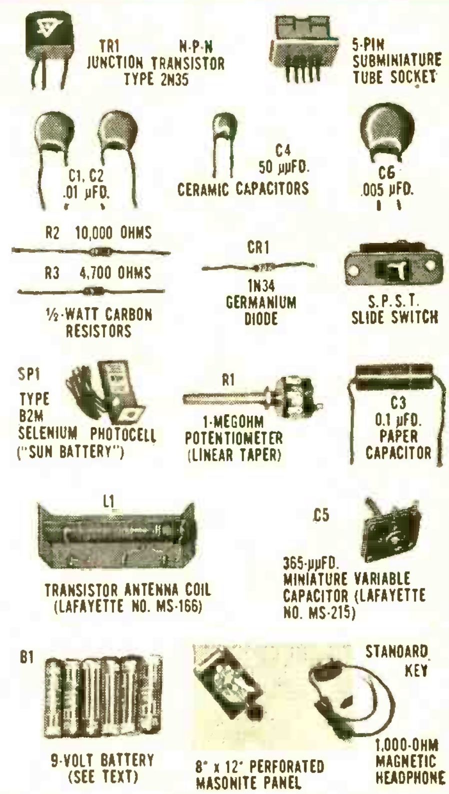
# TRANSISTOR PROJECTS
## FOR THE BEGINNER

**You can put transistors to work with these five circuits**

## PART I

**By Louis E. Garner, Jr.**

## PARTS LIST




IT'S only a few years since transistors were heralded as the electronic wonders of the future, but that future has moved in with a rush. These surprising crystals—popping up in new commercial applications every day—have started to compete with vacuum tubes in real earnest. Whether you are interested in electronics as a professional, an experimenter, or a casual hobbyist, the time has arrived to make friends with transistors.

This series of easy-to-assemble projects is designed to demonstrate basic applications at minimum cost. The circuits are constructed from a handful of standard, inexpensive parts and because of the knock-down construction you can use most of them over and over. Whether you build one or all these projects, you will get a better feel for transistor circuitry and operation.

The projects, however, aren't just demonstration circuits; each one is a practical device that is interesting to assemble and fun to use.

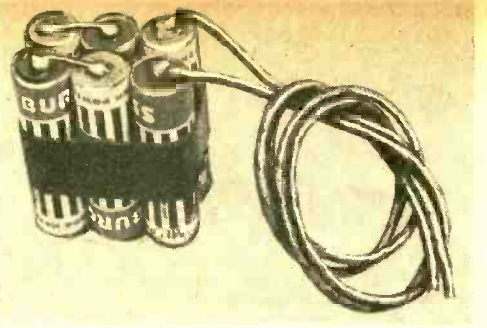
**Getting Ready.** To simplify assembly, the projects are put together breadboard-fashion on a chassis of perforated Masonite. Parts are mounted with machine screws and nuts to eliminate the labor of chassis design and redesign.

Mount standard rubber feet in the corners of the 8" by 12" Masonite panel. The feet will provide clearance for the mounting screws and keep the chassis from slipping while you're wiring the parts.

Make up a 9-volt power supply by fitting six penlite cells into standard clips or taping them together as shown at the right. Connect the cells in series by soldering short leads from the cap, or positive terminal, of one cell to the negative outer shell of the next. Use 8" wire lengths for the two end connections so you can hook the power supply into the circuit. If you have taped up your power pack, you also have to bend an aluminum strap around it to serve as a chassis hold-down.

While you're about it, make another scrap-aluminum bracket as shown in the project photos and at the top of the next page. Drill it to take a 5-pin subminiature tube socket for the transistor and a 3-lug terminal strip. Wire the terminal lugs to the first, third, and fifth socket pins as shown. You can then make—and unmake—connections directly to the lugs without any risk of damaging the fragile socket or transistor leads.

Still another bent-aluminum bracket will come in handy as a "control panel." Drill ⅜" shaft-clearance holes so you can mount a tuning capacitor or potentiometer as necessary.

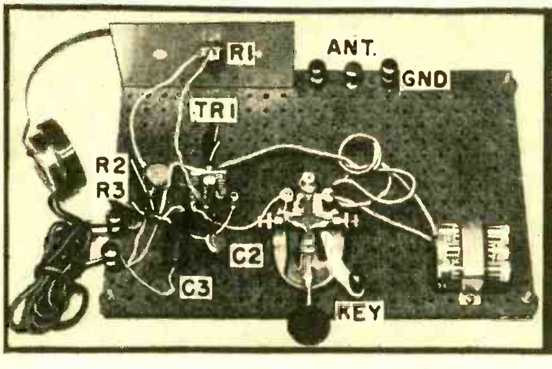


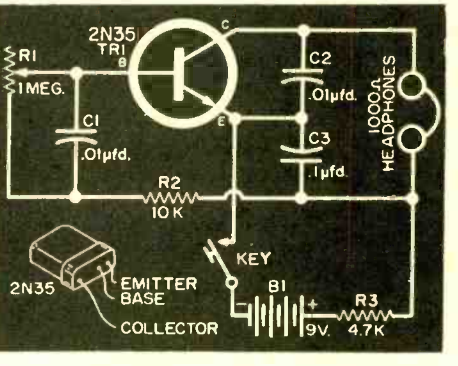
**Power pack** is a 9-volt battery made up of six series-connected penlite cells. You can tape the cells together as shown or fit them into standard clips.

**Parts Substitution.** A good set of working components is shown in the parts list, but you can make a number of substitutions without altering the circuitry in any important way. Note, for example, that in some photos tubular ceramic capacitors are shown while in others the same units appear as discs. The two types are, of course, interchangeable with each other as well as with paper or mica capacitors of equivalent value.

