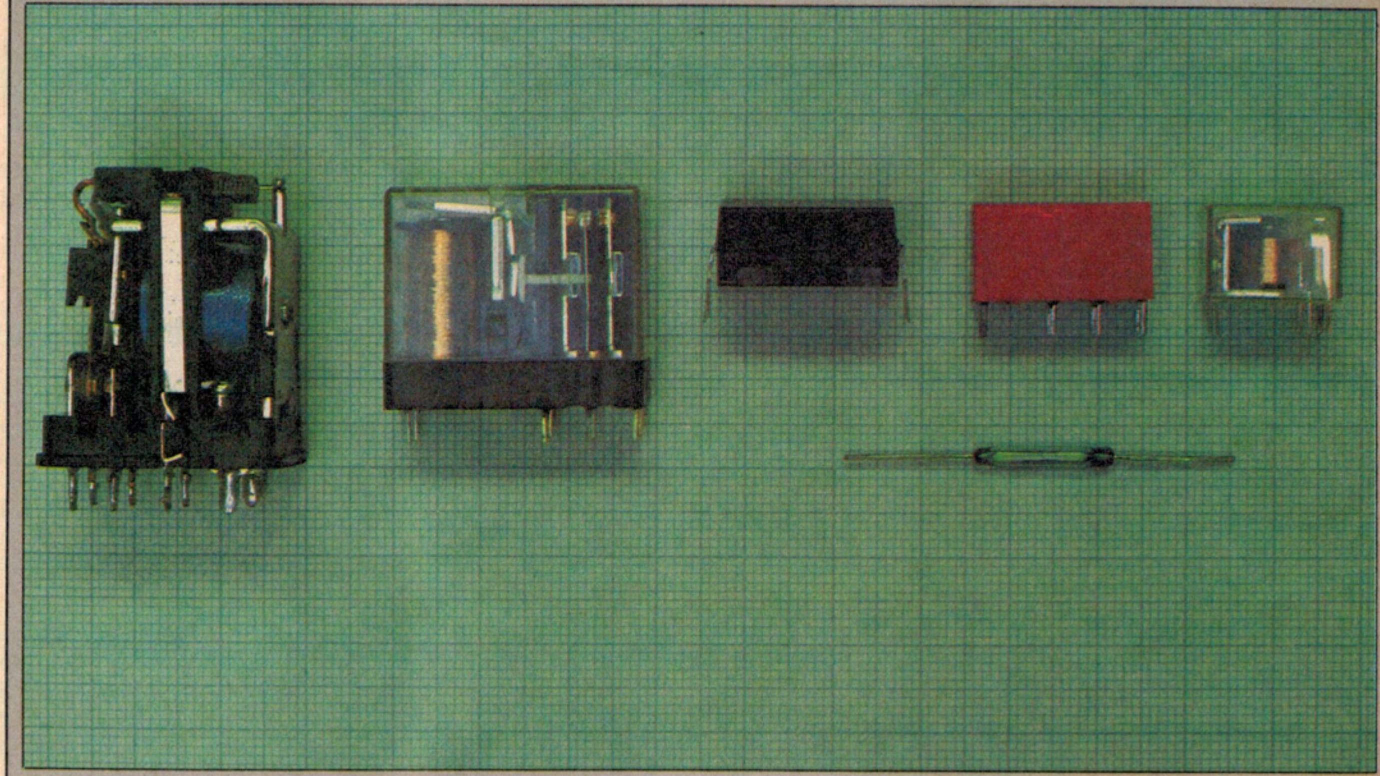
Everything you always wanted



While solid-state switches have now replaced electromechanical relays in many applications and types of service, there are still innumerable areas where the old-fashioned (?) relay still reigns supreme — and is likely to do so for many years to come. This feature covers all the theoretical and practical aspects of relay technology and includes a survey of all forms and types, from the common to the bizarre.

Collyn Rivers

UNTIL a decade ago, one of the most common electric and electronic circuit components was a partially mechanical device. That component was the electro-mechanical relay — typified by the Post Office type 3000. Tens of millions of these relays were made. They were, and indeed still are, used in applications as diverse as telephone network switching, industrial timers, burglar alarms, even computers.

The original Chain Home (CH) early warning radar systems — the vital system which helped the Battle of Britain pilots locate their enemy in World War II — each used thousands of relays in elementary computers which calculated the range of returning echoes. Those radar systems (still with relays) remained in active service until the early to mid-1960s.

Solid-state switches have long since replaced electro-magnetic relays in many applications and types of service, but there are nevertheless innumerable areas where 'old-fashioned' relays still reign supreme — and are likely to continue doing so for many years to come. Indeed the recent development of the printed circuit board mounting relay, directly drivable by TTL and CMOS ICs, and the hybrid relay (incorporating a solid-state input amplifier) has given the technology a new lease on life.

Relays (as we shall call them from here on) have a number of admirable characteristics. These include:

(1) Complete electrical isolation between input and output circuits.

(2) A huge range of resitance between switch-on/switch-off. When contacts are open circuit resistance is effectively infinite — when the contacts are closed resistance is a few milli-ohms.

(3) Many independent isolated outputs may, be associated with one input.

(4) Physical ruggedness. Most relays can withstand massive short-term overloads across both actuating and switching components.

(5) Relays are largely immune to electrical, radio frequency, and other forms of radiation — even at high levels. Mechanical vibration causes problems with most relays, but vibration and shock resistant models are commercially available — and used extensively in military applications.

(6) Actuating voltages and currents are relatively uncritical. Most relays will continue to work satisfactorily with coil voltage varia-

to know about relays

but never found in one place before

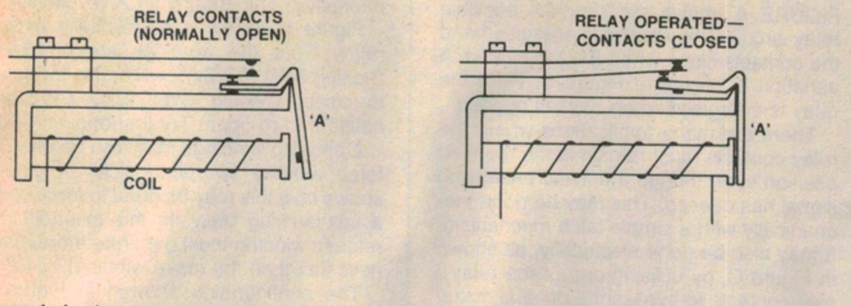


Figure 1. A relay with normally open contacts shown unoperated at left and operated at right. Note the over travel of the contact leaves. The armature is stopped by the core here.

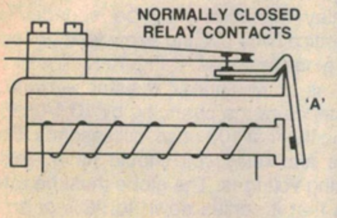


Figure 2. A relay with normally closed contacts. Note that the contact leaves are preloaded and the plunger on the armature operates the upper contact leaf.

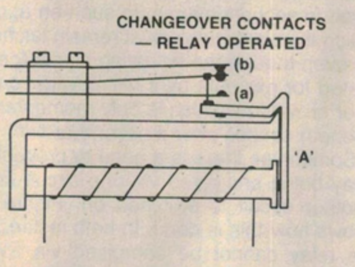
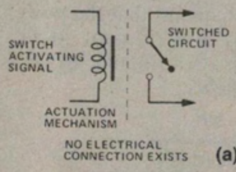
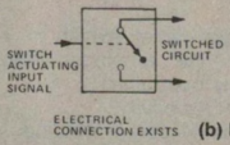


Figure 3. Relay with changeover contacts — one set of normally open contacts and one set of normally closed contacts. The armature is shown here in the operated position.



(a) Isolated switching



(b) Non-isolated switching

Unlike electromechanical switches, most solid-state electronic switches do not provide ideal isolation between the actuating signal source and the controlled source.

tions at least plus/minus 50% of nominal. Contacts too will generally withstand severe short-term overloads.

(7) Innumerable switching configurations are possible. Single actuators may be used to switch multiple sets of contacts — any of which may be 'normally open' or 'normally closed' as required.

(8) The operation of relays is largely self-evident and, for this reason alone, they are commonly used in equipment which must be maintained by non-electronically-trained staff. Fault finding too is simpler than with solid-state devices.

HOW RELAYS WORK

A relay is an electrically operated switch. The US Standard's Definition of Electric Terms defines a relay as "An electrically controlled device that opens and closes an electrical contact to effect the operation of other devices in the same or another electrical circuit".

The type of relay with which most electronics people will be familiar consists of an electromagnet, which, when energised, causes a movable armature to open or close one or more sets of contacts. The contacts in turn open or close external circuits.

There are however a vast range of relay types. The writer noted over 135 clearly definable types during the preparation of this feature. And most of those were available in an equally wide range of power ratings and contact configurations.

In the simplest of relays (one pair of contacts), one contact will usually be located semi-rigidly — it will have some degree of compliance. A second (moving) contact will be mounted on a moving arm — or on the end of a deflectable spring.

Figure 1 shows a typical arrangement — here the relay is 'normally open'. The contacts are separated until the relay winding is energised. When the winding is energised, the armature 'A' is attracted towards the winding core. The resultant movement causes the springs to deflect (according to Hooke's law) and the contacts to be pressed firmly together.

