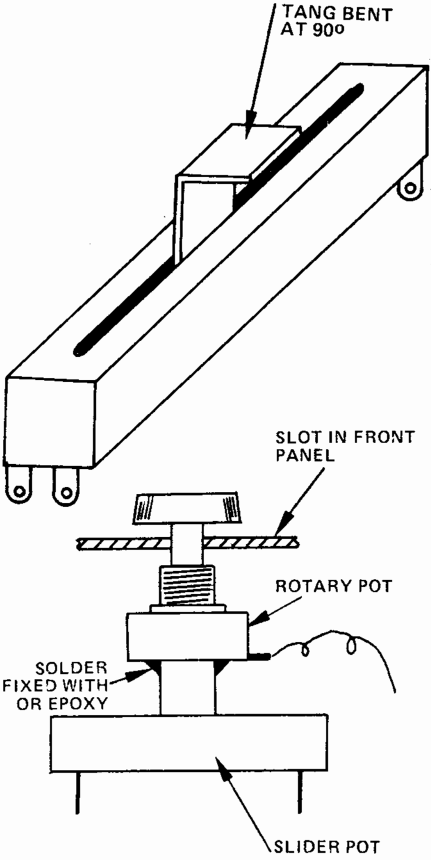


JOYSTICK

Shown is an idea used successfully to provide a 'joystick' type of control with a television football game, by mounting an ordinary rotary type potentiometer on the tang of a slider potentiometer. The rotary control is attached to the circuit board via flying leads.

Radio control enthusiasts could use the idea in conjunction with a proportional system, giving a very cheap alternative to 'joysticks'.

Square-law potentiometer

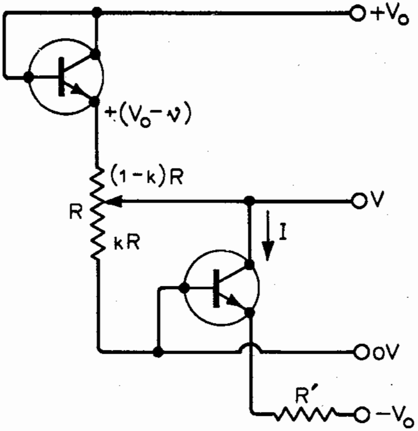
The circuit shown was developed to give a bias for a varicap diode, varying as the square of the angle of rotation of a potentiometer control. If this angle is θ and $k = \theta/\theta_o$ where θ_o is the full angle of rotation, we have, letting v be the offset voltage for the second transistor,

$$V_o - v = (1-k)R(I + V/kR) + V$$

$$V = k(V_o - v - IR) + k^2 IR.$$

Thus if $R' = R$ so that $I = (V_o - v)/R$ we obtain $V = k^2(V_o - v)$. An experimental test using transistors of type 2N5172, a 10-kΩ helipot and $V_o = 9$ volts yields a square-law response to better than ±1% over the range $0.1 < V < 8.5$ volts.

F. N. H. Robinson,
Clarendon Laboratory, Oxford.



Linear pot and op amp provide tapered audio volume control

by Robert C. Moore
Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Md.

Tapered potentiometers are used in audio amplifiers to compensate for the nonlinear response of the human ear. However, at a lower cost, a linear potentiometer and an operational amplifier can approximate the response of the tapered pot.

The audio taper for potentiometers is described by the gain function

$$V_{out}/V_{in} = f(\alpha) = 10^{2(\alpha-1)}$$

where the potentiometer displacement α can range from $\alpha = 0$ (in the full counter-clockwise position) to $\alpha = 1$ (in the full clockwise position). Signal attenuation through the potentiometer can be expressed in decibels as

$$Attenuation = 20 \log(V_{in}/V_{out}) = 40(1-\alpha) \text{ dB}$$

This expression shows that the attenuation in decibels is proportional to the potentiometer displacement from the full clockwise position. To obtain this reverse-logarithmic-gain function, special nonlinear potentiometers are usually used.

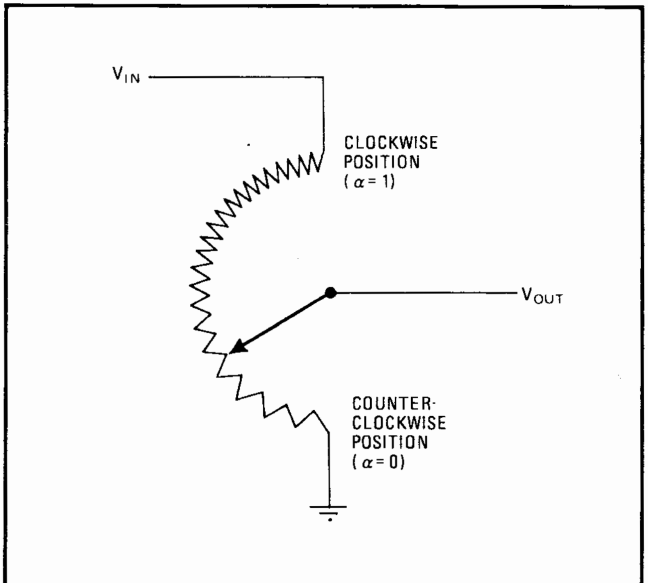
Because these potentiometers cannot be loaded heavily without distorting the gain function, in practical audio applications they are usually followed by a gain stage or a high-input-impedance voltage follower. However, the reverse-logarithmic-gain function can be closely approximated by using a linear potentiometer, a single operational amplifier, and one fixed resistor, as shown in Fig. 2. The operational amplifier adds the capability of voltage gain; in this circuit the maximum voltage gain is 8, or 18 dB. The voltage-transfer function for the circuit of Fig. 2 is

$$V_{out}/V_{in} = (-8\alpha)/(9 - 8\alpha)$$

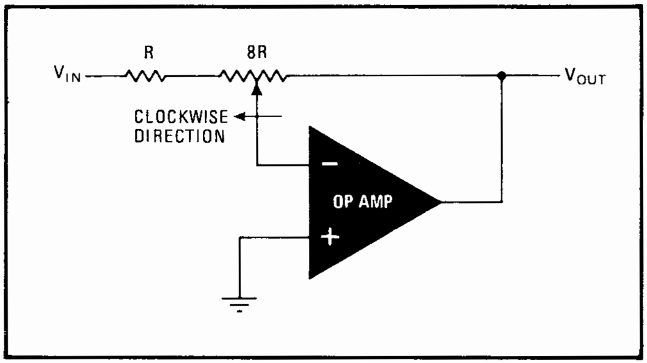
which closely approximates the attenuation function

$$Attenuation = 40(1-\alpha) - 18 \text{ dB}$$

over most of the range of α. As a desirable advantage,



1. Audio taper. Volume-level potentiometer for sound systems has tapered resistivity to compensate for exponential response of human ear. Expensive tapered pot (which should be followed by a buffer stage to prevent loading effects) can be replaced by a linear pot, fixed resistor, and op amp.



