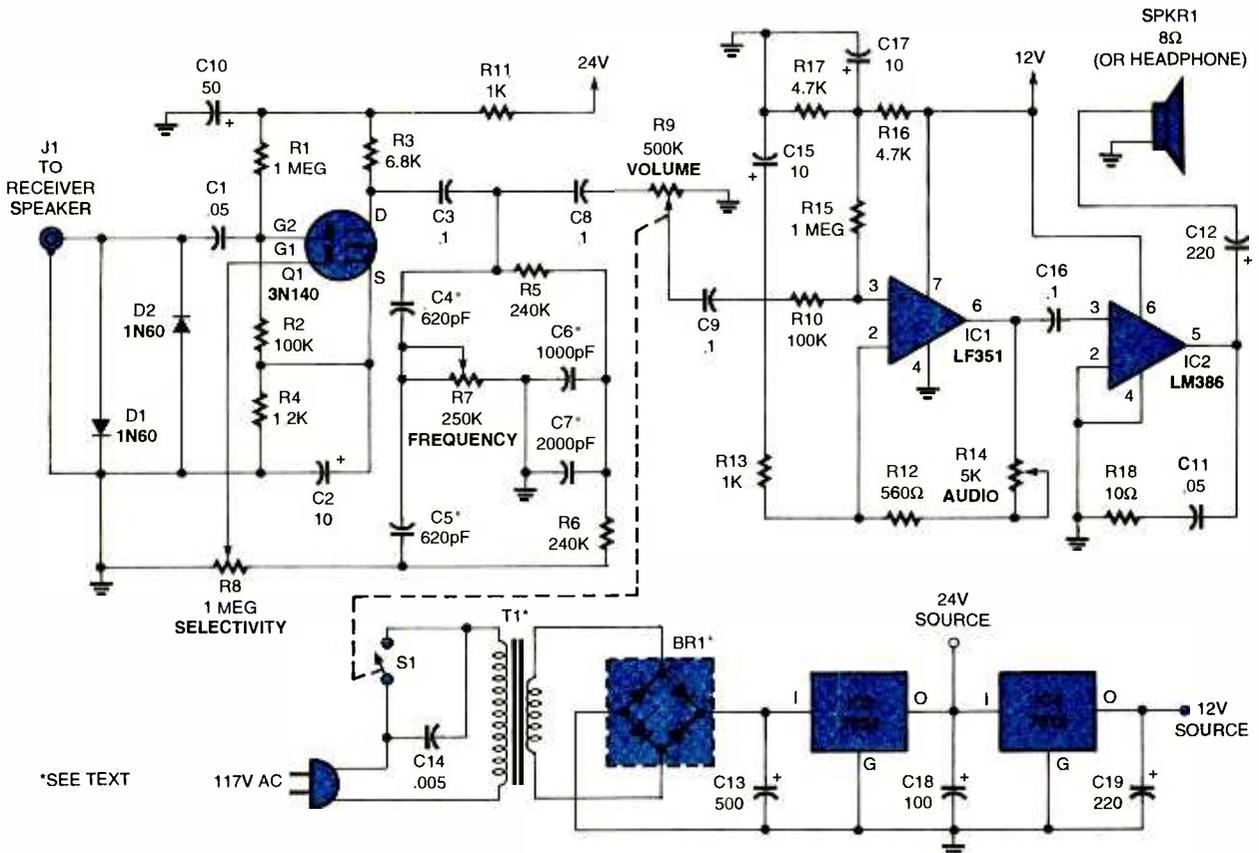
With C6 at 0.001 μ F and C7 at 0.002 μ F, the circuit should break into oscillation when the selectivity control R8 is advanced almost fully clockwise. If the device does not oscillate, try a different 0.001- μ F capacitor for C6.

When the board assembly is completed, set it aside until the cabinet parts are mounted. If the speaker has no mounting flange holes, cement it to the inside of the cabinet with epoxy. Similarly, cement a section of perf-board to the front of the cabinet (over the speaker) to protect it from being damaged. The power transformer, T1, should be positioned against the rear of the cabinet to leave room for the board. Finally, mount the board in the bottom of the cabinet using 1/4-inch standoffs (or a stack of washers will do) between the board and the cabinet

at each mounting screw.

When testing and using the Q-multiplier, connect the input jack, J1, to your receiver's speaker or headphone output. Apply AC power to the circuit and turn volume control R9 fully clockwise. Advance selectivity control R8 to the point where the unit breaks into oscillation, as evidenced by a tone in the speaker. If you cannot get the oscillation, adjust frequency control R7 until the unit oscillates. If you still cannot obtain the oscillation frequency, there is a wiring error. (Did you remember to remove Q1's bus wire?)

If you get the oscillation, the project is ready to use. Back off on selectivity control R8 till the oscillation just stops. Then turn on the receiver and tune in any CW station. As you tune across the station, or adjust your receiver's BFO, there will be one tone that suddenly peaks up, while tones on either side of this frequency are attenuated. Adjusting potentiometer R7 can change the frequency to which the Q-multiplier is tuned. But remember to readjust selectivity control R8 just below the point of oscillation whenever you change R7's setting.



Shown here is the schematic of the audio Q-multiplier which provides enhanced receiver selectivity and gain centered around a 1.5-kHz audio output frequency.

