SEMICONDUCTORS

PART 8: THYRISTORS AND TRIACS (THEORY)

BY ANDREW ARMSTRONG

BIDIRECTIONAL TRIODE THYRISTORS

Thyristors and triacs are used to control ac power in a more useful way than relays. Used properly they can be versatile and reliable, but used incorrectly they can fail expensively.

Back in the mists of time, before the transistor, was the valve. The thyristor also has its vacuum tube forebear, the thyratron. This is a cold cathode device which contains a gas.

When the gas is made to ionise by application of a trigger voltage to the control terminal it permits conduction between the main electrodes in the device. Conduction is maintained as long as there is sufficient current flowing to maintain the ionisation. The triggering process is similar to the triggering of a xenon flash tube.

The thyristor works remarkably similarly to the thyratron, but most thyristors require less control signal than thyratrons. The semiconductor structure of a typical thyristor is shown in Fig.69, and an equivalent circuit illustrating the two transistors included in it is shown in Fig.70. As you will observe, a diode is also included in the equivalent circuit, as is the effect with most thyristors.

Fig. 69

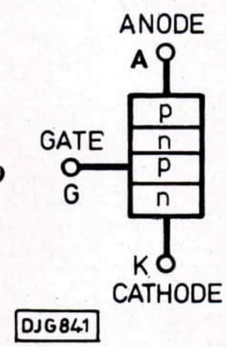
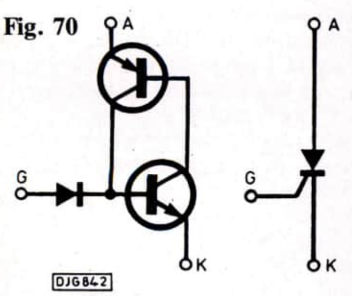


Fig. 70



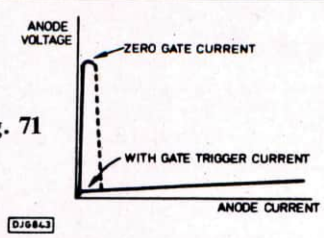
TRIGGERING

When the gate terminal is raised to a positive voltage sufficient to make a current flow, the lower transistor is switched on. This switches on the upper transistor, which holds on the lower transistor. Only a small current is required to trigger this self multiplying effect. The practical problem exists that too small a trigger current will start the process too slowly and local power dissipation will damage the device before it has switched on properly. Many such switching cycles will eventually cause total destruction, giving rise to the surprised comment "Why did it fail now, after working for weeks?"

An associated point to look out for in triggering a thyristor is the di/dt rating. When the device is triggered the current starts to flow over a limited area of the junction, and then spreads over the whole junction. If the load is such that the maximum rated current of the thyristor will atteempt to flow immediately after triggering, then repetitive switching cycles will overheat and destroy an increasing circle of junction, until the device fails.

A typical triggering characteristic is shown in Fig.71. Also shown on this graph is the phenomenon known as breakover, which simply means that the thyristor switches on if excessive voltage is applied. Depending on the nature of the load, this effect will normally protect the thyristor from destruction due to overvoltage.

Fig. 71



It is possible for a thyristor to be falsely triggered by a voltage well below the maximum rated voltage, if the voltage is applied rapidly enough, perhaps as a spike on the supply. There is a maximum dv/dt rating (rate of change of voltage) that a thyristor can withstand without falsely triggering, possibly in a damaging fashion. Too rapid a rise of voltage on the anode will trigger the device because self capacitance will cause a trigger current to flow.

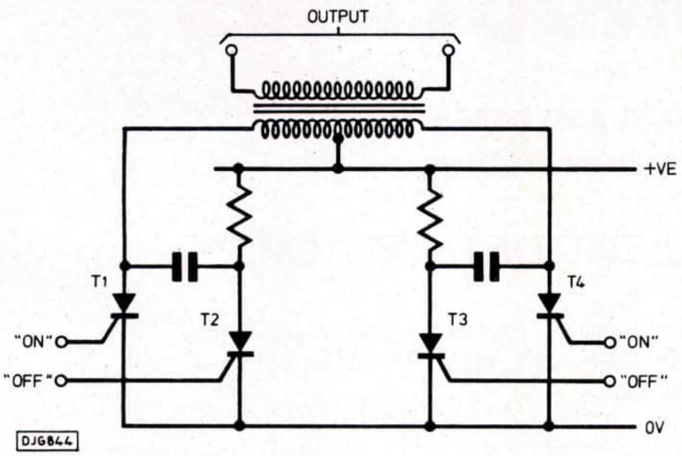
For the reasons above, thyristors are normally used with series inductance and an rc snubber network for protection against any fault conditions known to be possible in the circuit in use. The choice of these components will be considered in more detail as they apply to triacs.