2. Replacement. Linear potentiometer, fixed resistor, and operational amplifier, connected as an inverting amplifier, provide transfer function that approximates performance of audio-taper pot plus 18 dB of gain. The minimum input impedance is R.

Test your pot

If you've been faced with the problem of finding an intermittant open, you'll like this easy-to-build tester.

by Colin J. Shakespeare

Necessity, they say, is the mother of invention, and it was necessity that provided the impetus to design and build this particular piece of test equipment. My problem was to service the potentiometers in the control panel of a theatrical lighting system with the panel removed from the system. The controls are typically 10,000 ohm wire wound linear potentiometers which become noisy with age. This results in some rather startling and disturbing on-stage effects.

The potentiometer tester can, of course, also be used for testing any out-of-circuit potentiometer or any other circuit configuration where an intermittant open circuit is suspected. The circuit detects any momentary open circuit—down to the nanosecond region—and produces a visible flash of approximately one tenth of a second on an LED.

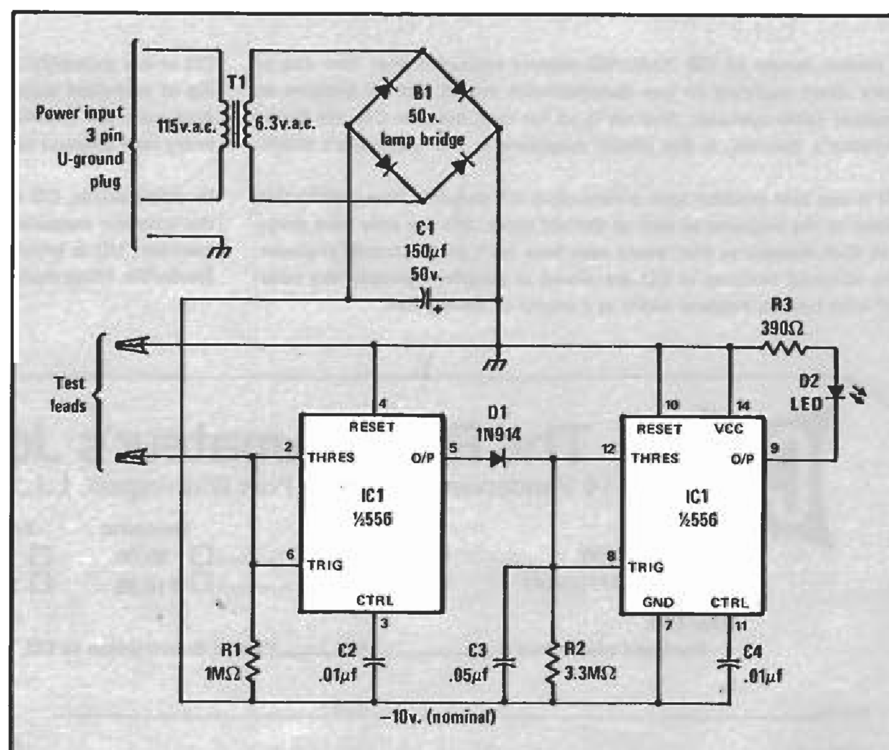
Simple circuit

As with any of these simple circuits, the power supply components cost more than the functional components, but in order to make the unit completely self contained a power supply had to be included. The circuit is tolerant of a wide range of supply voltages and power supply ripple. Component layout is not critical.

An inexpensive 6.3-volt transformer was chosen in the hope that it would give more than 6.3 volts on light load, which tends to be characteristic of the inexpensive ones. Any transformer which gives between 7 and 12 volts ac will work well in the circuit.

The circuitry, as shown, is operated from a negative supply voltage. In the case of my lighting control panel, the potentiometers happen to be connected together in pairs with diodes. Choosing the negative polarity made it possible to test the panel without unsoldering the diodes.

Half of the 556 IC is used as a voltage comparator. Provided the potentiometer



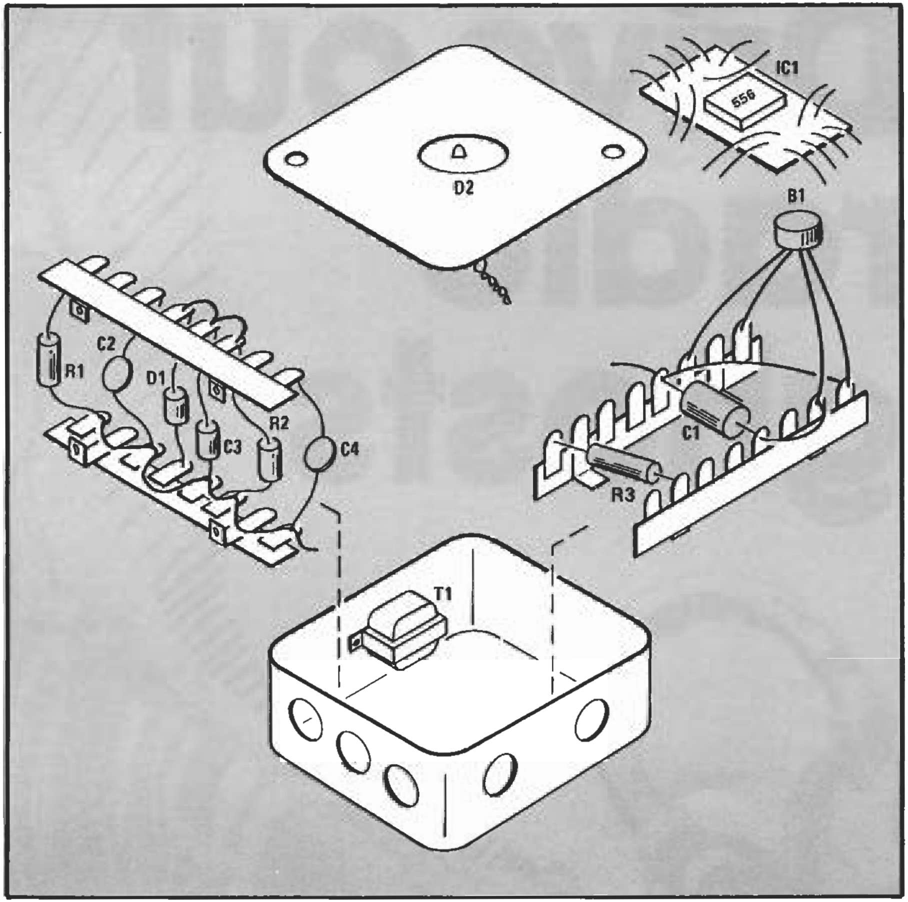
The potentiometer tester is build around a single 556 timer integrated circuit powered by a conventional full-wave bridge rectifier power supply. The circuit shown runs off the negative voltage output of the bridge. However, the circuit can be modified to operate from a positive dc voltage. The potentiometer or circuit under test is connected across the test leads.

under test is less than one half the value of R1, the input to the 556 will stay above the threshold voltage and so the output, pin 5, will be low. When the potentiometer under test goes open circuit, the input to the 556 falls below the trigger voltage and pin 5 goes high, charging the timing capacitor C3. By keeping C3 small, its charging time is comparable with the shortest duration open circuit that can be sensed by the 556. The time, in seconds, that the LED remains lit after pin 5 goes low is approximately equal to the value in ohms of R2 multiplied by the value in farads of C3.