In practice, the springs deflect further than is required simply to make contact. This over-travel has several functions. It causes the spring/s to store sufficient energy to ensure a quick clean break when coil energisation ceases. The over-travel compensates for the increase in the gap between contacts as the contacts and other moving parts wear. The sliding motions entailed also cause the contacts to be largely self-cleaning. However, as will be described later in this feature, this sliding action introduces problems of its own in some applications.

Excessive spring tension is prevented by arranging for the moving armature to butt up against a stop (often the relay core) once the intended contact pressure is reached.

Figure 2 shows a 'normally closed' relay. In this example a mechanical pre-loading is applied to the springs so that the contacts are held firmly together in the 'off' position. Energising the coil causes the armature to push the contacts apart.

'Change-over' action is illustrated in Figure 3. Here a mechanical pre-load holds the moving contact against closed contact 'a' when the coil is not energized. Energising the coil causes the moving contact to be held against fixed contact 'b'.

The electromagnet

The force generated by the electromagnet must be sufficient to overcome all the restraining mechanical forces which include striction, friction, inertia, spring tension, sliding friction as contacts meet and close, and spring overtravel.

The generating force which is available may be shown as:

$$F = \frac{2\pi (NI)^2}{A(R_O + \frac{x}{A})^2}$$

where:

NI = ampere/turns

A = pole face area

x = distance between armature and core in unoperated state

R_O = reluctance of iron portion of magnetic circuit

It will be seen that for an electro-magnet of any given physical size the force depends upon NI^2. That is, the square of the solenoid's number of turns of wire and the current flowing through that wire.

The ampere/turns at which the relay just ▶

operates (contacts touch but springs not fully deflected) is known as the ampere/turns sensitivity. This figure has little practical value as it is independant of coil dimensions. (Having wound a coil the ampere/turns sensitivity is a measure of what you have done but gives no guidance as to how to go about it!).

A parameter of more practical value is the power required to just close the relay ($P = I^2R$). This is usually called the 'power sensitivity'. Power sensitivity depends upon the volume and proportion of available winding space occupied by the winding. As might be expected, if one thinks about it long enough, the ratio of the N^2/R is constant (N = number of turns, R = coil resistance). This ratio is known as the coil conductance and is symbolized as G_c.

Hence, $R = N^2/G_C$ and $P = I^2R = N^2I^2/G_C$ watts. Which means that the power required is inversely proportional to G_c. Coil conductance is determined by coil dimensions — as follows:

$$G_C = \frac{elh}{w \pi (d+h)}$$

where:

e = winding space factor (which = 1 except for very fine windings, then decreasing slightly thereafter).
w = winding wire resistivity.
l = length of cross section of winding.
h = depth of cross section of winding.
d = diameter of core.

The power required to close the relay varies inversely with winding length, and directly with winding depth. Which explains why energy-efficient relays (like the PO type 3000) are long and thin.

Depending upon the desired operating voltage and current, relays may be wound with many turns of fine wire, or few turns of heavy wire. The resistance may be calculated from wire tables by assessing the mean turn length. Here's a few short cuts — as long as you are using the B & S wire gauge system.

For a winding of any given dimension and density, reducing the wire size by one gauge increases winding resistance by approximately 60%. The same reduction reduces the current required (for equal ampere/turns) by 20% and the voltage by 25%.

Winding resistance tolerance will be +/-10%. This may increase to about 15% above B & S No. 45 (depending upon wire manufacturer).

Assuming optimum dimensions, the number of turns for any given wire dimension is determined by the current density. Heat build up and dissipation must be also considered.

For most applications relays have more or less optimum physical and electrical dimensions. If a relay is made substantially smaller, here's what happens:

(1) The winding provides fewer ampere/turns of magnetic force for the same power input, but more ampere/turns are required to provide the necessary magnetic pull.

(2) The windings cannot readily dissipate the increased heat caused by the higher current density. ▶

RELAY APPLICATIONS

FIGURE A shows the simplest possible relay circuit. The winding is energised and the contacts close when SW1 is closed. A variation is shown in Figure B. Here the relay is energised when SW1 is opened.

There are many applications where the relay contacts must remain in the required position even though the initial energising signal has ceased. This may be done mechanically with a simple latch mechanism. It may also be done electrically, as shown in Figure C, by utilising one of the relay's own contacts to bypass the original make/break switch which caused the relay to be energised originally.

Electrical latching is commonly employed in security alarms. In such an application the alarm relay must remain latched on even though the actuating signal (generated for example by a microswitch on a door or window which is only momentarily opened) ceases after a second or two.

Sometimes there is a need to prevent a relay being energised via one circuit until another circuit is switched off. Figure D shows how this is done. In both instances the relay cannot be energised via SW1 until SW2 is opened.

Figure E shows how a relay and capacitor may be used to form a simple but reliable high-current oscillator or flasher.

Relays lend themselves admirably to logic operations. Figures F a/b/c illustrate the simplest forms — using switches to operate a single relay. More sophisticated logic operations can be performed using multiple windings on the same bobbin. Figure G shows one version, in which either of the two windings generates sufficient force for correct operation. Thus closing SW1 OR SW2 closes the relay.

A variation of Figure G is to have each winding alone insufficiently powerful to operate the relay. Both are required to be energised. This then is an AND circuit.

Figure H shows a differentially wound relay. Here the windings are opposed. Closing SW1 OR SW2 will cause the relay to close. Closing SW1 AND SW2 will cause it to re-open. Try that one with ICs!

Opposing windings may also be used to force a relay to open quickly. Figure I shows how this may be done to force open a self-latching relay. In this example the release winding must generate more magnetic flux than the make winding.

The configuration showsn in Figure J uses relays of differing sensitivities. Closing SW1 will energise the high sensitivity relay RL1, but not RL2. Switch SW2 shorts out the current limiting resistor R1 and brings in RL2.

Relay actuation may be speeded up dramatically by placing a low voltage tungsten globe in series — Figure K. The globe acts as a non-linear resistor — with a resistance range changing by 10:1 or 15:1 during the first 100 or so milliseconds. Both globe and relay coil should have similar working voltages. The globe must be rated such that it settles down to 90% or so of normal brilliance (for long-term reliability). The combination should be driven by a supply of approximately twice the relay's normally recommended working voltage.

Relay actuation and release may be slowed down by adding a few simple components. Figure La/b/c shows how. Triggering currents may be reduced to mere microamps by adding a simple transistor or IC amplifier — see Figures Ma/b/c. Relays such as this are also available commercially. ●

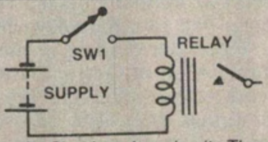


Figure A. Simple relay circuit. The relay is energised when SW1 is closed.

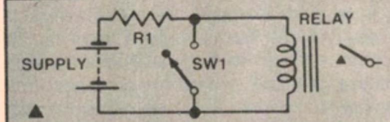


Figure B. In this configuration the relay is normally held closed and is opened when SW1 is closed.

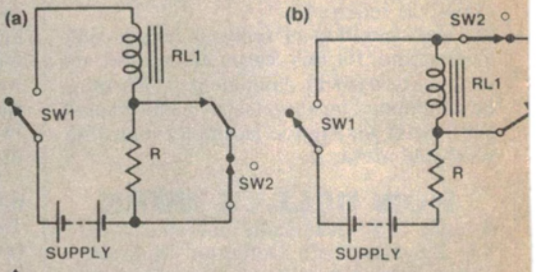


Figure D. These two configurations are commonly used safeguarding electrically powered machinery. In neither instan can relay RL1 be energised, by closing SW1, unless SW2 is fi opened.

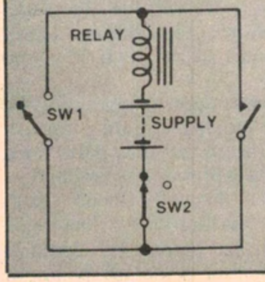


Figure C. Electromagnetic latching circuit. When SW1 is closed a second set of relay contacts close, by-passing SW1. The relay will now remain latched on until power is removed (by opening SW2).

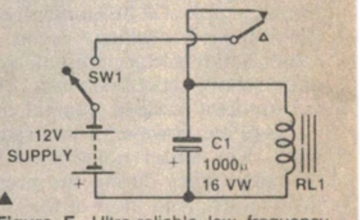


Figure E. Ultra-reliable low frequency oscillator/flasher.

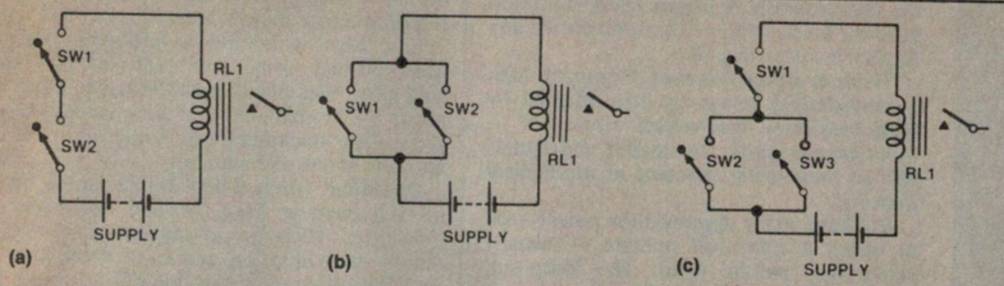


Figure F. Relay logic circuits, (a) relay closes when SW1 AND SW2 are closed, (b) relay closes when SW1 OR SW2 are closed (c) relay closes when SW1 AND SW2 OR SW3 are closed.

