VARIABLE RESISTORS OR 'POTS'

Variable resistors are often called *potentiometers*, or 'pots' for short, because one very common use for them is as an adjustable voltage divider. For many years they were often called 'volume controls', because another very common use was in adjusting the audio volume produced by amplifiers, radio and TV receivers.

Yet another early name for essentially the same component when it was used simply as a variable resistance was *rheostat* — meaning a device to 'set the flow' (of current).

Pots are made in a variety of physical forms, and with the actual resistance element made from different materials. Some pots are made for frequent manual adjustment via a control knob, while others are designed to be adjusted only occasionally with a screwdriver or similar tool, for 'fine tuning' of circuit performance. The latter type are usually called 'preset' pots or *trimpots*.

Most commonly encountered pots designed for manual control have a resistance element consisting of either a carbon-loaded resistance compound 'ink' coated on a fibre sheet, or a winding of resistance wire (nichrome, copper-nickel alloy or similar). Not surprisingly these are called 'carbon composition' and 'wirewound' pots respectively.

Higher quality pots for use in professional equipment may have the resistance element made from hot-moulded carbon loaded material, or from a metal-and-glass powder ('cermet') fired on a ceramic substrate, or a nichrome film deposited on a ceramic substrate and then etched in a geometric pattern ('bulk metal'). These give somewhat greater reliability, and often better resolution, noise and high frequency performance.

Most pots made for manual control are in one of two physical forms: the rotary type or the 'linear slider' type. As these terms suggest, the sliding tap contact or *wiper* moves along the resistance element in a circular fashion in the first type, but in a linear or 'straight line' fashion in the latter. In a rotary pot the wiper is therefore attached to a rotating spindle, while in a slider pot it's directly behind the control knob.

Most rotary pots made for manual control offer a total rotation of about 270 degrees — 3/4 of a single turn. However such a limited physical range can make accurate setting difficult, so multi-revolution pots are also made. These have the resistance element arranged in a spiral or helix, and the wiper moves along as the control spindle is turned through multiple revolutions (typically 10 or 20). This generally allows much more convenient setting, but such pots are not as common as the single-turn type because they're rather more expensive.

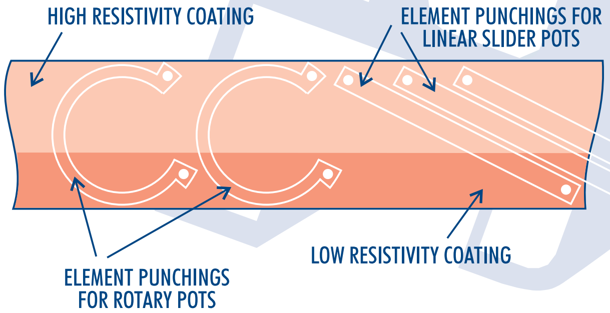

Fig.2: Today's 'log taper' pots have elements punched from strips with dual-resistivity coatings, which gives an acceptable approximation.

Both rotary and slider pots can have a resistance element of either the carbon composition or wirewound type. Carbon composition types tend to be cheaper to make and fairly quiet in operation, and are also capable of good resolution. Wirewound types are generally more reliable and more stable in their performance, but are 'coarser' in resolution due to the way the wiper makes contact with discrete turns of the wire element. Wirewound pots can also be made to dissipate more power, so pots made for use in circuits handling higher power are generally of the wirewound type.

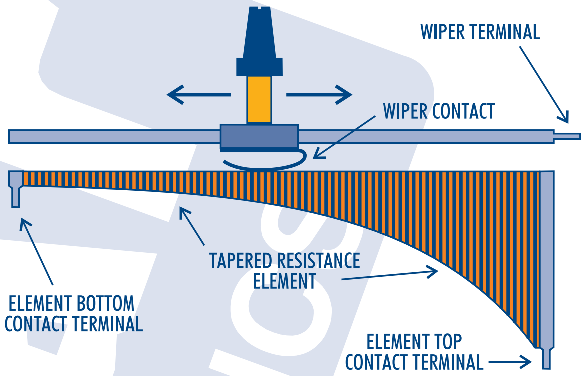

Fig.1: Early 'true logarithmic taper' pots actually had a tapered element...

Trimpots can be made in circular, multiturn circular, linear-slider and multiturn linear-slider form. Low cost varieties generally use an 'open' construction where the resistance element and slider are fully exposed, but as this allows contamination by dust and moisture, the better quality trimpots are generally housed inside a small plastic case — which is sometimes hermetically sealed. Some multiturn trimpots use a worm drive system with a circular element, while others use a linear element with the slider driven via a leadscrew. Either way, the reduction drive is designed to have very low 'backlash' — to allow smooth and accurate adjustment.

Resistance 'taper'

It's very common to see pots described as having either a 'linear' or 'log' **taper**. What's this all about?

Well, the first pots had a linear relationship between physical setting (i.e., rotation) and tapping resistance ratio; for example when the wiper was halfway along the element, the output voltage was 50% of the total across the whole element.