Easy to build

The circuit was built into a standard four-inch electrical box. Being a metal box, it is important that a 3-wire cord be used and that the box be properly grounded. It is also a good idea to tack the knock-outs down with solder, but this is easier said than done. Having made sure the inside of the box is grease free, you'll need a really hot soldering iron and maybe a little extra flux to get the solder to flow properly.

The LED will be more visible if mounted with a black background. In my version the top of the box was sprayed with a matt black paint and the LED inserted through a hold drilled into the middle. Of course, you can build your tester in a black plastic case, or any other suitable cabinet you have handy.



Parts layout isn't critical. Although the prototype was build in an electrical junction box, any cabinet will do.

Fudging Pots

This is a presentation of separate efforts by Hugh Gordon and Noel Boutin and discusses the modifications of potentiometers to suit specific applications.

The first set of circuits (figure 1) shows how to get a value of a pot or rheostat when you're in a hurry. Essentially one finds an R1 somewhat larger than the value you need and parallel a resistor to trim it down to the required value. Needless to say, this is a 'make do' solution. The rheostat kluge will not vary in a linear fashion and the pot kluge could produce unusual results in terms of frequency response and taper depending on the impedances of the source and load circuits.

Noel Boutin discusses ways and means of tailoring the taper of linear pots to suit a particular application. One can effectively reduce design cost by loading a cheaper linear potentiometer with a resistor. Figure 2a shows the two possibilities. The corresponding non-linear transfer function as a function of fractional displacement for various fractions of R (XR) is shown in figure 2b.

TT25, 26

Fig.1. How to pad a pot or rheostat to a desired value.

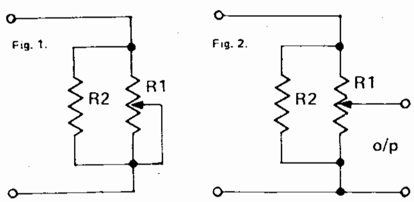
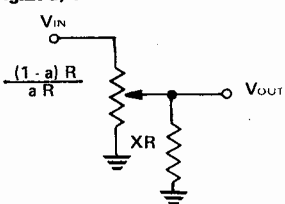
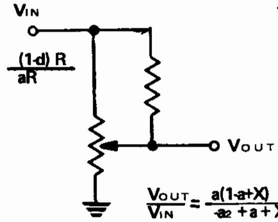


Fig.2. a) i



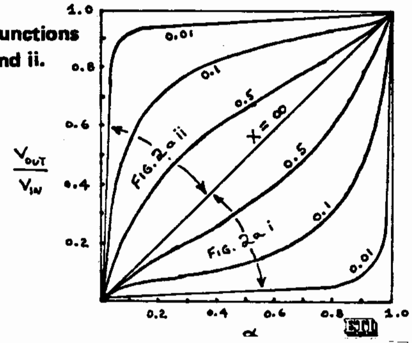
$$\frac{V_{OUT}}{V_{IN}} = \frac{aX}{-a^2 + a + X}$$

Fig.2. a) ii



$$\frac{V_{OUT}}{V_{IN}} = \frac{a(1-a+X)}{-a^2 + a + X}$$

Fig.2.b) Transfer functions for figures 2a) i and ii.



...the other. The second option... compromise.

Oversimplification

In the November 1978 issue, we discussed parts substitution. At that time, I showed how to change the value of a potentiometer—specifically, how to make a 175K pot out of a 500K pot and a 270K resistor (see Fig. 3).

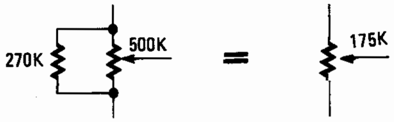


FIG. 3

Bill Clements, K4GMR, has pointed out to me that this is not always possible. It depends upon how the device is used. If it is used as a voltage divider (using all three terminals), the combination works like a single pot. Because most applications involve this type of use, you may never have noticed the exception.

However, when the combination is used as a two-terminal device, it does *not* function as a simple variable resistor. Place it into an audio tone-control circuit or into the R–C control circuit of a 555 timer, for example, and strange things may happen.

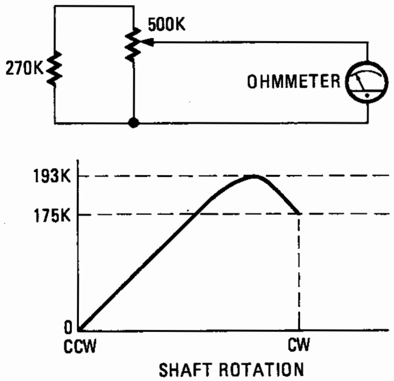


FIG. 4

In two-terminal use, with some values the resistance does not increase from zero to maximum as the arm is turned. The value may go from zero to a maximum, and then *down* to the value of the parallel combination!

Bill enclosed a complete mathematical analysis to show that the example given above varies from zero up to *193K* and then back down to 175K. Space won't permit including his analysis, but to check out his conclusion, you can give it the old breadboard test. The results will be something like those shown in Fig. 4.

I'll have to admit that a pot acting like

continued on page 84

HOBBY CORNER

continued from page 81

that could produce very confusing results in some circuits. I surely hope no one has pulled out his hair over one since last November! Many thanks to Bill Clements for calling this to our attention.

STATE OF SOLID STATE

An electronic potentiometer

ROBERT F. SCOTT,
SEMICONDUCTOR EDITOR

UPON HEARING OR READING THE words potentiometer or *pot*, we immediately think of a variable resistor having a rotary control shaft. But this is the age of electronics, and a potentiometer need no longer be a mechanical device adjusted by turning a shaft; it can be an electronic device that uses small voltages to emulate a potentiometer. One kind of device that can do that is Xicor's *E²POT* Digitally Controlled Potentiometer, which is available in several different versions as the X9MME 8-pin miniDIP series of solid-state non-volatile potentiometers. Basically, the device functions as a digitally-controlled trimmer resistor.