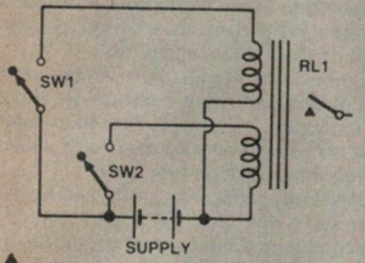


Figure G(a). Either of the two windings can generate sufficient force to close the relay contacts — hence closing SW1 OR SW2 will actuate the relay.

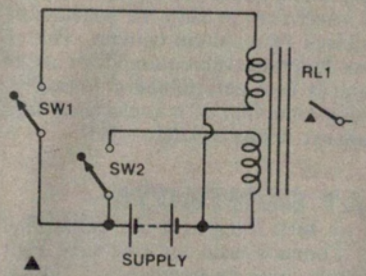


Figure G(b). In this variation neither winding alone is sufficiently powerful to operate the relay. Both are required for actuation. Thus SW1 AND SW2 must be closed.

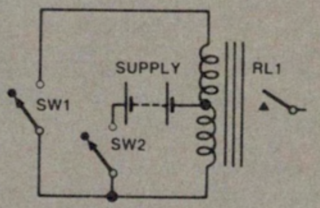


Figure H. Here the two coils are wound in opposing directions and either has enough power to close the relay. Thus closing SW1 OR SW2 will close the relay, but as the windings are in opposition closing SW1 AND SW2 will cause the relay to open again!

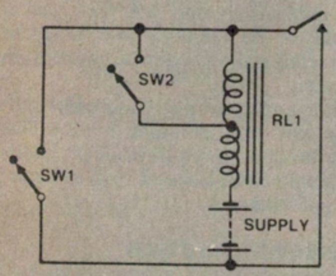


Figure I. An opposing polarity winding is used to force the relay open (overcoming the self-latching function) when SW2 is closed.

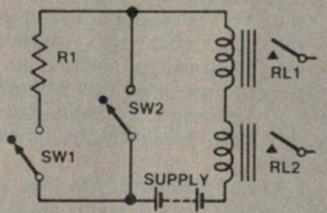


Figure J. Sequential switching. Closing SW1 will energise the sensitive relay RL1 but not the general purpose relay RL2. Switch SW2 shorts out the current limiter R1 and closes RL2.

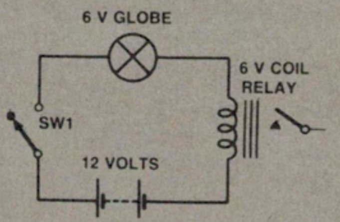


Figure K. Speeding up relay actuation — see text.

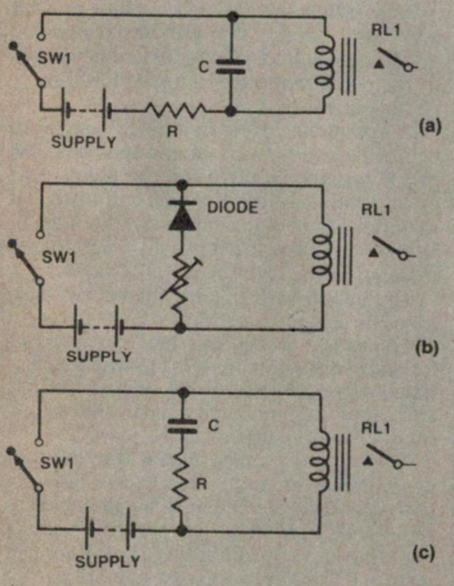


Figure L. Adding a few components slows down relay operating time. (a) slow to operate, (b and c) slow to release.

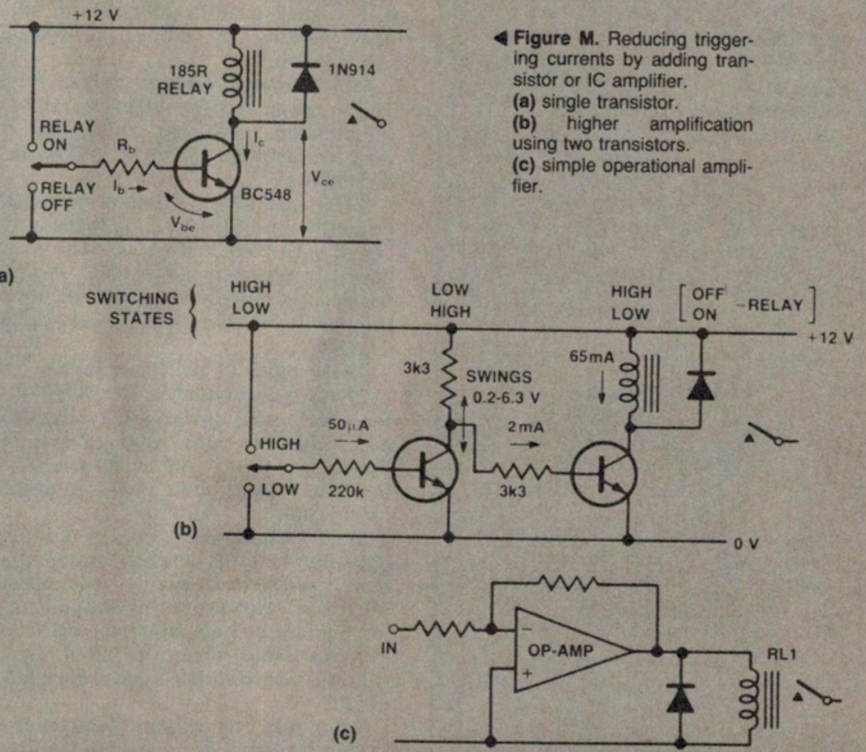


Figure M. Reducing triggering currents by adding transistor or IC amplifier.
(a) single transistor.
(b) higher amplification using two transistors.
(c) simple operational amplifier.

RELAY CHARACTERISTICS

Normally open relays are fairly predictable. Their pick-up levels can be adjusted accurately and will be maintained over long periods. Drop-out performance is less stable and cannot be predicted or sustained with any real accuracy.

There will be some bouncing as contacts come together — this may cause RF interference, and will introduce problems in counting applications (overcome by using a monostable). Relay designers attempt to minimize contact bounce by introducing a damping wiping motion — which also serves to clean the contacts.

Normally-closed relays are less predictable. They become unstable as the winding current approaches the pick-up level and may 'hunt' around the just-operated point.

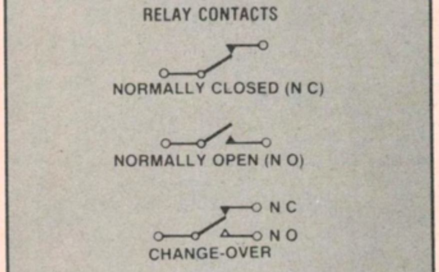
Both types of relay will exhibit erratic pick-up and drop-out behaviour if the circuits switched have large current transients. These may cause the contacts to stick.

Closing time is determined almost entirely by the time required for winding inductance to build-up the field — five to 50 milliseconds is typical of sensitive relays. The time required for the hardware to move is usually negligible by comparison (1-5 milliseconds).

Operation may be sped up by increasing operating voltage; increasing operating voltage yet further **and** adding series resistance (this reduces the circuit inductance/resistance ratio); and by reducing spring tension and contact gaps.

For **drop-out** there's normally a delay of a few milliseconds after winding current falls below the hold level. This will be decreased by as much as ten times if the coil is shunted by a diode (for instance to eliminate back-emf).

Most general purpose relays will operate reliably over a voltage range of at least 2:1. Many will tolerate even wider variations. Many aspects of performance however become less predictable and less accurately repeatable as the upper and lower limits of acceptable operating levels are approached. ●



Relay contacts. There are three fundamental relay contact arrangements: normally open (N/O), normally closed (N/C) and changeover.

(3) The armature is magnetically saturated at lower levels of force thus preventing any further increase in pull.

There is a plus however. Compact, high current-density relays are less affected by high frequency mechanical vibrations — their moving parts are smaller and lighter due to their lower moment of mechanical inertia.

We have so far discussed the power level at which a relay will operate — usually called the 'pull-in' level. The 'drop-out' level too needs to be considered.

A relay drops out at that level of power which is insufficient to carry the mechanical load required to maintain contact. This is much less than the level required for energisation and is best determined empirically, there being a number of non-electrical factors (measure it you turkey! — Ed).

RELAY CONTACTS

There's no such thing as a universal relay contact. Contacts used for switching high currents rely upon an opening and closing arc to keep them free of contaminants. Were that same contact material to be used for dry load switching, the contacts after only very few cycles, would close physically but not electrically.

Fine silver is often perceived as the best of all contact materials — certainly it has the best electrical and thermal properties of all common metals. Unfortunately silver is seriously affected by sulphidation which forms a high resistance film on the contact surfaces.