But when these pots were used as audio *volume controls*, it was soon discovered that their adjustment characteristic or 'law' wasn't right. The volume tended to grow far too rapidly as the pot was turned up from zero, while the rest of the pot's rotation didn't seem to have much control — it was often merely adjusting degrees of 'too loud'. Just about all of the pot's useful range as a volume control seemed to be squeezed into the first 60 degrees or so of rotation, making it hard to set the right level.

Engineers soon realised that this problem was due to the human ear's *logarithmic* response to sound levels. So the remedy was fairly clear: come up with a type of pot that

Single and dual-gang rotary pots of the compact type having a body 16mm in diameter.

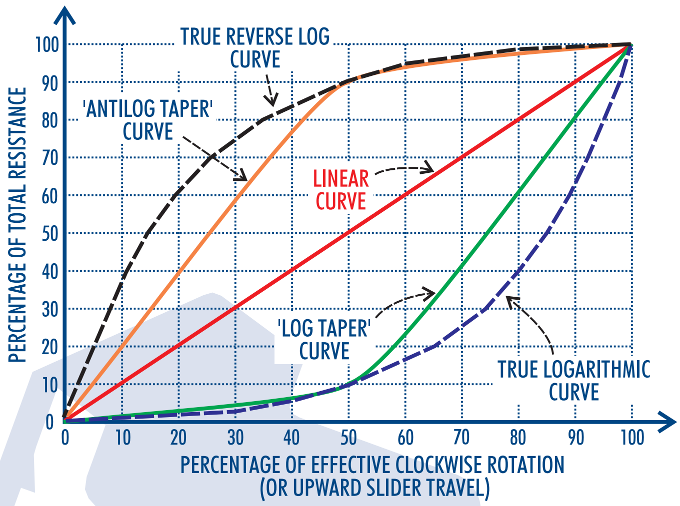

Fig.3: The rotation vs. resistance ratio 'law' curves for linear, true logarithmic and 'log taper' pots. Reverse log and 'antilog' taper curves are also shown.

allowed the output level to be adjusted in a logarithmic fashion, rather than a linear one.

The way they first achieved this was to *taper* the cross-sectional area of the resistance element along its length, rather than keeping it constant. This gave a low resistance change at first, gradually increasing as the slider moved around or along. By making the taper a logarithmic one, the pot's adjustment law could be made logarithmic too. So that's how the 'log taper' pot came about. The basic idea of a log-taper wirewound slider pot is shown in Fig.1.

Pots with a standard linear adjustment law are still necessary for a lot of applications, of course, and that's why they're available too. They're sometimes called 'linear taper' pots, although that term is obviously a bit contradictory.

Now surprising though it may seem, modern 'log taper' pots generally **don't** have a true logarithmic adjustment law. That's because the 'tapered element' way of making volume control pots was very costly, so engineers soon worked out a much simpler and cheaper way to achieve a *rough approximation* of a logarithmic law. This was by making a carbon composition pot with the material used in the resistance element itself varying in composition, so the resistance at the start of rotation is low, and increases later to achieve a reasonable approximation of a taper.

In fact they soon discovered that quite acceptable volume control could be achieved using a pot with very close to a two-slope resistance element, with the transition at about 50% of rotation. This had the big advantage that the resistance elements of either rotary or linear-slider pots could be simply punched out of a strip of material coated with the two different compositions — low and high resistance. (See Fig.2 at lower left.)

Needless to say this approach lowered the cost of making 'log taper' pots considerably, so that's why the vast majority of these pots actually have this kind of 'rough approximation' logarithmic law.

The resistance/rotation 'curves' for linear, true logarithmic and 'log taper' pots are shown in Fig.3. Also shown are the curves for rotary 'reverse logarithmic' and 'antilog taper' pots, which are virtually the same as true logarithmic and 'log taper' pots but made for the opposite or *anticlockwise* operation. These are not common nowadays, but are still made for a few specialised applications.

Note that when pots with an accurate and truly logarithmic curve are needed, they're often still made using a wirewound element on a tapered former. Either that or a 'bulk metal' element with a carefully graduated zig-zag pattern.

Naturally the main use for common 'log taper' pots is for controls which need to adjust a quantity in an approximate logarithmic fashion — like audio volume controls. Linear pots are used for most other applications.

Resolution

The term *resolution* is used to refer to the smallest change in tapping ratio that can be made by moving the pot's wiper. Obviously it's an important point when a pot or trimpot is being to accurately adjust circuit operation.

The resolution of wirewound pots tends to be fairly poor, because the element is wound from discrete turns of resistance wire and the wiper contact can usually only slide from one turn to the next. The output of the pot therefore tends to vary in small regular steps, each corresponding to the voltage drop in one turn of the element.

Pots using an etched 'bulk metal' element tend to have a similar problem. However pots which use a carbon composition, hot moulded carbon or cermet element tend to have somewhat better resolution, because the resistance of their element is more finely graduated.