In place of the miniature variable capacitor, *C5*, you could use any standard 365-μμfd. broadcast-band tuning capacitor, or even a screwdriver-tuned padder. And for the 1000-ohm magnetic headphone, you

## 1 CODE-PRACTICE OSCILLATOR

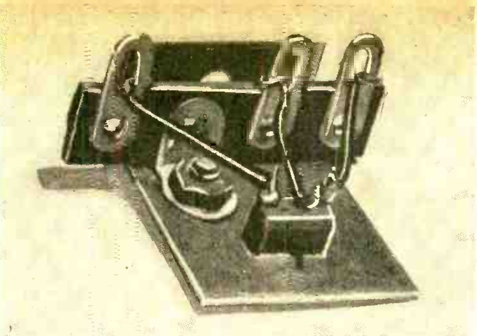



For learning the sound and touch of a radio ham's second language, nothing takes the place of a code-practice oscillator. This simple job has as good a tone as any you'll find, and being transistorized, it can keep pouring out *dits* and *dahs* practically forever on its original power supply.

It takes fewer than a dozen connections to put the whole thing together, so invest a few extra minutes double-checking all connections before you fit the transistor into its socket and press the key. When you do get to it, close the key and adjust *R1* for the most pleasing tone.

This circuit is an adaptation of the familiar vacuum-tube Colpitts oscillator. Capacitors *C2* and *C3* in series are shunted across the inductance of the headphone. The combination forms both a tuned circuit and an impedance-matching network. The latter matches the high impedance of the collector-emitter output to the low impedance of the base-emitter input. The bias current is fixed by *R2* and the tone control, *R1*. Resistor *R3*, in series with the power supply, isolates the tuned circuit from the battery and serves also to limit the collector and base currents.



**Transistor-mounting assembly** can be made by bending a piece of scrap aluminum to hold 3-lug terminal strip and 5-pin subminiature tube socket.

could substitute any magnetic phone of high impedance.

Miscellaneous items, such as knobs, rubber feet, binding posts, machine screws, solder lugs, scrap metal, and the like aren't listed and you can use whatever type you have on hand.

**Wiring.** In these experimental circuits the parts layout and lead dress aren't critical. You can follow the illustrations or rearrange the pieces in any way.

If you want to reuse the parts in several projects, it is best to leave the leads and pigtails full length except on the transistor. These should be trimmed to about ¼" so they'll fit the socket.

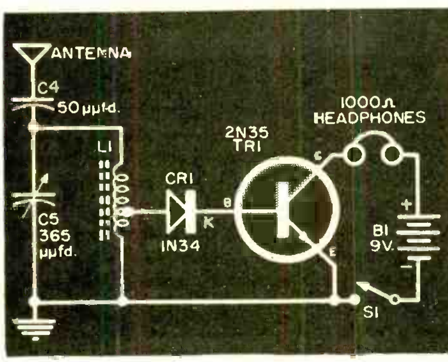
Each time you wire in the 1N34A diode, pinch the lead you are soldering with a pair of pliers. Holding pliers somewhere between the body of the diode and the wire tip being soldered serves to trap the heat and keep it from damaging the delicate crystal.

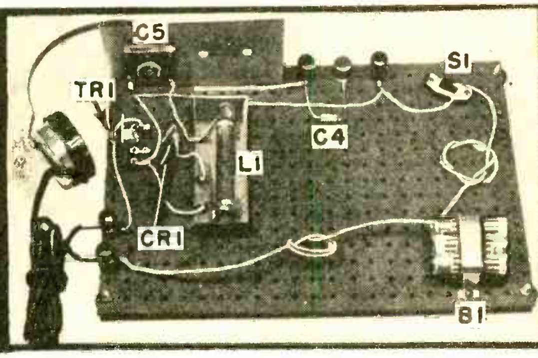
For safety, install the transistor last in all projects—after you've double-checked the wiring. Make sure, also, that battery polarity in every case follows that indicated in the diagrams.

An *n-p-n* junction transistor (type 2N35) is used in this first group of experiments. It requires battery polarity just opposite to that of the more familiar *p-n-p* units. Schematic symbols are similar for the two types except that in this one the arrow identifying the *emitter* electrode points *away* from the base line.

The *common-emitter* circuit — roughly similar to the *grounded-cathode* vacuum-tube circuit—is used in all these experiments. As you might imagine, the hookup gets its name because the emitter electrode is common to both the input and output sides of the transistor. When it is connected directly to circuit ground, this basic arrangement is sometimes called the *grounded-emitter* configuration.

## 2 BATTERY-POWERED RECEIVER

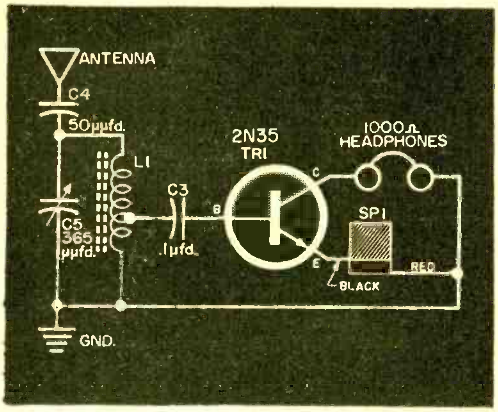



Though this simple receiver has a lot more gain than a crystal set, it still needs a good antenna and a ground for best results. A commercially available "transistor antenna coil"—tapped to provide a good impedance match to the input of the transistor—is used in the tuned circuit.