A digitally-controlled potentiometer can be adapted to many applications where mechanical potentiometers or digital-to-analog circuits cannot be used, or would be inconvenient to use. For example:

- It provides for automatic potentiometer calibration or adjustment on an assembly line.
- It eliminates the need for manual adjustments of mechanical potentiometers.
- It makes possible remote control via a keyboard of variable adjustments, such as volume and brightness.
- It simplifies adjustment or control of a remote device via a radio, LAN, or modem link.

99 resistors

The device is essentially an array composed of 99 resistive elements with 100 tap points that are accessible to the "wiper" element. (100 points because the taps are located between adjacent resistor elements and at each end of the resistor string.) The X9MME's functional diagram and pinout are shown in Fig. 1. The wiper's position is digitally controlled by TTL-Level voltages on the $\overline{CS}$, U/$\overline{D}$, and $\overline{INC}$ inputs. Table 1 shows the mode selection. The position data is stored in a non-volatile memory and is automatically recalled on power-up. The memory is capable of retaining the wiper position data for 100 years.

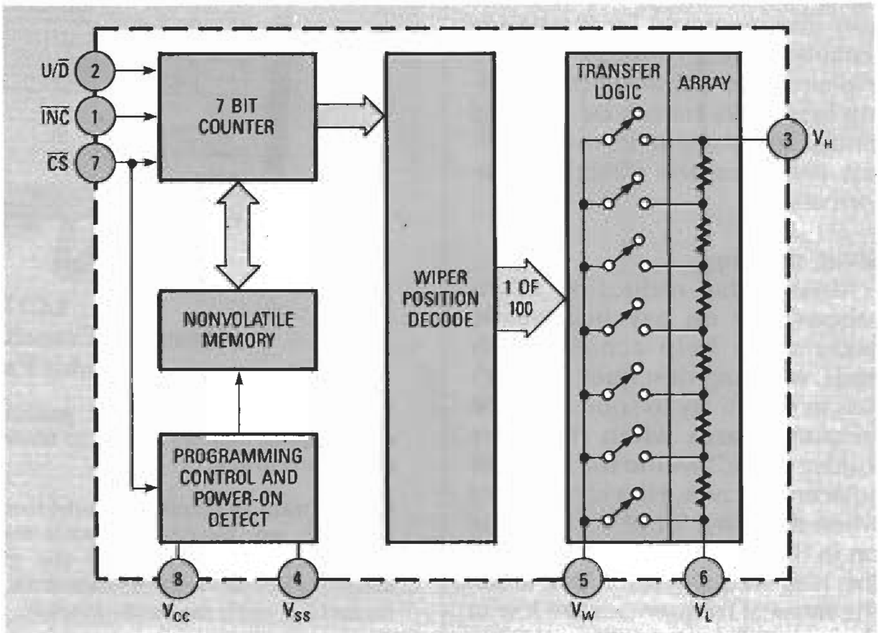


FIG. 1

TABLE 1

Mode Selection			Mode	Power
CS	INC	U/D		
L	‾_	H	Wiper Up	Active
L	‾_	L	Wiper Down	Active
_/‾	H	*	Store Wiper Position	Active

* equals high or low

The X9MME *E²POT* is available in three versions, each having different value ranges. The *X9103P* is 10K, the *X9503P* is 50K, and the *X9104P* is 100K. The resolution—the value between tap points—equals the maximum end-to-end resistance divided by 99, or 101, 505, and 1010 ohms for the *X9103P*, *X9503P*, and *X9104P*, respectively.

Other *E²POT*'s features include:

- Single-chip MOS implementation
- Three-wire TTL control

- Operation from a 5-volt supply
- Analog voltage range of ±5 volts
- Temperature compensation for ±20% of end-to-end resistance range
- Wiper current of 1-mA maximum
- Typical wiper resistance 40 ohms at 1 mA
- Resolution 1% of resistance

For information on pricing and availability of the E^2POTS's, write to *XICOR INC.*, 851 Buckeye Court, Milpitas, CA 95035.

Be warned by pots that are going to pot

Failure of a potentiometer is usually caused by a bad contact between wiper and resistance element and can be catastrophic in some situations. So, **if you can't guarantee perfect mechanical contacting, why not provide a failure warning system, as Hewlett Packard does in its patient-monitoring equipment?** The technique is simple, says Gary Patrick, the engineer at HP's Medical Electronics division in Waltham, Mass., who thought of the idea.

Simply tie the pot's wiper to the supply voltage through an alarm threshold circuit and a resistor much higher in value than the pot. Now, if the wiper contact opens, the pot resistance is removed from the circuit. All the available current passes through the loop containing the alarm and is high enough to exceed the threshold controlling the alarm. The alarm itself could be as simple as a single LED indicator or more complicated, like a gate trigger circuit that powers a bell.

POTENTIOMETERS

PART 12 OF OUR COMPONENT SERIES LOOKS AT THE VARIOUS POTENTIOMETER TYPES THAT ARE IN COMMON USE TODAY

POTENTIOMETERS ARE MADE in such a bewildering array of sizes, shapes, styles, and combinations that it is difficult to sort out what best suits a particular situation and what alternatives there may be. Apart from that, they come in a variety of wattage ratings, voltage ratings, resistance variation 'laws', etc — and how are you going to sort through that lot?

Potentiometers perform some control function by varying a resistance element or by tapping off a voltage from a fixed resistance. The variable resistor may need to be varied continuously so that some control function is performed, or it may be a 'preset' control which is only required for some calibrating or 'trimming' function. Preset potentiometers are generally called 'trimpots'.

So, potentiometers are generally split into two broad categories — **continuously variable** types, which are equipped with a shaft for the attachment of a knob, and **trimpots** which are generally equipped with a screwdriver slot.

Types

There are five basic types of potentiometer, classified according to the type of resistance element employed:

(1) Carbon composition
(2) Carbon Film
(3) Hot-Moulded Carbon
(4) Cermet
(5) Wirewound

Carbon composition pots have a composition element moulded to the required size and shape and generally employ a metallic spring-wiper. They are generally quite inexpensive but have the disadvantage that they become noisy after use. Carbon film pots consist of a resistive film that is sprayed or screened onto a phenolic former of the required size and shape. A metallic spring-wiper is also generally used in this type of pot, and the element will withstand many more rotations than a composition type before noise problems. Carbon film pots are also inexpensive and are the commonest types in use, along with Hot Moulded Carbon types. Carbon film pots have a good degree of resolution whereas the composition types are poor in this respect.

Hot Moulded Carbon potentiometers are manufactured by a process wherein the resistive element, insulating base, and terminations are moulded into one integral part. A carbon wiper contact is usually employed. They have a high wattage rating on a size-to-size basis and a high degree of conformity between units. This factor, together with their very high resolution, has led them to be increasingly used as precision controls. They exhibit low noise levels in operation compared with carbon film and wirewound types.