A further problem with fine silver contacts is that they tend to stick and weld together — ending the life of the relay — and sometimes that which the relay was controlling!

The problems of sticking and welding are largely overcome by combining fine silver with a small quantity of cadmium but this does nothing to reduce resistance to sulphidation.

Minor arcing, and high contact pressure can be advantageous. Arcing burns off the sulphidation, and high contact pressures (and the resultant sliding action) scrubs off the residue.

Silver and silver cadmium contacts are primarily used for switching loads of a few amps at 12 volts and above. The material has fairly high contact resistance — a potential drop of 0.2 volt is typical for normally sulphided silver and silver-cadmium contacts.

These types of materials should not be used for audio circuits. The sulphide film tends to capture dirt particles — which generate noise as signal voltages attempt to break them down. The inexorable sulphide build up renders these contacts unsuitable for intermittent operation.

Gold-flashing silver contacts reduces sulphidation to levels which are acceptable for more low-level switching — intermittent or otherwise. However, this flashing is destroyed if the contact ratings are exceeded — even for a short time. The initial resistance is lower than with most other unplated materials.

Solid gold contacts are sometimes used for low level and dry switching but are very prone to sticking if cleaned to the degree required to obtain low resistance contact.

Low level switching is probably best accomplished using gold-platinum-silver; gold-silver-nickel; or gold-diffused silver alloys — in that order of excellence and price. The maximum rating for all three alloys is about one ampere.

Palladium (from the platinum family of metals) contacts have excellent low-noise properties. They are not subject to sulphidation or oxidisation and have good longevity — about ten times that of fine silver.

On the other hand, palladium is particularly susceptible to the formation of insulating polymers if the contacts are used in very low level or dry switching circuits.

The conductivity of palladium is poor and because of this palladium contacts are limited to switching currents of less than five amps or so. Palladium contacts are used extensively in telephone-type relays.

An excellent general-purpose combination is to have one pure palladium contact and a second palladium contact coated with a 0.025 mm (0.001") 22 carat gold overlay. This combination is as equally suitable for low level and dry loads as for medium levels of power.

Tungsten is commonly used for high voltage/high current applications. It is however prone to oxidisation and for this reason (particularly in dc circuits) one tungsten contact is often paired with one palladium alloy contact.

Paralleling contacts hugely increases reliability for low and medium loads. This should not be done though for heavy loads — where single contacts tend to give better all-round peformance.

The switching action

As relay contacts close, a number of tiny areas of metal deform, elastically or plastically, until the total area is sufficient to support the contact force. (This initial deformation is one of several factors that cause contact bounce).

And, if the contacts are switching any but very light loads, the initially contacting metal areas will for a brief instant be heated to the point where the metal will boil — or be vapourised.

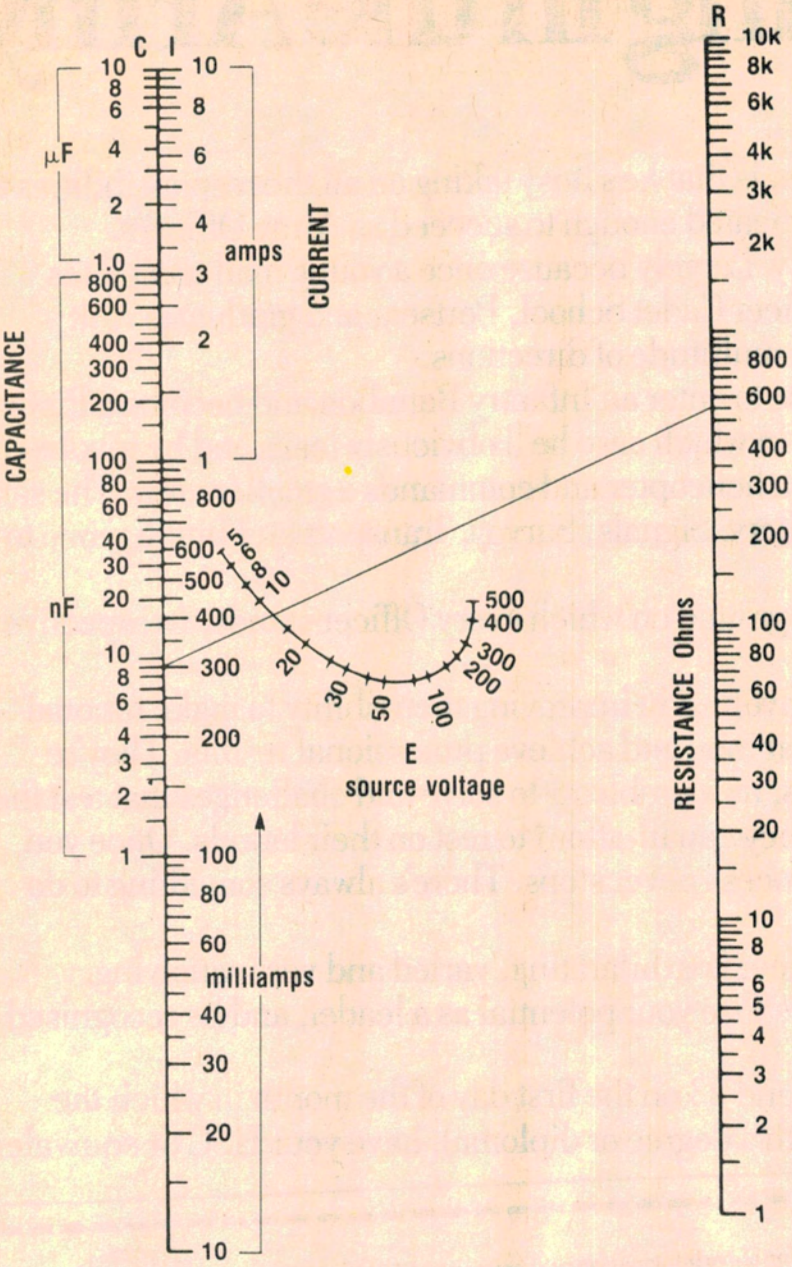
A microscopic weld or 'bridge' may even be formed, and with dc circuits this will break asymmetrically when the points next open (and causing a minute transfer of material from one contact to the other). With ac circuits there is usually a nett loss of material in the form of metallic vapour.

The heating effects described above also occur as contacts open.

Controlled arcing can be advantageous for some contact materials in some applications. The arcing burns off sulphur, oxides and other contaminants which build up on some contact materials.

Nevertheless, whilst useful for this purpose, arcing for more than a few milliseconds is destructive and must be quenched as rapidly as possible to prevent contact material loss (to atmosphere) and contact material transfer from one contact to the other. These problems are minimised by using the arc suppression techniques described elsewhere in this supplement.

Whilst contact arcing cures some prob- ▶



R-C QUENCHING

This nomogram will give you the resistor and capacitor values for simple series R-C quenching of relay contacts for dc and ac sources switching resistive or inductive loads.

For dc applications with resistive loads the source voltage, E, is the supply voltage and the current, I, is the current flowing in the load immediately prior to opening of the relay contacts.

For ac applications with resistive loads, the source voltage, E, is the peak value of the supply and the current, I, is the peak value of the load current.

For inductive loads E is the overvoltage produced by the current interruption (can be measured with a CRO) and the current, I, has to be calculated from this voltage and the resistance of the load.

To use the nomogram, run a straightedge between the load current and the source voltage, right across to the resistance scale. The capacitance to use is adjacent to the load current, the resistance to use can be read from the scale. The example shows a 300 mA load current being switched from a 12 V source. The capacitance indicated is 9 nF (use 10 nF) and the resistance about 550 ohmss (use 560R).

Minimum resistance to be used is half Ohm, minimum capacitance is 1 nF. For E less than 70 V, R may be three times the indicated value; for E between 70 and 100 V, R may be ±50% of the indicated value; for E between 100 and 150 V, R may be ±10% of the indicated value and for E greater than 150 V, R may be ±5% of the indicated value.

$C = \frac{I^2}{10}$ μF (dc; for ac, use peak values) $R = \frac{E}{10\,I^x}$ where $x = (1 + \frac{50}{E})$

Nomogram from AMF Inc.

Figure 5.

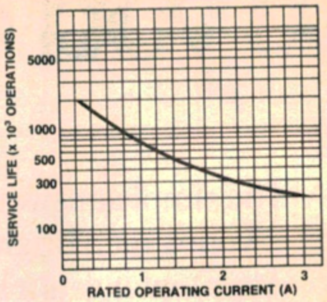
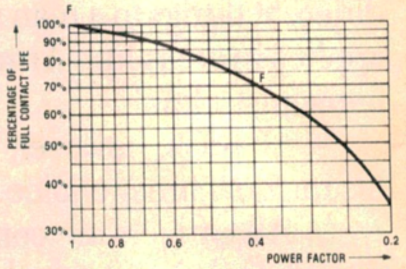
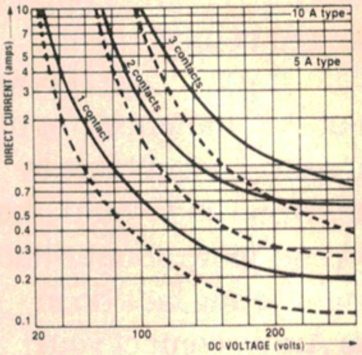


Figure 4. Graph shows how contact lire can be extended by reducing contact load for a typical power relay. This relationship does not necessarily exist for low current relays — nor necessarily for power relays used at voltages or loads insufficient to generate slight arcing.