When you wire up the set, pay special attention to the polarity of the diode. On some 1N34's the cathode end is marked by a broad stripe or the letter "K"; on other diodes the terminals are identified by a small schematic diagram similar to the one which is used here.

Signals picked up by the antenna-ground system are coupled—through *C4*—to the tuned circuit made up of *L1* and *C5*. Variable capacitor *C5* is used for station selection as in any conventional receiver. The tap on *L1* is designed for good selectivity as well as maximum energy transfer to the transistor circuit. Detection—the separation of the audio and radio components of the tuned signal—takes place in the 1N34 diode and the base-emitter circuit of the transistor. The program that comes through should be heard clearly and with good volume in the headphone.

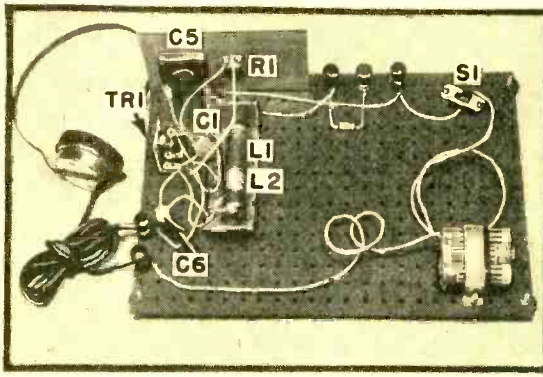


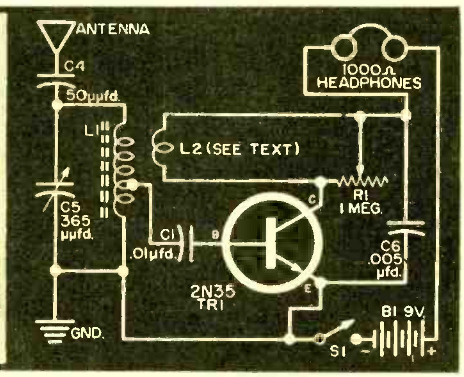

## 3 SUN-POWERED

Transistors are so efficient they can operate in radio receivers on electrical power taken from the sun. If you'd like to test this for yourself, you only have to substitute a selenium photocell for the 9-volt power-supply used in project 2. The unit shown (marked *SP1* in the diagram) is the B2M "sun battery" made by International Rectifier Corp.

In addition, you may want to substitute *C3* for the germanium diode. Whether this extra change will improve reception de-

## 4 REGENERATIVE RECEIVER




You can greatly increase the sensitivity of the receivers shown in projects 2 and 3 by adding regenerative feedback. A couple of simple wiring changes will do the trick.

One new part—"tickler" winding *L2*—appears in the diagram and photo above but not in the parts list because you make it yourself by winding 10 to 15 turns of plastic-covered hookup wire around the middle of *L1*.

Two other parts—*R1* and *C6*—are added to the circuit of project 2, and a .01-μfd coupling capacitor (*C1*) is substituted for the 1N34 germanium diode.

After you have completed the wiring changes, slip on the headphones and slowly turn potentiometer *R1* through its entire range. At some point you should hear a "putt-putt" or oscillation tone. If you don't, reverse the connections from *L2*.

This feedback tone is a sign that the set is regenerating the way it should. Back off the potentiometer until the "putt-putt" sound just disappears, then carefully tune the station you want by adjusting capacitor *C5*. Readjust *R1* for maximum volume.

Circuit operation is similar to that of other regenerative receivers. Signals picked up by the antenna-ground system are coupled through *C4* to the tuned circuit consisting of *C5* and *L1*. Varying the frequency of *C5* selects the desired signal which is then transferred (through *C1*) to the base-emitter of the transistor. This circuit amplifies the radio frequencies and detects the audio.

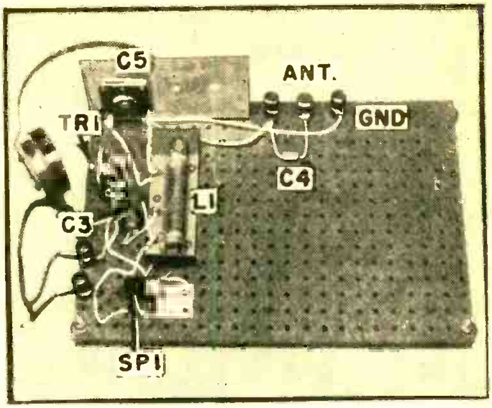
But as the name "regenerative" suggests, the amplified r.f. signal is routed back to the tuned circuit through the feedback winding of the coil. On its repeated journeys through the transistor it picks up ever greater amplitude.

The resistance across potentiometer *R1* governs the amount of energy that is fed back through the "tickler." Advancing the setting of the potentiometer—that is, increasing its effective resistance—boosts the r.f. feedback and thus increases the gain. Capacitor *C6* serves to bypass any r.f. that tries to sneak off in the wrong direction (through the headphones and battery) and carries it back to the transistor circuit.