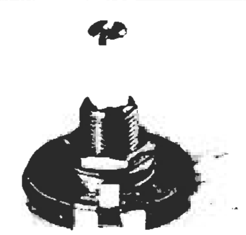


Fig. 1. The common, basic style of potentiometer. It has a threaded bushing and nut for panel mounting through a single hole and standard solder lug terminals.

Cermet potentiometers find wide application in precision controls, as trimpots and in many stringent applications (the element is rugged, exhibits low noise levels in use, and has good resolution). Wattage ratings are similar to those for hot moulded carbon pots of a similar size. They are generally somewhat more expensive. A metallic wiper is usually employed.

Wirewound potentiometers consist of a resistance wire would on a former with a metallic wiper, although a graphite wiper contact is sometimes used on low value, high wattage types. They have the disadvantage of being noisy, the resistance changes in small 'steps' as the wiper passes over the turns of wire, and they are usually more bulky than other types of equivalent value. However, they can be made in very low resistance values and they are able to dissipate much more power than other types of equivalent value.

Styles

The most common, basic style of potentiometer is illustrated in Figure 1.

In some applications, 'Tandem' or 'Ganged' potentiometers are required (for example for stereo tone and balance controls). They consist of several potentiometers all connected to the one shaft and stacked one behind the other, as illustrated in Figure 2. 'Dual-Concentric' potentiometers appear similar to the dual-ganged pot on the left in Figure 2. However, in this case, each pot is separately controlled by means of two concentric shafts. Dual-concentric pots are often used where there is limited space (e.g., for the RF and audio gain controls on a communications receiver).

The assembly illustrated in Figure 3 consists of four potentiometers mounted on the four sides of a metal box and connected by means of a special linkage to the lever which may be moved in any direction. These assemblies are used for complex control functions such as quadrophonic 'balance' controls, radio controlled models etc.

Switches are often mounted on the rear of potentiometer assemblies and connected (mechanically) to the control shaft so that the one control knob may serve several functions. There are three basic types of switches generally used: the rotary type, the push-pull type and push-push type. A rotary style of switch is often employed as a mains-power switch on a control, such as a volume control. It has the advantage that when the switch is moved to the ON position the control is at minimum. But, it has the disadvantage that anything up to the first 15% or 20% of the control cannot be used. On many controls this is of

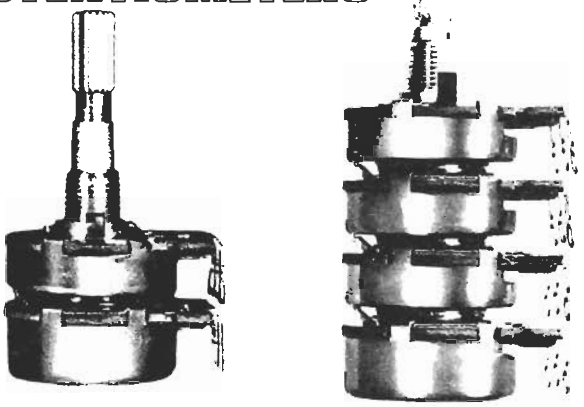


Fig. 2 'Tandem' or 'ganged' potentiometers consist of several potentiometers controlled by one shaft. 'Dual-concentric' type are similar to the one on the left except that they are separately controlled by concentric shafts, one inside the other — the inner, shaft controlling the 'back' pot and the outer shaft controlling the 'front' pot.

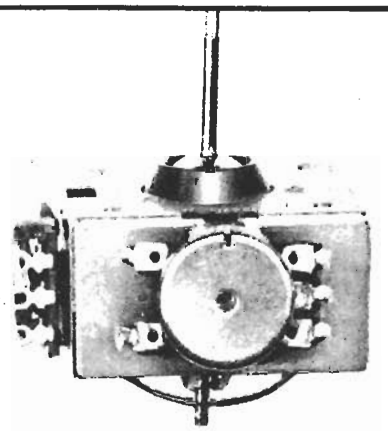


Fig. 3 Lever-controlled 'quad' pot assembly. These assemblies are used for complex control functions such as quadrophonic sound 'balance' and in model control applications etc.

little consequence. Push-Push and push-pull switches have the advantage that the control may be left in a certain position and switch operation does not disturb it. With a volume control however, this may be disastrous as the equipment may be turned on while the volume control is at a high setting, or worse still, full on!

While solder-lug terminals are commonly found, potentiometers are also manufactured with terminals suitable for printed circuit board mounting.

Power Ratings

With the exception of wirewound types the majority of standard potentiometers are obtainable in ratings of 0.1, 0.2, 0.25, 0.5 and 1 watt. Potentiometers are derated in much the same manner as fixed resistors. If this information is desired it is best to consult the manufacturer's literature.

Wirewound potentiometers are obtainable in ratings up to 100 watts (!!) but more usually they are available in ratings (depending somewhat on their resistance value) of 0.5, 1, 2, 5, 10, 15 and 20 watts. The higher power ones are usually quite bulky. Cermet and hot moulded carbon types are generally the smallest size for a given rating.

Resistance Law

The resistance 'law' of a potentiometer refers to the manner in which the resistance changes (as measured between as end terminal and the wiper terminal) with rotation of the shaft. There are a considerable number of different 'laws' in common use. The main ones however are: linear, logarithmic, and 'S' law. These are illustrated in Figure 4. Note that various log laws are used, the 20% log law is the more common one however. The laws for both clockwise (CW) and counter-clockwise (CCW) log are illustrated, as the potentiometer may be connected to operate in reverse fashion if desired. The various common laws are given a letter code which is stamped or marked on the body of the assembly along with the resistance value. The code is quite straightforward, as follows:

A = linear law
B = logarithmic law
C = reverse logarithmic (or anti-log)
S = 'S' law.

A pot may be marked 25kA, which is a 25k ohm, linear law potentiometer. Another may be marked 1M/C, which is a one megohm, reverse logarithmic pot.

The linear law control varies resistance in direct proportion to the rotation of the shaft. This type of pot is commonly used in voltage control applications, on tone controls and other applications which require a straightforward resistance variation.

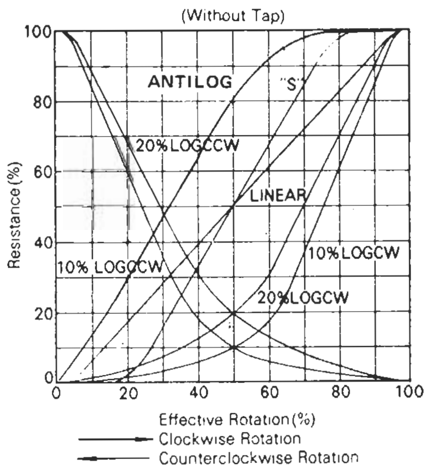


Fig. 4. The common resistance-versus-rotation 'laws' as 'tapers' for potentiometers.