CONTACT LIFE, INDUCTIVE LOADS

Where a relay is required to switch inductive loads, increased contact wear due to arcing reduces contact life. This reduction is shown in the diagram here. You can obtain the actual contact life compared to the full contact life (quoted for operation on resistive loads) from this diagram if you know (or can calculate) the power factor of the load.



CONTACT BREAKING CAPACITY

This diagram shows the maximum dc breaking capacity for two differently rated relays versus circuit voltage for resistive loads (solid line) and inductive loads (broken line, L/R ratio less than or equal to 40 ms). The 10 A type, rated to break 10 A at 24 V, can only break 0.5 A at 100 V where a single contact and a resistive load is involved. On an inductive load with a time constant of 40 ms it can only break 5 A at 30 V, 330 mA at 100 V. If the relay has several contact sets, connecting the contacts in series can greatly increase its braking capacity at voltages above the rated voltage, but not the maximum breaking current. With two contacts in series, the 10 A relay will break over 2.5 A at 100 V (resistive) or 1.5 A (inductive). With three contacts in series, the 10 A relay, initially rated at 24 V, will break 100 V.

lems it introduces another. It carbonises organic material that has become adsorbed or condensed on the contact surfaces.

At most relays' designed ratings the levels of voltage and current being switched are high enough to break through these carbonised deposits and contact/contact resistance will remain more or less constant throughout the relay's rated life. But these deposits can and do cause problems if a relay is used to switch (low current) loads substantially below the relay's rated level.

Softening voltage

Once the contact points have closed the voltage drop across them causes their temperature to rise. This causes the contact area to soften and increase, and any molecular thicknesses of material trapped between them is vapourised.

At this point, resistance is reduced to fractions of a milli-ohm and becomes stable regardless of further increases in current up to and beyond the relay's maximum load rating. This phenomena begins to occur at quite low temperatures — for gold it begins at about 100 °C, and for silver at about 180 °C. The respective voltage drops are about 0.09 V and 0.08 V respectively, dropping as temperature increases.

Dry loads

Some applications involve switching circuits in which power is not made or broken by the contacts — that is, current flows and ceases flowing after the points close and before they open again. Circuits such as these are known as 'dry'.

The majority of problems with such circuits are likely to be found where very low levels of current are switched. Organic film and particulate contamination are the primary cause of these problems.

Light loads

Light loads present slightly different problems, particularly with platinum contacts. As with all relay contacts, microscopic sliding occurs as the contacts are pressed together. Here, the heat thus generated is sufficient to polymerize the organic material adsorbed or condensed on the contact surfaces. The resultant substance (a powder) causes high and varying levels of resistance. The only solution is frequent cleaning.

Platinum contacts are best avoided for these applications: gold or gold-palladium alloys are much better. They are almost totally immune from polymer formation.

Intermediate loads

Switching intermediate loads is undesirable. The voltage and current is insufficient to break down deposits and in such conditions contact/contact resistance will increase almost immediately. Many circuits will be able to tolerate the resistance build up but it can cause problems in marginal applications. The worst possible conditions are where the contacts must switch both high and low levels of voltage and current.

Heavy loads

Most relay manufacturers quote contact ratings at their product's designed maximum loads (or close to them). Minor derating may increase contact life, but not dramatically. Reducing the load to 20% of nominal rating typically increases contact life 10 times for power relays — see the accompanying graph, Figure 4.

It is important to note that the total current switching capacity of multiple contact *power* relays cannot be increased by paralleling contacts. The individual contact sets will not pick up and drop out simultaneously.

As contact loads and operating termperatures increase, there is an accompanying increase in the precipitation of solid carbon or carbonaceous debris on the contact surfaces. However the switching currents and voltage that cause this buildup to occur are usually also high enough to maintain relatively clean low-resistance contact in local contacting areas.

Cleanliness will also be assisted if the relay (ideally just the contact area) can be housed separately from the remaining components. This reduces exposure to volatile hydrocarbons, the liberation of which is assisted by the heat generated by high power equipment.

Gold and gold alloy contacts should be avoided for switching loads higher than 0.5 ampere unless ultra-low contact/contact resistance is essential — their erosion rate accelerates over such loads. Silver, silver alloys, silver cadmium oxide and palladium are best.

Protecting contacts

Relay contacts generally operate most satisfactorily at or close to their designed rating. But this is not always possible. In some applications current surges will occur at the worst possible time — just as the contacts initially open or close.

This will occur when switching tungsten lamps, ballasts, solenoids, relay windings(!), electric motors and capacitors. With such loads, the initial surge current may be from five to twenty times the steady state load and relays must be specified accordingly.

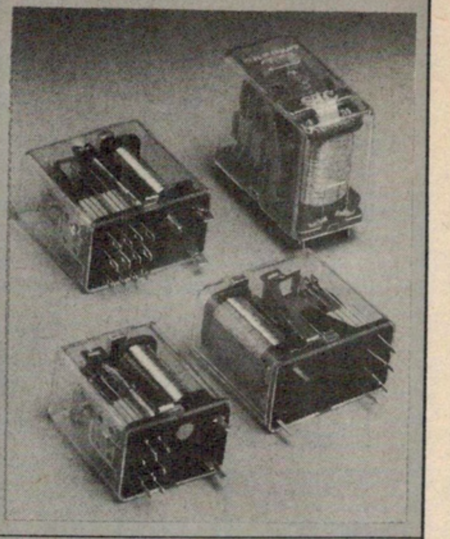
In these applications it is particularly necessary to use heavy duty contacts and/or high contact pressures, and with actuating mechanisms that inhibit contact sticking or welding.

Contact protection with *resistive* loads is relatively simple. A capacitance wired across the contact points (and as close to them as is practicable) will prevent any appreciable arc from forming as the contacts open. A low-value resistor placed in series with the capacitor prevents the capacitor being discharged rapidly through the contacts (and thus causing an arc) as the contacts reclose.

The accompanying nomograph (Figure 5) shows the optimum values of resistance and capacitance for various applications.

Inductive (dc) loads cause quite severe problems when the circuit is opened, for much of the stored energy will be dissipated as heat (in the form of arcing) unless an alternative path is provided.

The most common method of protection is to connect a diode across the inductive load — Figure 6 — with polarity arranged so that the diode blocks the current at con-



HISTORY

THE electromechanical relay was developed in the mid-1830s — for 'relaying' telegraph signals over long distances.

In 1837 Cooke and Wheatstone patented an electromagnetic relay for remote actuation of a signal bell (British patent No. 7710).

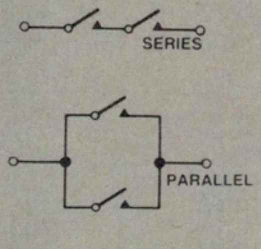
Edward Davy gained a patent (No. 7390), for a 'telegraphic relay' a year later. Davy opposed the granting of the Cooke and Wheatstone patent, but his objection was overthrown. Nevertheless, J. J. Fakie in his book *'A History of Electrical Telegraphy in the Year 1837'* London 1884, noted that Davy was working on electrical telegraphy as early as 1836.

In the USA, Morse was granted a patent (substantially similar to Davy's) in 1840 — US Patent No. 1647.

Davy in his patent wrote "I claim the mode of making telegraph signals or communications from one distant place to another by employment of relays of metallic circuits brought into operation by electric currents."

That's how relays came to be so-called.

SERIES PARALLELING CONTACTS



Series. You can connect contacts in series to reduce the effects of arcing and to improve voltage rating; however, contact/contact resistance increases and may affect current rating.

Parallel. Connecting relay contacts in parallel should only be done to improve reliability. It will not affect current rating as the contacts will not open and close simultaneously. Thus, the rating of one contact alone will apply.

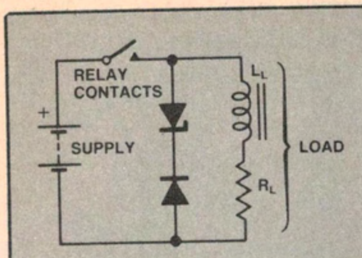


Figure 6. Protecting contacts against inductive loads (optional), Zener diode speeds up release time. ▲

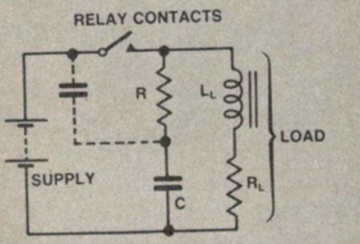


Figure 7. One method of protecting contacts against inductive loads — see main text for values. ▲

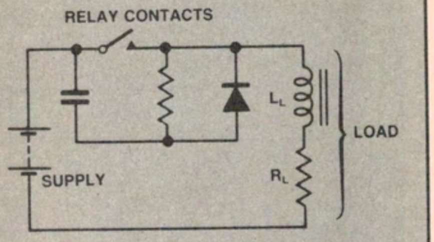


Figure 8. Alternative method of protecting contacts against inductive loads. ▲

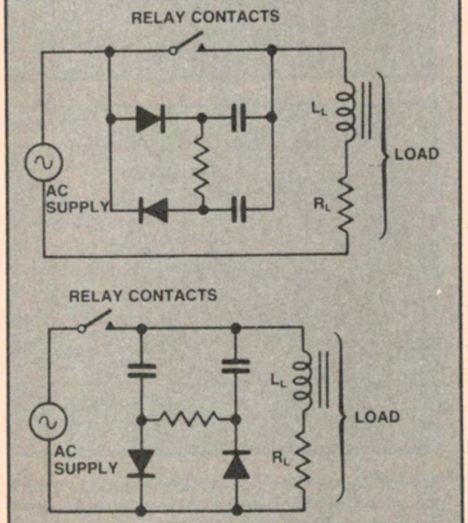


Figure 9. These two arrangements will provide almost 100% protection, even with massively inductive loads. ▲

tact closure but allows the stored energy to be conducted through it when the relay contacts open. This arrangement will usually speed up release time. An even faster release may be obtained by wiring a zener diode in series with the protection diode.