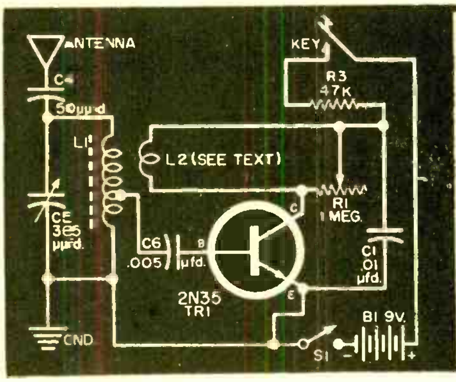
## RECEIVER

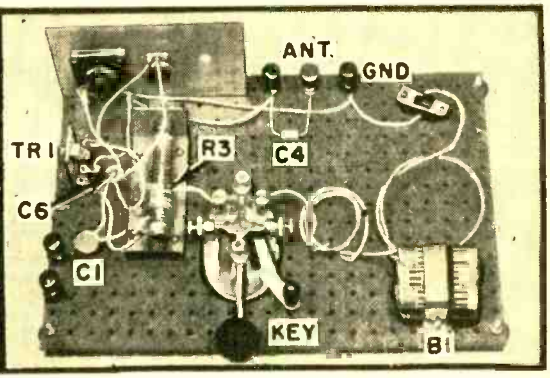
p·nds on the characteristics of the individual transistor and on the antenna and ground that you use. The only way to make sure is to try both arrangements and see which gives better results. Keep in mind that a sun battery doesn't deliver as much power as six penlite cells—don't expect as much output from the receiver.

And notice that the circuit doesn't include a switch. When you want to turn this set on, you just expose the battery to direct sunlight.




## 5 CODE TRANSMITTER




If you've ever built a regenerative receiver like the one shown opposite, you know that misadjustment of the feedback potentiometer can make the set squeal like a stuck pig.

Squealing occurs when the circuit is thrown into oscillation. The high-pitched noise can be a bit of a nuisance in a receiver, but it does have this use—it permits you to turn a receiver into a transmitter by making a few minor changes.

As you can see by comparing the circuit above with the one at the left, the most important alteration is that a hand key and resistor *R3* take the place of the headphone. In addition, capacitors *C1* and *C6* have been interchanged to improve the tone quality of the broadcast signal.

Simple as it is, this transmitter is capable of radiating a weak modulated signal at almost any frequency in the standard broadcast band; you can pick your frequency by adjusting tuning capacitor *C5*. Keep in mind, however, that the circuit isn't stable enough for use as a ham transmitter, so don't let it broadcast too far from home base. To hold the range down, use *only* a short antenna lead.

To set up the transmitter, place its antenna a few feet from any broadcast receiver. Turn the receiver volume full on and tune it to a dead spot near the middle or the lower end of the dial.

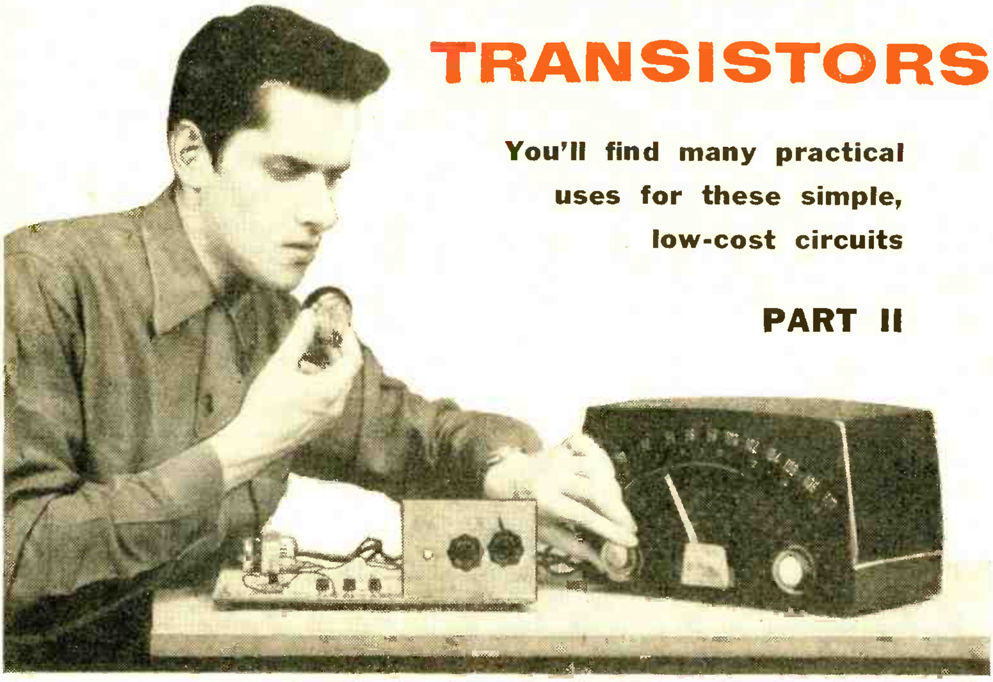
Next, switch on the transmitter, close the key, and set *R1* at nearly maximum resistance. Tune *C5* gradually till you hear a high-pitched tone in the loudspeaker of the receiver. You can now adjust the sound to your taste by resetting *R1* and sharpening receiver and transmitter tuning.

The transmitter works just like a regenerative receiver that has gone into oscillation. It puts out a *modulated* signal, however, because of a blocking action in the base-emitter circuit of the transistor. The frequency of the audible signal is governed by the amount of feedback plus the time constant of the *RC* circuit composed of *C6* and the input resistance of the transistor. Since the potentiometer determines the amount of feedback, it serves as a simple control over the modulation tone. —30—

# FIVE NEW JOBS FOR TWO TRANSISTORS

**You'll find many practical uses for these simple, low-cost circuits**

**PART II**



**By Louis E. Garner, Jr.**

TRANSISTORS were born with a couple of important advantages that vacuum tubes never enjoyed. They're tiny and they draw very little current—you can use two, three, or a dozen with a very modest power supply.