With a log law control, the resistance increases very gradually during the initial rotation of the shaft, most of the resistance change occurring in the last 20-30% of the rotation. This type of law approximates the natural sensation of loudness as our ears follow a logarithmic law in their sensitivity to sound amplitude. Consequently, such controls are frequently used as volume controls so that they produce an apparent linear increase in sound output as the shaft is rotated. If a linear control were used, the greatest change in perceived volume would occur within the first 10-20° of shaft rotation.

Anti-log laws provide the reverse the greatest change in resistance takes place in the early portion of the shaft rotation, the least change occurs in the last 30-40% of shaft rotation.

The 'S' law provides only a small change in resistance for the initial and final 20% of shaft rotation and provides a linear variation between these extremes.

Other laws include semi-log and linear-tapered. These have curves that lie between the log and linear curves on the graph in Figure 4. The semi-log law provides a somewhat greater change of resistance-versus rotation over the first 40% of shaft rotation than with the log curve. The linear-taper provides a nearly logarithmic variation over the first 50% of shaft rotation and a linear variation thereafter.

Resistance Ranges

Most types of carbon element potentiometers are made in values ranging from 50 ohms up to 2 M. Some older types were made in values as high as 500 M. Cermet potentiometers are made in values ranging from 10 ohms to 10 M.

Some manufacturers make their pots to values in the standard E6 (20%) series (i.e.: 47 ohms to 2 M for carbon types). However, many pots are made with values according to the following decade series: 10,15,20,25,50 & 100. i.e: 2 k5, 5 k, 10 k, 15 k, 20 k, 25 k, 50 k, 100 k etc . . .
Some (typically of US make) include 75 in the value range.

Wirewound potentiometers are made in values ranging from 10 Ω to 100 k.

Slide Pots

These are pots having a linear element rather than a circular element as in standard pots. They are available generally with a carbon element having slider ranges of typically 50 mm, 75 mm, and 100 mm in the various laws as previously illustrated.

Slide pots have particular advantages of their own. One being that it is easier to see the proportional position of the control at a glance than with standard potentiometers. In some circumstances the slide pot provides a much more convenient form of control, for example in multi-channel audio mixer applications.

Trimpots

Trimpots are usually 'preset' controls. That is, they are only adjusted occasionally to set certain circuit parameters or conditions, for calibration purposes etc. Consequently they are generally adjustable by means of a screwdriver slot on the control shaft, although some have an integral knob to allow finger adjustment.

Trimpots are made in a wide variety of styles and sizes, as illustrated in Figure 5. Some types are enclosed to prevent the ingress of dust etc which can cause the control to become noisy in operation. Many types are only single-turn controls with the wiper covering only 180° in some cases, while others cover the more conventional 270-280° of rotation. Other trimpots are made for more critical applications and have a multi-turn control which allows a much finer and more accurate adjustment.

Manufacturers make trimpots in values ranging from 50 ohms to 5 M for carbon element types, and typically up to 30 M for Cermet types. Wirewound types are made in values typically ranging from 100 ohms to 5 k. Wattage ratings for the various types are typically 0.1, 0.2, 0.25, 0.5 up to 1 W. Trimpots are available in the same range of laws as are standard potentiometers, although most common styles have a linear law. Other characteristics are the same as for the type of element employed.

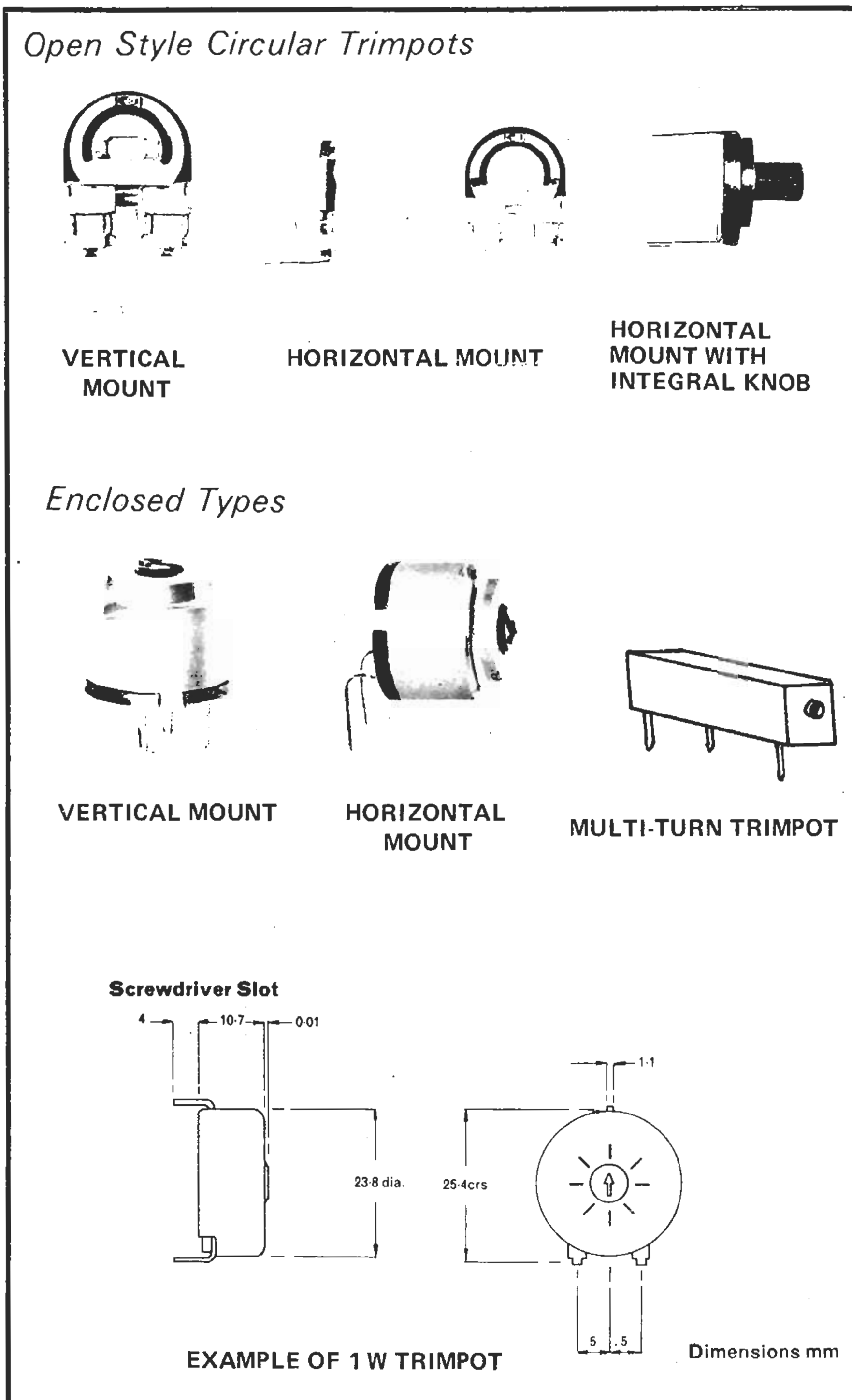


Fig. 5. Examples of various styles of trimpots.