Another method is to connect a varistor across the contacts or the load. This switches from a very high resistance to a very low resistance when the back emf exceeds the varistor's clamping voltage.

Yet another alternative is to wire a resistor/capacitor network across the load or the contacts. The capacitor should be about one microfarad per ampere switched, and the resistor should either match the load (but not exceed it) or be about 0.5 to 1.00 ohm per volt switched — see Figure 7. The resistor should be a bit higher in value for small load currents (insufficient to cause a stable arc).

In critical applications the combination of resistor, capacitor and diode (Figure 8) will provide virtually 100% protection. In this arrangement the capacitor charges via the diode and discharges via the resistor. Circuit values remain as for the simpler resistor/capacitor combination but care must be taken to ensure that the capacitor and diode are of adequate working characteristics.

A further technique, used occasionally with relay coils, is to add a second but short circuited winding. The resultant damping effect attenuates the rate of change of magnetic flux in the iron core and thus the level of induced voltage.

Another nasty to watch out for is distributed line capacitance. Problems may occur if a relay is located remotely from the load to be switched. Here the line will act as a capacitor and will charge up the instant the relay contacts close. This capacitance will be seen by the contacts as an initial short circuit and contact current will flow accordingly.

Alternating current circuits

Particular care needs to be taken when switching electric motors. Starting currents are commonly 500-600% of running on-load currents. Thus a ⅓rd horsepower motor, requiring an amp or so on load, may draw over six amps during start-up.

Transformers can be especially tricky during circumstances which inevitably will occur from time to time. When power is removed, the transformer core may retain remanent magnetism. If power is re-applied at such a point on the ac waveform where voltage is of the same polarity as the remanent magnetism, the transformer core may saturate during the first half-cycle of that re-applied power. Because of this, inductance will be virtually non-existent, impedance will drop to little more than the dc resistance of the winding. The resultant in-rush current may be 1000% or more of normal and will continue until the core comes out of saturation some few cycles later.

There's *worse* yet! It happens when power is re-applied at or near the zero cross-over point. If that occurs *and* the increasing voltage is of the same polarity as the remanent magnetism, both the core *and* the air gap may saturate. And if that happens the in-rush current may be as high as **4000%.**

Surges of such magnitude generate severe electromagnetic and RF interference — which can destroy or damage other circuit components. The surges also stress the transformer windings and laminations both mechanically and thermally.

The above comments may assist those misguided folk who've used zero-voltage switches to control inductive loads. For, totally contrary to general belief, the best point at which to switch a transformer is at the peak of the sine-wave.

The above phenomena has only recently been noted. Readers who wish to pursue it further should read *Inductively Loaded SCRs Control Turn-on to Eliminate First-Cycle Surges,* Electronic Design, March 15, 1979. Also, *Controlling Transformer In-rush Currents* EDN, July 1966; and *The Great Zero Cross-over Hoax* NARM Proceedings, May 1974. (Further features on this and allied problems associated with SCRs, Triacs, and zero-voltage switching, also written by Collyn Rivers, will appear in ETI shortly).

Contact life in inductive alternating current circuits may be significantly extended by connecting a resistor/capacitor across the load for low voltage circuits (up to 48 volts), and across the contacts for voltages higher than that. The time constant should approximate that of the load. Note though, that for this form of protection to be effective, the impedance of the load must be substantially lower than that of the capacitor/resistor.

Better protection will be afforded by the arrangement shown in Figure 9. Diodes must be 800 volt peak inverse rating, and the capacitors (about 1 μF/amp) 400 volts dc. The resistor should be 100k/2W or thereabouts. This arrangement is also particularly effective for reducing RF hash.

As has been shown, the life of a relay is not necessarily related to the switched load. Power relay life is generally extended by derating (a reduction of 500% in load current switching will typically extend life from 10^5 to 10^6 operations). However for many other applications, derating may actually *decrease* reliability.

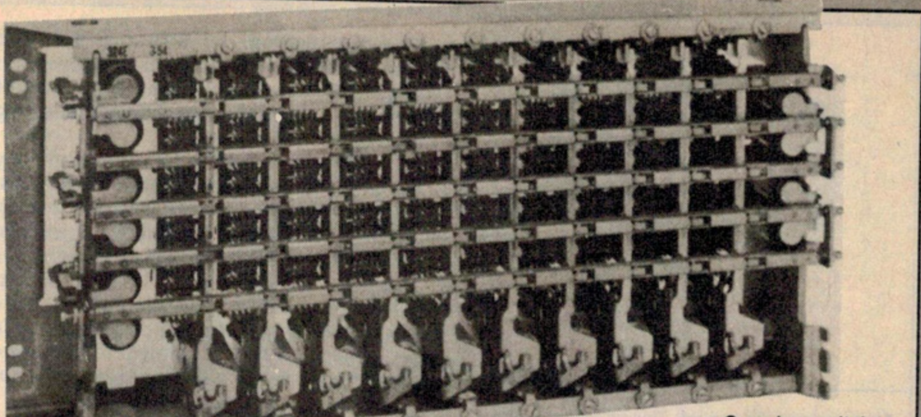
Where load conditions are unusual it is best to obtain advice from the relay manufacturer. Correct maintenance helps. Here again, the manufacturers' advice should be followed. Different contact materials require quite different cleaning methods and fluids. Each will absorb mono-molecular layers of volatile molecules.

As a general guide, avoid the use of lubricants, abrasive cleaners and files unless specifically advised to do so. Don't even *think* of adjusting spring tension or gap size unless you have exact instructions or work for Telecom!

In critical (non-power switching) applications, reliability will be enhanced enormously (typically five or more orders of magnitude) by wiring two separate contacts in parallel.

A really worthwhile tip (where circuits allow) is to arrange such that the most frequently touched parts are at earth or zero potential. This should reduce damage if your screwdriver slips! ▶

RELAY TYPES



Crossbar switches: these relays make connections across a grid or matrix. They are still used for this purpose in many telephone exchanges.

There are well over 100 different types of relay. Most are produced with a wide choice of actuating and switching levels, contact configurations, ac or dc operation, and commercial or military standards of construction.

Most of the material in this feature relating to coil windings and contact materials and characteristics applies to the relays described in this section — any anomalies should be obvious.

AC: ac-energised relays are similar in construction to dc relays. however as an alternating current, by definition, passes through a zero value each half-cycle, the magnetic field generated by an ac-energised winding will likewise have corresponding zero values each half cycle of applied alternating current.

It is necessary therefore to ensure that the relay armature remains closed as magnetism falls away during every half cycle of the energising input. This may be done crudely but quite effectively by making the armature so heavy that it is held in position by sheer inertia!

A second and somewhat more elegant way is to use two windings — each on a separate core — and each connected out of phase with the other.

A third method uses a heavy copper ring acting as a shorted turn. The energizing ac in the main coil winding induces a current in the copper ring. This current lags the main coil winding current and consequently passes through zero sometime later — thus there is always some magnetic pull available to hold the armature closed.

AC relays are generally used in non-critical applications. They are unsuitable for complex switching circuits, or for applications where timing is critical.

Balanced Armature: these relays have armatures which are pivoted at their centres of mass. they are in a state of equilibrium in respect to external static and dynamic forces and hence they are relatively immune to vibration and shock loadings.

Balanced armature relays are produced in a wide range of types and sizes.

Crossbar switching: these are multi-contact relays and switches used for making and breaking connections across a grid or matrix. They were/are primarily used in earlier telephone exchanges (Figure 10).

Current Sensing: nowadays generally replaced by solid-state triggering circuits, these relays operate reliably at pre-set current levels. A 'snap action' mechanism is generally included to prevent contact chattering or creeping. Thermal mechanisms are also used for sensing and switching current — these devices respond to the heating rather than the electromagnetic effect of the energising current.

Delay-slugged: opening and closing time is delayed by up to half a second by placing a large copper collar around the winding. This delays the build-up and collapse of operating magnetic flux.

The same effect is also achievable electrically by using a capacitor/resistor network with a conventional relay.

Differential: these have two or more windings which are most commonly employed in simple logic operations — AND, OR, etc. Diffential relays may also have a 'polarised' action. These will be arranged such that the direction of armature and contact movement depends upon the polarity of the coil voltage/s, either from a 'centre-off' or bistable positions.