Each of the five projects described last month was built around a single transistor. Most of the circuits on the following pages employ a second transistor and a few additional parts. The small increase in bulk and cost makes possible a great increase in the range, the power, and the variety of new devices you can build. As before, these breadboard units are designed for knock-down construction.

**Transistors—p and n.** A junction transistor is a sort of sandwich made up of three layers of semiconductor material (a material which is neither a good conductor nor a good insulator) such as germanium. The center of the sandwich, known as the *base,* is flanked on one side by the *collector* and on the other by the *emitter*. The two types of junction transistors available to hobbyists can be distinguished by the way the layers are arranged.

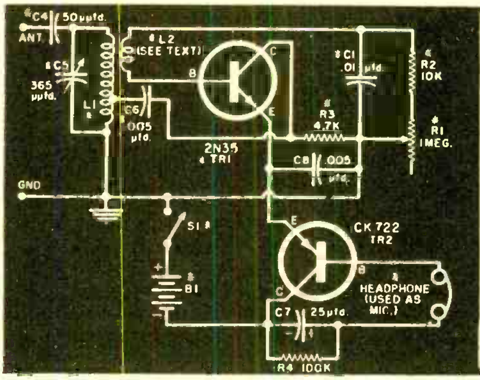
In an *n-p-n* transistor (such as the 2N35 used in the first group of projects), the base or central layer is a *p*-type semiconductor and the outer layers are both *n*-type material. The *p-n-p* transistor (like the Raytheon CK722 added to these circuits) is exactly opposite—its *n* base is flanked by two *p*-type layers.

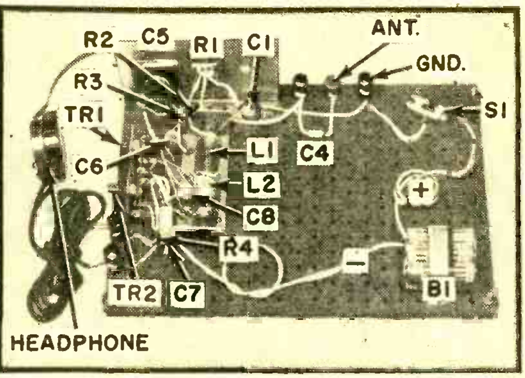
As you've probably guessed, the letters *p* and *n* stand for positive and negative. In a *p*-type semiconductor, one or more electrons are missing from the crystal structure; each missing electron leaves a positive charge that is known as a "hole." In the *n*-type semiconductor there is a surplus of electrons which are free to move, or "diffuse," through the material.

Aside from polarity, the two types of transistors are very much alike and can be used in similar circuits. In general, *n-p-n* units have somewhat better high-frequency response.

From a construction point of view, the main difference between these two kinds of junction transistors is that they need opposite d.c. voltages on their electrodes. As you'll see in the projects that follow, this fact can actually simplify coupling circuits, when *n-p-n* and *p-n-p* transistors are used in combination.

# 1 WIRELESS MICROPHONE




● Good party fun and serious electronics experimenting have a happy meeting ground in this wireless mike. For with the low-powered voice transmitter, you can surprise or amuse your friends by broadcasting h o m e - g r o w n announcements through any AM receiver in the house. The headphone, generally used for listening, doubles here as an inexpensive microphone.

The circuit requires a feedback winding (*L2*) in addition to the store-bought parts; make this coil by winding 10 to 15 turns of ordinary hookup wire around the center of antenna coil *L1*.

The *n-p-n* transistor, *TR1*, serves here as an r.f. oscillator, and its frequency is determined by the tuned circuit made up of *L1* and variable capacitor *C5*. "Tickler" winding *L2* provides the feedback needed to start and sustain oscillation. Base bias current—governing amount of feedback—can be regulated by potentiometer *R1*.

The *p-n-p* transistor, *TR2*, acts as both audio amplifier and modulator. Since the two transistors are effectively in series across the d.c. power supply, the same emitter current flows through both units. Normally, current variations in one would appear in the other. Bypass capacitor *C8*, however, grounds r.f. variations in the common emitter. It thus keeps r.f. out of the audio stage while permitting the signal developed in *TR2* to modulate the r.f. in *TR1*. This arrangement eliminates the need for a modulation transformer.

To use the wireless mike, connect it to a good ground and run an antenna lead to within a few feet of a standard receiver. Tune the receiver to a dead spot near the middle or lower end of the dial. Set *R1* at nearly maximum resistance. Then gradually tune *C5* and listen for either a live background hiss or a motorboating "putt-putt" sound. If you get no signal, reverse the connections to *L2* and try again.

If the set "putt-putts," back off *R1* until the sound just disappears. Then recheck the tuning of the receiver, and you should be ready to go on the air.

Use the headphone as a mike. It's not tremendously efficient, however, so hold it close to your mouth and talk up. ●