Connecting Potentiometers

One thing that baffles electronic project constructors is the 'correct' way to connect a potentiometer.

The best way to illustrate how to do it is by example. The most common application of a potentiometer is that where it is required to vary a quantity (signal, voltage, etc) so that an increase occurs when the control shaft is rotated *clockwise.* The best example of this is a volume control.

In Figure 6 a pot is illustrated typically as you would see it when you come to make the connections. The arrow indicates the direction in which the control shaft will be turned to increase the output. THE TERMINAL IN THE CENTRE IS ALWAYS THE WIPER CONNECTION. So, terminal 1 (on the left as you view it to wire it up), connects to 'ground' or minimum. Terminal 2 (the wiper) connects to the output (in some cases it can also be the input terminal; operation of the pot still remains the same). Terminal 3 (the one on the right) connects to the input (or the output if the input is connected to the wiper).

Try it out for yourself. Get a 1 k (linear is best) pot and a battery (anything from 1.5 V to 9 V will do), hook up the battery with the positive to terminal 3, and the negative, to terminal 1. Connect a voltmeter with the negative to terminal 1 and the positive lead to terminal 2. Commence with the control shaft at the fully anti-clockwise position (hard left!). As you slowly rotate the shaft clockwise, the reading on the voltmeter will rise. True! It's easier to do it than it is to read about it. The wiper, in this case, commences at terminal 1 and moves towards terminal 3.

Some applications require the pot to work in the reverse fashion. For example, as a frequency or pulse rate control in an oscillator or multivibrator. In such cases, an increasing effect occurs as the wiper traverses towards the 'minimum resistance' end of the control. The pot is simply connected so that terminal 1 is the 'maximum resistance' end of the control and terminal 3 the minimum.

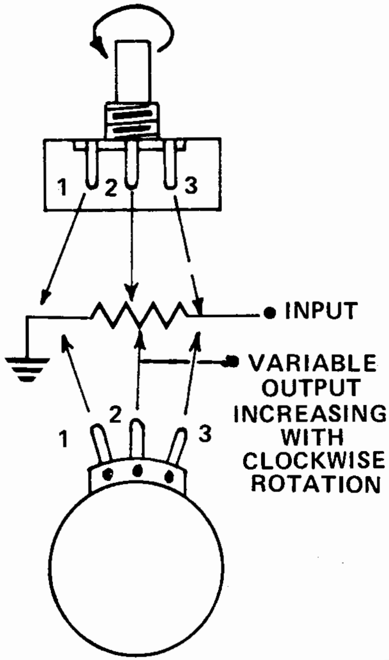


Fig. 6. Connecting a pot as a simple 'increase clockwise' control (e.g. volume).

Fig. 7. Pots in some applications require only a variation in resistance. Which terminals are connected together depends on the circuit effect.

In some applications the circuit shows that the wiper is shorted to one of the 'end' terminals. But which one? Terminal 1, or 3? In such cases it depends on whether the 'maximum effect' occurs at minimum or maximum resistance. Look at Figure 7. The circuit shows that as the wiper traverses the element it shorts out the section of the track it has just traversed, decreasing the resistance as it moves towards the terminal which is not connected to the wiper. Leaving one 'end' terminal unconnected achieves the same purpose.

If the *maximum* effect (from the circuit in which the pot is to be connected) occurs at *minimum* resistance then terminals 1 and 2 are connected together. Maximum resistance (and thus minimum effect) occur at fully anti-clockwise rotation (hard left!). The effect increases as the control is rotated clockwise.

On the other hand, if the *maximum* effect occurs at *maximum* resistance then terminals 2 and 3 are connected together. Thus, as the control is rotated clockwise from the fully anti-clockwise position the resistance, and thus the effect, increases. ●

Tell me about EEPOT's.

Suppose you took a 100-position selector switch and 99 resistors of, say, 1000 ohms each. You could connect them up to make a 100-position volume control, as was done in older broadcast-quality audio attenuators. Now, what would really be nice is finding some way to *remote-control* the switch setting. That way, you or a computer could change the switch position at will.

The switch would be able to "remember" its correct setting and would still be correct the next time that you applied power.

Well, the folks at *Xicor* have done you one better. They have come up with an 8-pin mini-dip beastie called an *EEPOT* that can be used as a remotely controlled volume control. You can also think of it as an unusual digital-to-analog converter or else as a multiplier that can multiply a digital and an analog value together.

Three of the available devices include the X9103 (10K), the X9503 (50K), and the X9104 (100K). *Xicor* has been known to send out free samples on letterhead requests; otherwise, they cost under $5.

Figure 1 shows you a block diagram of an EEPOT. A pair of leads are used for the +5-volt DC supply and ground. Three leads are used for the two ends and the wiper of the equivalent potentiometer. Finally, three leads, named CHIP SELECT, UP/DOWN, and INCREMENT are used for the digital control.

The position in the resistor string is selected by one of 100 internal field-effect transistors connected as data selectors. The present position is remembered by a seven bit, modulo-100 counter. When the chip is selected, you can raise or lower the position one count at a time, through use of the UP/DOWN and INCREMENT inputs.

To initially set your volume-control position, you bring the CHIP SELECT low. If you want a "louder" output, you make the UP/DOWN input high and then pulse the INCREMENT line by bringing it low and then back high again exactly once. Repeat for each step as needed.