The next two relays really do exist — to the surprise of your otherwise erudite editor! They also add a certain charm to the discipline.

Electrostatic: These are delightfully and totally basic — essentially a pair of moving capacitor plates (to which contacts are mechanically linked) and arranged so that charge forces move the plates together or apart.

Naturally, these relays only work at very high voltages, but they work equally well on ac or dc, responding to the rms value with ac. They have to be seen (preferably from a safe distance) to be totally believed.

Electrostrictive: perhaps not as rare as electrostatic devices but still not seen every second day. These utilise the movement generated across a piezo-electric crystal (or a ferro-electric material) when the material is subject to an electric field.

They have a number of unusual and endearing characteristics. Efficiency is one. Piezo-electric materials behave rather like capacitors (which in effect they are) so that energy requirements are limited to charging the devices. This may be done by one big pulse or a series of little ones. The relay then remains closed until the charge across the crystal leaks away internally (or via an external resistance). Operation is limited to dc.

High Speed: actuating speeds of less than a millisecond are obtainable primarily through the use of low mass, low moments of inertia, low eddy currents etc.

Within limits, relays may be sped up by driving the windings at their highest rated voltage or current. A very effective method, once used by the writer to speed up a 12 volt power relay, was to connect a 12 volt tungsten lamp in series with the winding, the whole then being run off 24 volts.

The lamp has very low resistance for the first 50-100 milliseconds (dropping about 1.5 volts across itself). Thus the relay is initially hit with close to 24 volts. The voltage then falls to the designed level as the globe reaches operating temperature.

Relays may also be sped up by driving the windings from a low-impedance source. Bear in mind though that excessive speed may result in equally excessive contact bounce.

Ac relays can be sped up in similar ways, but operating speed will generally have a random aspect as there is rarely any way of knowing at which point on the ac waveform the relay winding will start to become energised.

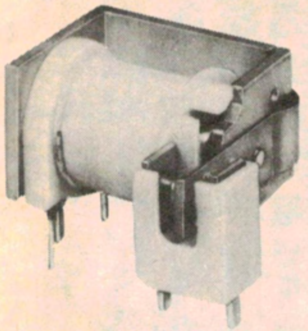
High voltage: these relays switch up to 10 000 volts at one amp or so alternating current, or about 0.2 amp dc. They may also be used to switch lower levels of voltage but in circuits working at very high voltages above earth.

Apart from the obvious requirements, such as high dielectric strength insulation, high voltage relays have large contact gaps plus rounded and polished conductors to reduce corona discharge.

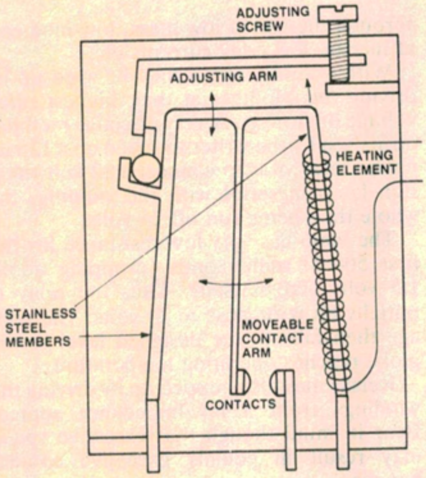
Power requirements are much higher than usual — 5 watts dc or 25 volt/amps ac being typical.

Hot wire: this type of relay uses the linear expansion of a length of wire, heated by the current passing through it, to open and close a set of contacts.

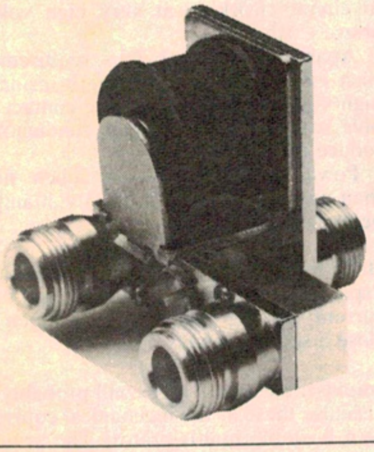
Impulse: electronic types will probably best visualise these as the mechanical equivalent of a bi-stable multivibrator! The armature and contact movement is such that they move sequentially from a first stable position to a second stable position each time the winding is energised.



High current, pc mount. This pc mount Potter & Brumfield relay (from Technico), shown about twice life size, will switch 30 A.



Linear expansion relay: current flowing through the heating element on the right hand member of the otherwise symmetrical metal yoke causes that member to expand differentially. The resultant movement is mechanically amplified causing the contact to open or close at preadjusted current levels. Changes in ambient temperature are automatically compensated for by the bi-symmetrical construction.



Coaxial relay. This RF switching relay is a coaxial changeover type that preserves the input/output impedance of 50 ohms by means of its special construction.

Linear expansion: as with the hot wire relays described above, the linear expansion relay relies upon the linear expansion of materials to provide a mechanical switching action.

A common type of linear expansion relay has two (mechanically identical) rigid metal arms around one of which is wound a heating element (Fig 11). The energizing current flows through this winding and thus heats up one of the two arms. The resultant expansion is multiplied by a simple but precise linkage and causes a set of contacts to open and close. Changes in ambient temperature affect both arms in a similar fashion — thus providing automatic compensation.

Low-level: used to switch 'dry circuits' (no power flows through the contacts until they are fully closed) or loads of less than 0.1 volt and/or less than a milliamp.

Contact surfaces are generally gold, a gold alloy, or platinum.

These relays go for ever (several billion operations is not atypical) as long as their voltage and current ratings are not exceeded.

Magnetic latching: self-latching is generally accomplished by using an additional pair of relay contacts to switch the relay directly across the power supply once the relay has been energised — even momentarily.

However, latching may also be performed magnetically — by having a permanent magnet as well as the usual soft-iron core. The (permanent) magnetic flux holds the relay in the operated state after the electromagnetic energy ceases.

The relay is reset by reversing the polarity of the electromagnetic flux, or by momentarily energising a reset coil winding, or via a mechanical mechanism.

Magnetically-latching relays are essentially bi-stable. They may be operated or reset by pulsed energy and once set will remain so securely and virtually indefinately and of course, once latched, no power is required to hold the relay in that position.

Magnetically-latching relays are highly resistant to vibration and shock loads. They are used extensively in aerospace applications.

Magnetostrictive: not often encountered — these utilise the dimensional change resulting when ferro-magnetic materials (usually nickel alloys) are subject to a magnetic field.

In one form, a coil is wound around a bundle of nickel-alloy rods. When the coil is energised, the rods become slightly longer. This movement is mechanically amplified by a lever arrangement and used to open or close a pair of the contacts.

Mechanically latching: as the name implies, these relays use a mechanical mechanism to latch them in the operated state once the electromagnetic energizing force has ceased. They are reset manually, or electrically via a separate coil and armature.

These relays are often used as machinery or circuit overload warning devices. When a load exceeds a pre-set level the relay is caused to operate and by so doing to draw human attention to the fact that some action is required.

Mercury Plunger: these are curious looking devices used to switch currents up to 100 amps. In the 'off' position a magnetic plunger floats on top of a pool of mercury. An electro-magnet, when energised, attracts the magnet down into the mercury, which being displaced, rises and bridges a pair of contacts.

A normally-closed version has the plunger held down by a spring. The electromagnet, when energised, works in opposition to the spring force.

Another version allows the displaced mercury to empty slowly through an orifice into a chamber filled with inert gas. The gas is allowed to seep through a porous ceramic plug thus introducing a controlled time delay.

Mercury Wetted: see reed relay.

Meter relays: these were at one time used extensively to switch at precisely determined levels of voltage, current, power or whatever. They have largely been replaced by solid-state electronic circuits. They are essentially conventional electrical (D'Arsonval) meter movements in which a moving contact, replacing the pointer, touches a second adjustable stationary contact.

Like the Rolls-Royce, meter relays were/are largely a triumph of workmanship over design.

Phase Sequence: many electrically driven (three-phase) machines, particularly those used in the construction industry, are connected temporarily to various mains supplies, often by totally unskilled staff. In such applications there is a very real possibility of damage or accidents being caused by the motor rotating in an incorrect direction due to the phase sequence of the mains being incorrect.

Phase sequence relays check that the phase sequence is correct and either indicate aberrations — or corrects them automatically.

Polarised: many of the different types of relays described here may have one or more permanent magnets to provide a polarising magnetic flux which can normally flow in either one or the other of two symmetrical paths. The armature then moves in response to the nett force produced by the two flux paths.

The permanent magnet flux increases relay efficiency, sensitivity, and operating speed. It also improves resistance to vibration and shock.

Printed Circuit Board: these are high sensitivity relays designed to be energised by solid-state logic and other circuitry. These devices deserve to be covered separately — and consequently have been — elsewhere in this supplement.

Reed Relays: reed relays are a type of relay in which flat metal blades, often sealed within a glass tube, triple as armatures, springs, and conductors. Some even act as the contacts too (Figure 12).

Reed relays may be actuated by permanent magnets, or a magnetic field — in the latter case they are generally inserted within a solenoid.

The devices have innumerable applications. They are very fast, extremely reliable, and inexpensive.

There are innumerable variations including one in which the contacts are 'wetted' by mercury drawn up the reeds by capillary action.