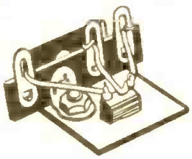
## • LIST OF PARTS •

*B1—9-volt battery (6 series-connected penlite cells)
B2, B3—Penlite cells (divided into 7.5- and 1.5-volt batteries; see Project 2, "Photocell Relays")
*C1, *C2—0.01-μfd. capacitor
*C3—0.1-μfd., 200-volt paper capacitor
*C4—50-μμfd. capacitor
*C5—365-μμfd. miniature variable capacitor (Lafayette MS-215)
*C6—0.005 μfd. capacitor
C7—25-μfd., 25-volt electrolytic capacitor
C8—0.005 μfd. capacitor
C9—0.25-μfd., 200-volt paper capacitor
*CR1—1N34A germanium diode
*L1—Transistor antenna coil (Lafayette No. MS-166)
*L2—Feedback winding (10-15 turns hookup wire; see Project 1, "Wireless Microphone")
*R1—1-megohm potentiometer, linear taper
*R2—10,000-ohm, ½-watt resistor
*R3—4700-ohm, ½-watt resistor
R4—100,000-ohm, ½-watt resistor
R5—100-ohm, ½-watt resistor
RL1—S.p.d.t. relay, 4000-ohm coil (Advance No. SO/1C/4000D or equivalent.)
*S1—S.p.s.t. slide switch
*SP1—Selenium photocell or "Sun Battery" (International Rectifier Corp. Type B2M)
*TR1—Junction transistor, *n-p-n* (Sylvania Type 2N35)
TR2—Junction transistor, *p-n-p* (Raytheon Type CK722)
*1—1000-ohm magnetic headphone
*1—8" x 12" perforated Masonite
2—5-pin subminiature tube sockets
1—Sensor plate (see Project 3, "Rain Alarm")
1—Flashlight lens
1—Piece of cardboard tubing
Misc. solder, binding posts, rubber feet, knobs, machine screws

***Asterisks in parts list and diagrams indicate components used in Part I of this series.**

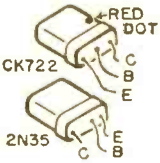
MORE TRANSISTOR PROJECTS ➔

# WIRING HINTS



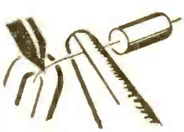
● Make a breadboard wiring assembly for each transistor by mounting a 5-pin subminiature tube socket and a 3-lug terminal strip on an L-shaped strip of scrap aluminum. Wire the lugs to the first, third, and fifth socket pins. Make all circuit connections to the lugs.

● Trim transistor leads to 1/4" to fit the sockets. Leave the pigtails of other components full length so you can wire—and rewire—them in different circuits.



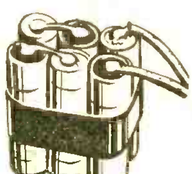

● Pay special attention to the wiring of the two transistors. Socket connections can be identified by lead spacing on the 2N35 and a red dot on the CK722.

● Always install transistors last—after double-checking the wiring. Don't switch on the power until you're sure the right transistor is in the right socket.



● Each time you wire the 1N34 diode (CR1), grip the lead with a pair of long-nose pliers to carry off the heat of the soldering iron.

● Use simple lap joints when soldering leads.



● Make up a 9-volt power supply (B1) by wiring six penlite cells in series. Batteries B2 and B3 (in the photocell relay on the opposite page) are made by using one cell separately and five in series.

# 2 PHOTOCELL

● Would you like your porch lamp to blink on automatically when the sun goes down? It's no trick to use light—or the absence of it—to flip a switch.

A selenium photocell—used in the sun-powered receiver last month as a power source—does a little switch of its own in these layouts and becomes a signal source. Actually, of course, the sun battery continues to do exactly what it did before: it generates current when it is exposed to light. After it's amplified, the current triggers a relay.

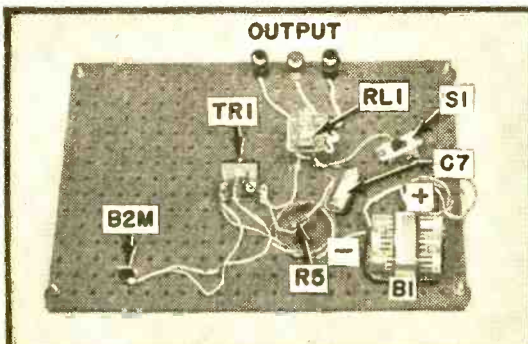
Two photocell units are shown here. Under strong light conditions, the one-transistor amplifier is all you need. However, the two-stage circuit will give better results over a wider range of applications.

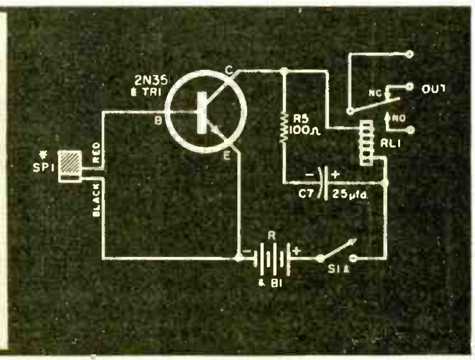
Adjustment screws on the relay switch allow you to vary both spring tension and the spacing of the contacts. In general, lowering spring tension and narrowing the gap between armature and pole pieces make the relay responsive to smaller signal impulses. It is worth noting, however, that relay adjustment can be very tricky. If you haven't worked with these switching devices before, you will probably find it best to go along with the "factory adjustment" of the spring and gaps.

Under "no-light" conditions (with either of these circuits), there is very little base current flow in *TR1*. The emitter-collector circuit of the transistor therefore has a high resistance and current in the coil isn't enough to operate the relay.

However, when light strikes the selenium cell, current in the base-emitter circuit increases and is amplified by the transistor so it can close the relay.

Any interruption of the light source restores the circuit to a *no-current* condition and lets the relay drop open. Resistor *R5* and capacitor *C7* are connected across the



# RELAYS

relay's coil to absorb any inductive "kicks" that may develop because of sudden changes in coil current.