PARTS LIST FOR THE AUDIO Q-MULTIPLIER

SEMICONDUCTORS

- D1, D2—1N60, germanium, general-purpose diode
 IC1—LF351 low-noise, JFET-input, op-amp, integrated circuit (NTE857M, or equivalent)
 IC2—LM386 low-voltage, audio-power amplifier, integrated circuit (NTE823, SK9210, or equivalent)
 IC3—7824 fixed, 24-volt, 1-amp, regulator, integrated circuit (NTE972, SK3670, or equivalent)
 IC4—7812 fixed, 12-volt, 1-amp, regulator, integrated circuit (NTE960, SK3592, or equivalent)
 Q1—3N140 dual-gate MOSFET (NTE221, Thomson SK3065, or equivalent)

RESISTORS

- (All fixed resistors are 1/4-watt, 5% units.)
 R1, R15—1-megohm
 R2, R10—100,000-ohm
 R3—6800-ohm
 R4—1200-ohm
 R5, R6—240,000-ohm
 R7—250,000-ohm, linear-taper potentiometer
 R8—1-megohm, linear-taper potentiometer
 R9—500,000-ohm, audio-taper potentiometer
 R11, R13—1000-ohm
 R12—560-ohm
 R14—5000-ohm, trimmer potentiometer
 R16, R17—4700-ohm
 R18—10-ohm

Use the minimum amount of receiver signal necessary to obtain a clean output tone. Excessive receiver output will cause the circuit to generate noise bursts. If you want to connect headphones at the circuit's output, connect an 8.2- to 10-ohm, 1-watt resistor from the output (negative end of C12) to ground.

Keep in mind that the Q-multiplier cannot eliminate all QRM. If you are monitoring a CW signal with a tone around 1 kHz and the interfering signal has a tone near 800 Hz, there will be little suppression of the interfering signal. The Q-multiplier works best at suppressing a signal that is at least double the frequency of the desired tone.—*Craig Kendrick Sellen, Waymart, PA*

Fine circuit, Craig; this project should be useful to every ham and SWL.

That's about it for this month's column. Remember—this is **your** column—keep those circuits, solutions, and ideas coming in. Besides the fame of seeing your circuit in print, for each circuit that appears, you will receive a special gift. Write me—Alex Bie, *Think Tank*, Popular Electronics, 500 Bi-County Blvd., Farmingdale, NY

CAPACITORS

- C1, C11—0.05- μ F, ceramic-disc
 C2, C15, C17—10- μ F, 16-WVDC, electrolytic
 C3, C8, C9, C16—0.1- μ F, ceramic-disc
 C4, C5—620-pF, ceramic-disc
 C6—1000-pF, ceramic-disc
 C7—2000-pF, ceramic-disc
 C10—50- μ F, 35-WVDC, electrolytic
 C12, C19—220- μ F, 16-WVDC, electrolytic
 C13—500- μ F, 35-WVDC, electrolytic
 C14—0.005- μ F, 500-WVDC, ceramic-disc
 C18—100- μ F, 35-WVDC, electrolytic

ADDITIONAL PARTS AND MATERIALS

- BR1—1-amp, 100-PIV, full-wave bridge rectifier (RadioShack 276-1152, or equivalent)
 J1—Phone jack
 S1—SPST switch (part of R9)
 SPKR1—8-ohm speaker
 T1—25.2-volt AC, 450-mA, standard power transformer (RadioShack 273-1366, or equivalent)

NOTE: Transistor Q1, and the ICs and diodes, are available from DC Electronics, P.O. Box 3203, Scottsdale AZ 85257; Tel: 800-467-7736 or 800-423-0070.

CIRCUIT CIRCUS

(continued from page 53)

gates is high. Both inputs of gate3 are also high, producing a logic-low output, as in a standard OR gate.

Our last constructed gate is the NOR gate shown in Fig. 8D. If we just think about it for a minute, we can save some logic tracing by briefly going back and looking at the description of the NOR gate. The NOR gate is an OR gate with an inverter connected to its output. Therefore, gate4, in Fig. 8D, simply inverts the output of the OR gate of Fig. 8C, turning it into a NOR gate.

Any time in the future when you are breadboarding a new circuit and find that you are short an OR, NOR, AND, or NOT gate, scratch around in the junk box and see if you can find a NAND gate and continue on. I also hope that the basic logic-gate information we covered here will be helpful as well.

It's time to close for now—see you here again next month, same station, same time—logically speaking!

Comments? Via e-mail at cdrakes@ipa.net, or snail-mail at P.O. Box 445, Bentonville, AAR 72712,

ANTIQUE RADIO

(continued from page 50)

same (2 volts at 0.06 amps DC) filament supply because I substituted 30-series tubes for the originals in both radios. Other battery sets I might want to operate could have 01-A tubes (whose filaments require 5 volts at 0.25 amps) or X199s (3.3 volts at 0.06 amps).



Newly-minted cabinet for the Radiola 20 is very similar in style to the original. Power-supply circuit card can be seen at left.

Accordingly, I decided to put together a universal-battery substitute, which has a female-edge connector as its output. The circuit cards on the A-K 32 and Radiola 20 are equipped with male-edge connectors to mate with that female, and they have resistor networks to adjust the voltages, as necessary, for the particular set. In order to demonstrate either set, I slip the relevant edge connector into the output connector on the power supply and away we go.

Vic has supplied excellent documentation for his ingenious power-supply scheme, so we'll turn the column over to him again next month and go on with his letter. See you then!—Ellis

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