Reed relays justify a feature on their own. The only one known was written by the present author in 1971. It has recently been reprinted in ETI's associated publication *Circuit Techniques Vol 4* (January 1984). The content is still applicable.

Resonant Reed: these have been largely replaced by solid-state devices. Their purpose is to make or break a circuit at specific (adjustable) mechanical or electrical frequencies.

In their electrical form they consist of a thin springy reed suspended above an electromagnet. When the winding is energised at a frequency corresponding to the reed's fundamental resonance the reed is excited into a major mode of vibration at the same frequency. The moving reed touches a second, fixed, contact once each cycle.

Rotary: used originally for military applications, these relays use armatures which rotate to close the gap between one or more pole faces. Their main characteristic is extreme resistance to shock and vibration.

Rotary relays are produced in a wide range of sizes and types — from microminiature devices used in scientific instruments to massive devices which will withstand the shock of gunfire in tanks and naval vessels.

RF Switching: these are commonly used for switching antennas and associated equipment. They are designed for minimum loss at high frequencies, and often produced such that their switching components have a similar characteristic impedance to the coaxial cables connected to them.

Auxillary contacts are often included for switching coincident non-RF circuits.

Snap action: this implies a very rapid change from one stable state to a second stable state. It is usually achieved by using part of the relay actuating mechanism to store mechanical energy during initial movement and then releasing this energy to 'snap' the contacts open or closed during the final stages of movement.

The usual method is to use some form of 'over-centre' mechanism but the action may also be achieved electrically, for example discharging a capacitor through the coil winding. Magnetically polarised relays tend to have snap action characteristics.

Solenoid: solenoid actuation is commonly employed where the contacts must be moved over large distances or where high contact pressures are essential.

Seolenoid relays are generally limited to non-critical on/off applications.

Both ac and dc types are available. Both are characterised by very high in-rush currents for the first few microseconds. This is caused by the distributed capacitance within the winding. With ac solenoids the change in impedance as the armature moves through the solenoid will cause current surges.

It is generally essential to use some form of protection against the extremely high voltage transients which are generated when a solenoid relay is disconnected.

Users should note that solenoid relays are commonly position-sensitive — some even rely upon gravity to move the plunger!

Stepping switches: these cover a wide range of relay-like devices are are basically switches which operate sequentially when energised by a series of pulses. Figure 13 shows one typical form.

These relays/ switches were used by the million in telephone exchanges and switchboards worldwide. They are also still commonly used in vending and other machines.

Stepping switches generally employ some form of electromagnetic actuator which causes one or more contacts to move semicircularly across further banks of contacts. In most applications the moving contact moves one step per energising pulse.

The devices commonly require 48 volts for energising, but stepping switches are also produced operating from 6 volts to 240 volts.

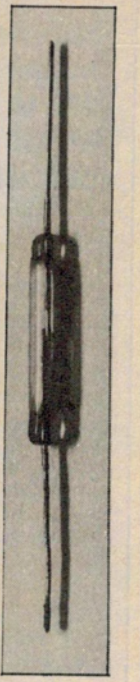
Telephones: typified by the ubiquitous Post Office type 3000, the term actually encompasses many different types and configurations of relays.

Most look something like Figure 14. They tend to have long, small diameter windings and provision for various combinations and numbers of contacts. They are difficult to assemble and adjust, but once set up they are extremely reliable.

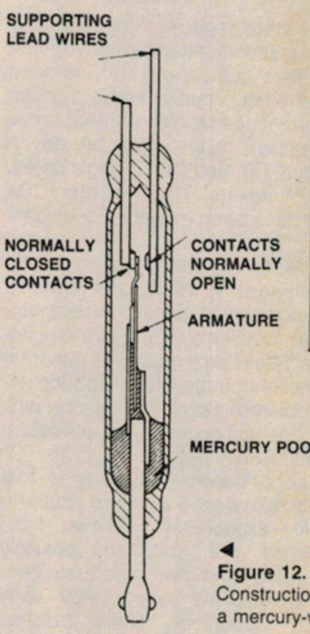
Vacuum relays: these relays have their contacts enclosed and sealed in a high vacuum. The coil winding is generally external and the contacts are actuated by magnetic transfer or mechanically via metal bellows forming part of the (generally) glass vacuum enclosure.

Vacuum sealed relays are costly but can switch very high voltages and currents for their physical size.

Voltage sensing: relatively similar to current sensing devices except that compensating networks are required to offset changes in ambient temperature. This is because a current sensing relay responds directly and only to the current flowing in the coil, and is this unaffected by ambient changes. A voltage sensing device however responds to the product of coil current and coil resistance and is thus directly affected by ambient change. ●



Reed relay. ▶
This tiny reed relay has a body just 16 mm long and about 3.5 mm diameter.



◀ **Figure 12.** Construction of a mercury-wetted relay.

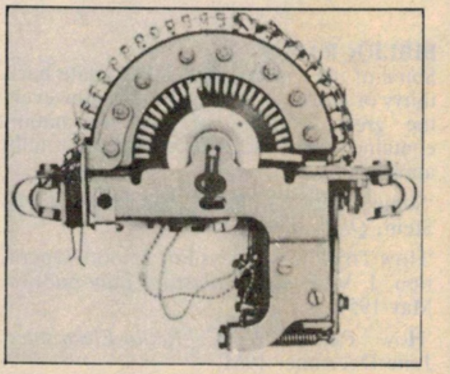
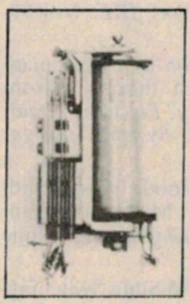
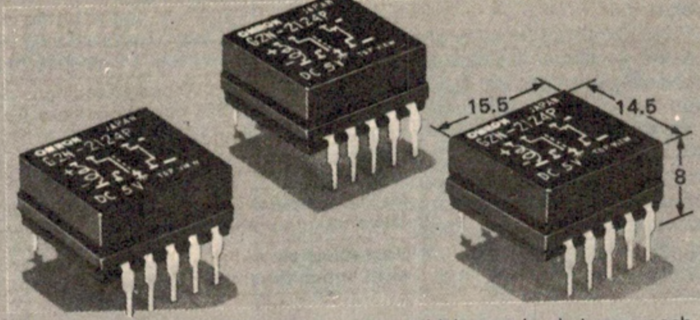


Figure 13. ▲ A stepping switch relay.



◀ **Figure 14.** Yes, it's a type 3000 relay!

DRIVING RELAYS FROM LOGIC CIRCUITS



Many designers specify unnecessarily complex and sometimes inherently unreliable solid-state componentry to interface their logic or other circuitry to drive medium to high current loads. Yet printed circuit board mounting relays may be driven **directly** from TTL and CMOS logic gates, or buffers or drivers. The necessary bits and pieces have been available for at least a decade!

There are a few drawbacks and very many advantages. First, the bad news.

Whilst being almost immune to false triggering from transients, static etc, electromechanical relays do themselves generate electrical noise and this may introduce unwanted problems in sensitive logic circuits. Shielded construction and arc suppression circuitry will usually provide a cure.

The second possible difficulty is that mechanical relays have a limited, (but predictable) life expectancy. However if the correct types are specified, possibly slightly derated, and given adequate contact protection, life expectancy may exceed 10^7 operations. There are few applications which even begin to approach that many cycles — in many applications the loads fail long before the relays.

On the plus side, electromechanical relays are virtually immune from false triggering — whether from load, power, static or other transients; nor do they required components to protect them against such evils.

Unlike solid-state relays, electromechanical devices need not be derated for any realistic operating temperature, nor do they require space consuming heatsinks.

There's no need for commutating dv/dt protection. Isolation between input and output is excellent — typically 100 megohms or more — with dielectric strength commonly exceeding 1000 volts at 50 Hz.

Where relays really score is in applications where the input must drive multiple outputs and especially so where the outputs are a combination of opening, closing or change-over circuits.

Here's how it's done.

TTL

Most commercially available pcb relays designed for use with TTL circuitry require energizing currents ranging from 4 mA to 25 mA (at 5 Vdc). A typical example is shown in Figure 1. Plenty of TTL ICs are more than capable of driving these relays. The 54/74 series of gates will readily handle 20 mA. The 7433 series quad switches sink 48 mA from each of the four outputs.

The 7400 series TTL buffers and drivers will readily drive most pc board relays directly — up to and including those having multiple contact 10 amp ratings. And if this is not enough there are any number of IC drivers with TTL or MOS inputs having high current output transistors fabricated into the same substrate as the logic gates. These devices will sink several hundred milliamps and can drive relays capable of switching 25 amps or more.

CMOS

The 4000 series logic gates operated at 12-15 volts will sink about 5 mA — this is sufficient to drive many sensitive pc board relays (Potter & Brumfield's Model LM for example requires 3 mA for its 5000 ohm coil and switches 1 A at 240 Vac).

As with TTL it's always possible to use a signal amplifying interface.

HYBRIDS

An increasing number of pc board mounting relays are now being produced with signal amplifiers built in. These mechanical solid-state hybrids generally use a bipolar transistor or Darlington amplifier.

A typical hybrid relay is rated at 10 amps 240 volts ac and requires less than one milliamp to drive it. ●

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