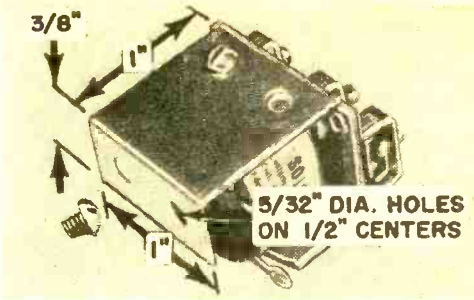
Because of its greater sensitivity, the two-stage layout can be used where it is necessary to focus on a single source of light. Thus, if you want sunlight to switch some appliance, you can shield the photocell from surrounding glare that might give a false signal. Use a cardboard tube for a shield. Mount it over the cell and point its open end at the "control" light.

To allow for a wide range of operating adjustments, a potentiometer is included in the two-stage circuit and the 9-volt battery pack is tapped to provide a 7½-volt (5-cell) "E" supply and a 1½-volt (1-cell) bias voltage. To set up the switching mechanism, close battery switch *S1* and focus the control light on the photocell. You should be able to set the potentiometer to an almost hairline balance that will close the relay as soon as light strikes the cell and open it when the beam is broken.

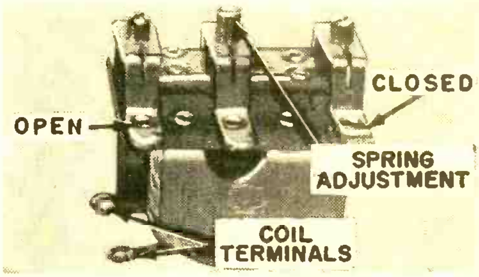
You can also "tune" *R1* to a less sensitive spot. With the right adjustment, the unit should operate as if it were a "latched" switch. That is, once the contacts are closed, they will stay closed even if the light beam is broken. Or conversely, the relay will open when the light goes off and stay open after it comes on again.

To control a lamp, snip one conductor in the power cord and wire the cut ends across the relay's output terminals. Plug the altered appliance cord into a 117-volt outlet as usual.

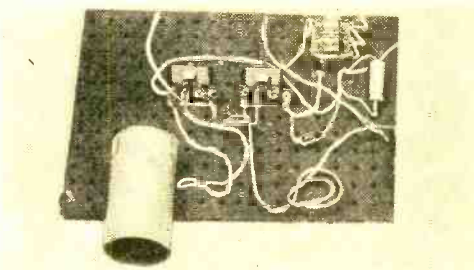
If you want the controlled device to turn on when *no* light strikes the photocell, connect the lamp cord in series with the "normally closed" contacts. For a directly opposite switching service—that is, if you want a lamp to *turn off* when light reaches the photocell—use the "NO" pair. ●



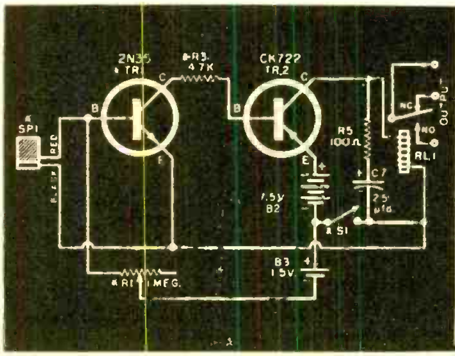

**Make a bracket** for the relay from scrap metal. Space mounting holes to match your relay and leave top screws accessible for adjustment.

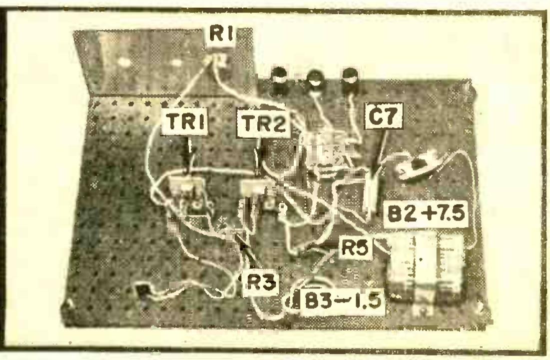



**Screw adjustments** vary the relay's sensitivity. Center screw alters spring tension; outer ones change gaps on "open" and "closed" contacts.



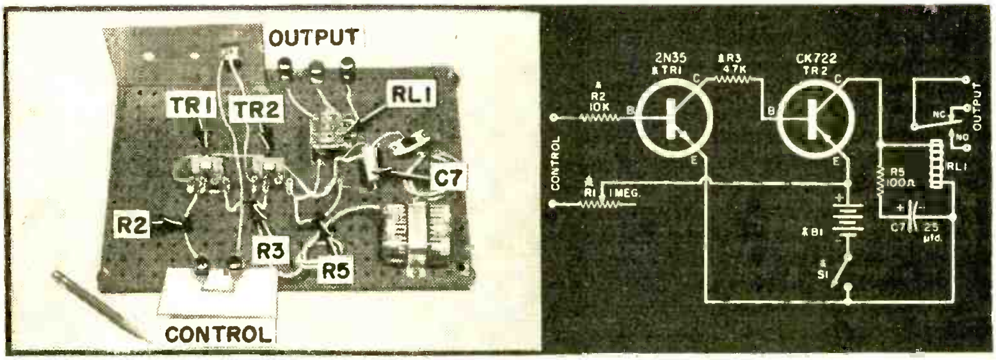
**Light-shield tube** can be 3" to 12" long. Paint the inside flat black. For maximum sensitivity, insert a flashlight lens in tube to concentrate rays.




3 MORE TRANSISTOR PROJECTS

# 3 RAIN ALARM




● It's no fun getting up in the middle of the night to close windows, but it's a lot less fun when you have to mop the floors in the morning because you slept through a rainstorm the night before.