Needless to say another important aspect of resolution is the ease of actually moving the pot's wiper through a small distance, in order to make an adjustment. If you can't do that easily, the pot's electrical resolution tends to be academic.

So where resolution is really important, multiturn pots tend to be more often used than the single-turn variety.

Contact resistance

Another factor which has an effect on resolution is the *contact resistance* between the pot's wiper and resistance element. This also effects the **noise** which may be generated by the pot, both when it's being adjusted and when it's simply operating with a fixed setting.

Pots are made with a variety of wiper contact styles and materials. Many common carbon composition pots use a simple wiper stamped from nickel-plated spring steel, but with multiple 'fingers' to give parallel wiping contacts — and hence reduce contact resistance.

Higher power wirewound pots may use a wiper with a 'brush' made from a single small block of carbon, but the block is made with a loading of copper powder to keep the contact resistance as low as possible. It almost becomes a copper contact with graphite lubrication.

High grade pots with a cermet or bulk metal element generally have a multi-finger spring metal wiper of gold plated phosphor bronze or steel.

Many small trimpots of the cheaper variety have a simple spring metal wiper with a pressed 'dimple' contact which touches the element. This can be quite satisfactory when the trimpot doesn't get a lot of adjustment, but with frequent adjustment the contact resistance tends to rise.

Ganged pots

As you're probably aware, multiple pots can be combined so they're activated by the same control spindle. These are known as **ganged** pots. Generally only two pots are combined in this way, but it's possible to have more.

(By the way it's also possible to have two pots combined physically but so they're still adjusted separately, by means of concentric spindles — one inside the other. These are called **concentric** pots, and are made mainly for OEM applications.)

In most cases, the elements and their wipers of ganged pots are electrically quite separate, and brought out to their own terminals. They're simply designed to be adjusted 'in parallel', via a single control knob.

Generally ganged pots have identical total resistance values too, although it's of course possible to make them with quite different values if that's needed. This would normally require a special order from the manufacturer.

For many applications of ganged pots, it's important that the individual wipers closely follow each other in terms of their tapping ratio (for their respective elements). In other words, their *tracking error* should be as low as possible. This is largely a matter of quality control during manufacturing, to minimise mechanical tolerances.

Hop-on and hop-off

You'll find the terms 'hop-on resistance' and 'hop-off resistance' sometimes used in connection with pots, and you can probably almost guess what they refer to.

Most pots, whether they're of the rotary or linear-slider type, and regardless of the type of resistance element they use, tend to have metal contact strips at the ends of the fixed element. And the wiper contact generally touches and rests on these metal strips, when it's at either extreme of its travel. However when it's moved away from the extreme, it soon 'hops on' to the actual resistance element, and then ultimately 'hops off' at the other end.

Ideally the change of resistance ratio that occurs at these hop-on and hop-off points should be zero, so that there are no 'sudden changes' when the pot is used as a volume control, for example. However it isn't easy for pot manufacturers to achieve this; the best they can generally do is keep the hop-on and hop-off resistances below about 1% of the total value of the resistance element. This is so low that it usually can't be detected in most audio and similar applications.

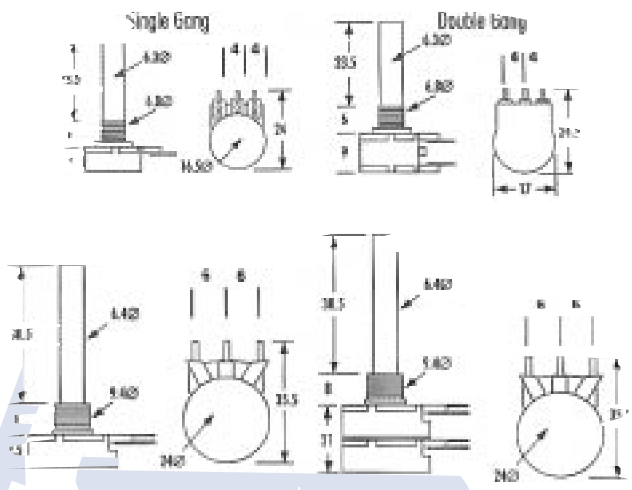

Fig.4: Key dimensions of the 16mm and 24mm rotary pot sizes stocked by Jaycar. Both single and dual gang versions are shown.

High grade pots with hot-moulded carbon, cermet or wirewound elements generally offer very low hop-on and hop-off resistance values.

Pot marking codes

As well as being marked with a character string indicating the total value of the resistance element — for example '100K' or '1M' — the case of a pot generally also carries a code letter showing its resistance taper or curve.

Nowadays most pots are marked according to the simplified taper coding system adopted by Asian component manufacturers:

A = log taper
B = linear taper

However in older equipment you may come across pots marked according to an earlier taper coding system. Note the potentially confusing differences:

A = linear taper
C = log or 'audio' taper
F = antilog taper