Now for the neat part. The internal position counter is "backed up" by seven non-volatile memory cells. When you deselect by making the CHIP SELECT high, the memory cells "remember" the counter position for you, even after supply

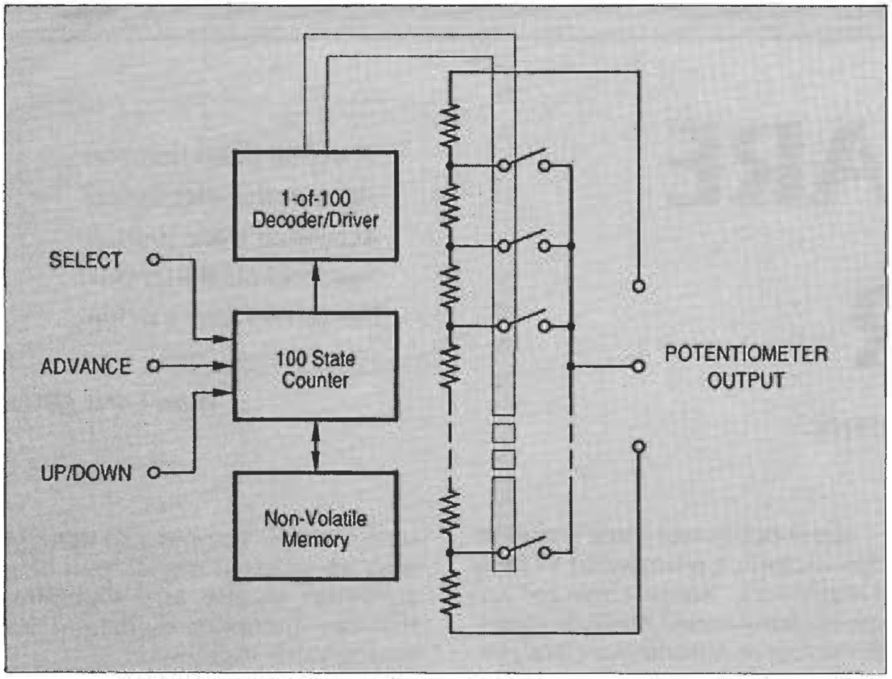


FIG. 1—AN EEPOT CAN SIMULATE an ordinary potentiometer and can be remotely controlled, either manually or by a computer. The wiper position is remembered during any power-down times by an internal non-volatile memory.

power is disconnected. Thus, if you use the beastie to remotely set the volume on your stereo, you will have the same volume setting the next time you apply power.

There are a few "gotchas," though. While a hundred positions are more than enough for most audio uses, it just plain isn't nearly enough resolution for such neat things as remotely setting a floppy-disk drive's speed. While the output distortion is quite low, you are limited to a maximum of + or −5 volts of analog input signal. And you should not try to source or sink more than half a milliampere of output current.

There's one very important use rule: *You absolutely must not disconnect the supply power while the chip is selected.* As is typical with most non-volatile memories, powering down while active can lead to incorrect memory values being stored.

You also have to keep the chip's power applied when you are actually using the output. Thus, while we do have a low-power device, it is not suitable for truly micropower uses.

Figure 2 shows you the pinouts, while Fig. 3 shows you a "bounceless" pushbutton that will let you experiment with the INCREMENT input on your EEPOT without anything fancy in the way of computers or test gear.

A bounceless switch is also shown for the CHIP-SELECT input. Note that debouncing is absolutely essential for those two inputs when you are working with mechanical contacts.

The UP/DOWN input does not need any mechanical contact debouncing, provided that you wait a few milliseconds each time you change it.

In the real world, you are more likely to use the "already clean" and parallel outputs of a personal computer port or the output commands from a remote controller integrated circuit to drive your EEPOT. In those cases, any extra debouncing circuits are not at all needed.

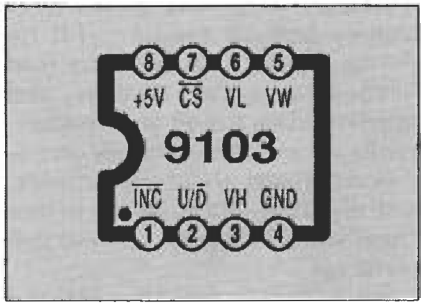


FIG. 2—EEPOT PINOUTS. VL, VW, and VH are the terminals of the output potentiometer. The chip select $\overline{CS}$ is brought low to change position, but is left at +5 otherwise. Position is changed by bringing $\overline{INC}$ low and then high again, with direction set by up/down pin U/$\overline{D}$. A high U/$\overline{D}$ advances the position.

Now, I could sit here and tell you all the marvelous things you can do with a volume control whose setting is remotely and digitally controllable and then later remembered during power down times. Things like variable-gain amplifiers, electronic multipliers, self-calibrating instruments, and stuff like that.

Instead, we'll use the EEPOT for our first contest. Just dream up a good use or two for that IC. Be sure to send your entries directly to me via the address in the box, and *not* to the **Radio-Electronics** editorial offices.

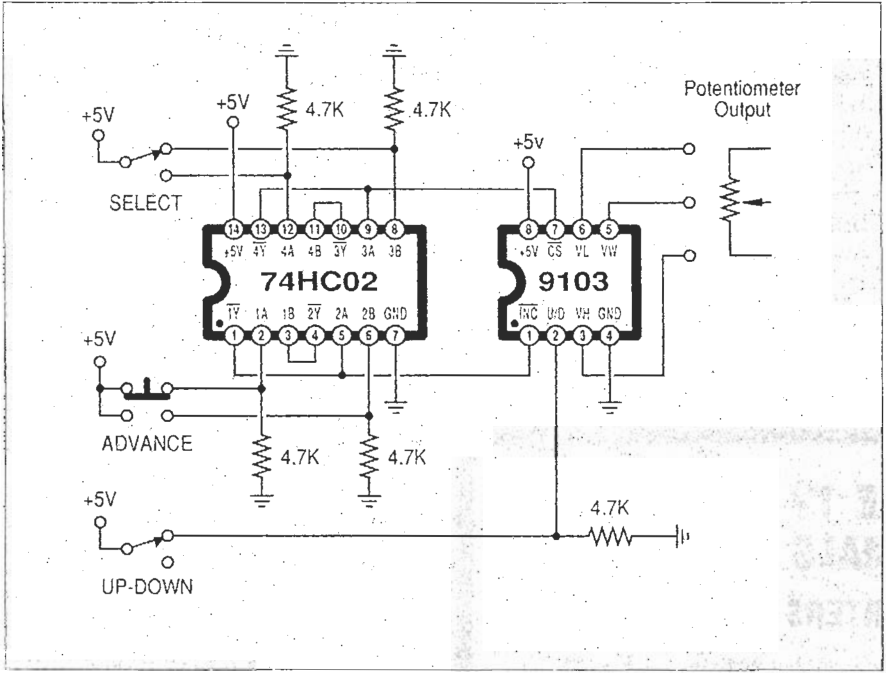


FIG. 3—USE THIS CIRCUIT to test your EEPOT. The debouncing shown is only needed when you are using mechanical contacts.

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POT LINEARITY CALCULATIONS

To the Editors:

I believe that the curves in Fig. 1 of "Calculation of Potentiometer Linearity and Power Dissipation" by David L. Heiserman (August, 1967, p. 59) are mislabeled. The article states that linearity is more closely approximated as the ratio R_L/R increases, while the graph indicates the opposite.

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The two curves labeled $R_L/R = \infty$ *and 1 are correct. The remaining curves labeled 2, 4, 8, 16, and 64 should read* ½, ¼, ⅛, 1/16, 1/64, *respectively.—Editors*

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