You don't have to be caught with your windows up, however, if you provide yourself with an electronic rain watcher. This one will flash a warning when moisture short-circuits its "sensor" plate.

The transistorized relay circuit, similar to that of the two-stage photocell layout on the preceding page, has a rain-sensitive signal source in place of the light-sensitive source.

You can make a suitable rain "sensor" in several ways. The basic plate consists of two exposed, narrowly separated conducting elements on an insulating board. A drop of moisture that bridges the gap between the conductors completes the circuit and causes the relay to snap closed.

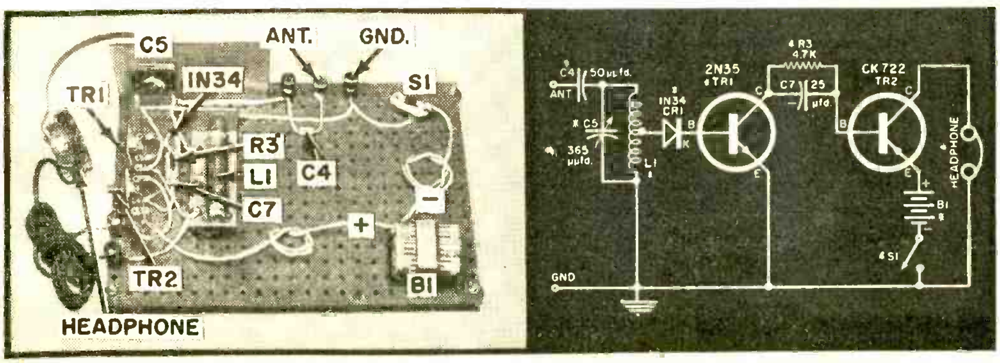
One way to make the moisture detector is to start with a sheet of copper-clad plastic of the kind used for printed circuits. With an etching compound made for this pur-

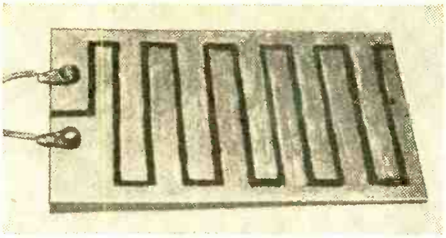
# 4 HIGH-GAIN RECEIVER

● If you built the simple battery-powered receiver described last month, you need only make a few additions to complete this de luxe version. To the earlier model it adds a direct-coupled stage of audio amplification for greatly increased station pickup, sound power and clarity.

Since the receiver isn't regenerative, it doesn't need the tickler winding (*L2* of the "Wireless Microphone" project). However, if you have added these extra turns of wire, just leave its two leads unconnected.

The most interesting feature of this circuit is the direct coupling between the collector of the *n-p-n* transistor (*TR1*) and the base of the *p-n-p* unit (*TR2*). This





**Rain "sensor"** can be made by etching copper-clad plastic as above, or by painting or cementing conductive strips on a non-conductor.

pose, you can cut a narrow insulating canal through the metal face.

Or you can turn the procedure upside down and "print" conducting lines on a base of non-conductive plastic. Use a silver paint (such as General Cement's No. 21-1) or cut strips of aluminum foil and cement them to the base. Leave a narrow insulating gap between the conductors and lay them out in a winding pattern to increase the total area of exposure.

Wire the leads from the "sensor" plate to the terminals marked "control." For the alarm, connect a lamp, bell, or buzzer to the "normally open" relay contacts. The alarm itself, of course, must be plugged in to a suitable power source. ●

simple hookup is made possible by the opposite d.c. characteristics of the two types of transistors. As far as operation is concerned, in fact, you could omit the coupling network consisting of *R3* and *C7* and wire the collector of *TR1* directly to the base of *TR2*. Resistor *R3* is used for safety only; it serves to limit the current on the electrodes which might otherwise run too high under some conditions. When it is included, bypass capacitor *C7* is also needed to minimize the effect of the resistor on the signal level.

Broadcast signals picked up by *a good* antenna-ground system are coupled through *C4* to the tuned circuit. Variable capacitor *C5* selects the desired signal and the low-impedance tap on *L1* transfers it to the base of *TR1*.

The germanium diode detector (*CR1*) and the base-emitter circuit of the first transistor separate the audio signal from the r.f. The sound is amplified by *TR1* and is fed through capacitor *C7* to the input of *TR2*. In this audio-amplifier stage, the signal is given a further boost and is then routed to the headphone. ●

## 5 METRONOME

● Music students—and even advanced performers—can make good use of this electronic timekeeper. Its tempo beat, heard through a single headphone, is clearly separated from distracting outside sounds.

Essentially, the metronome is an oscillator circuit similar to one you might use for practicing code. The frequency of the metronome's "beat rate" is determined by the feedback capacity and the total resistance in the return path of *TR1*. To bring the operating frequency well below that of a code oscillator, two feedback capacitors—*C3* and *C9*—are wired in parallel.

Potentiometer *R1* can be used to tune the metronome; its series resistor, *R4*, is included merely to limit the frequency-adjustment range. If *R4* were omitted (or rather replaced by a direct-wire connection), tuning might be slightly more critical. Otherwise there should be no difference under normal operating conditions.

Resistor *R3*, between the collector of the first transistor and the base of the second, plays a similar role. It could also be replaced by a direct-wire lead. But while it does not affect operation, it does protect the transistors against excess current.

If you can't get the metronome to pulse out the beat rate you want by adjusting potentiometer *R1*, experiment with slightly different values for fixed-resistor *R4* and feedback capacitors *C3* and *C9*. ●