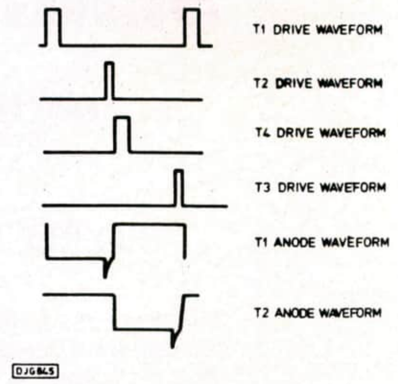
GATE TURN OFF

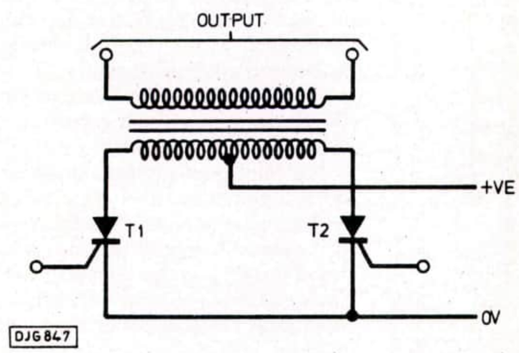
Most thyristors, when switched on, will remain switched on until the current falls below the level required to maintain the avalanche effect which maintains conduction. Certain special devices more recently available can be switched off with a reverse voltage applied to the gate. These devices are known as gate turn off thyristors, or gtos. They are intended for use in some lower frequency switched mode power supplies, inverters, tv deflection circuits etc.

With this type of device it is much easier to use thyristors in dc applications. It may seem strange to wish to do so when transistors are available for the purpose, but thyristors are very efficient in some types of switching applications.

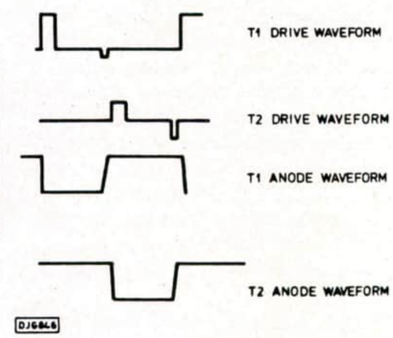
Fig.72 shows a typical method of switching ordinary thyristors in an inverter. The commutation thyristors are normally off, and are switched on when the associated load carrying thyristor must be switched off. When the commutation thyristor is triggered a voltage step from load voltage to 0V appears on its anode. A corresponding negative going step appears on the other side of the capacitor, which pulls the anode of the load carrying device negative, and hence switches it off smartly. The capacitor then charges up, due to the load current, which perforce stops. The current through the resistor is enough to reset the charge on the capacitor over a cycle, but not enough to hold on the commuta-







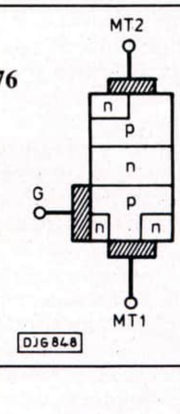
Top left: Fig. 72
Top right: Fig. 73
Bottom left: Fig. 74
Bottom right: Fig. 75



tion thyristor. The drive waveforms are illustrated in Fig.73.

The circuit and waveforms for a gto controlled inverter output stage are shown in Figs.74 and 75. See how much simpler this is. At present conventional thyristors have higher maximum power ratings than gtos, but increasingly powerful gtos are regularly developed.

Fig. 76



TRIACS

The home constructor has few applications for thyristors, which conduct only in one direction. Much more widely used is the triac, or "bidirectional triode thyristor" as some data manuals quaintly call it. Its semiconductor structure is shown in Fig.76. As you can see, between MT1 and MT2 there is a path through a pnpn structure as well as an npnp route. This means that the device can conduct in either direction, but because the path taken by the current is different in either case, a reversal of the applied voltage will switch off the device.

Because both the gate and MT1 are connected to both the p and the n layers at one end of the device, either polarity of gate drive will generate current flow across the pn junction and thus generate charge carriers which will commence the process of switching on the device. However, the mechanism of switch on is more direct and assured if the polarity of the gate drive is the same as that applied to MT2, because in this case the mechanism is the same as that of a simple thyristor.

The more complicated triggering arrangements of a triac reduce the efficiency by which triggering current is used, so the triggering current required for a triac is approximately ten times higher than for a thyristor of a similar current rating.

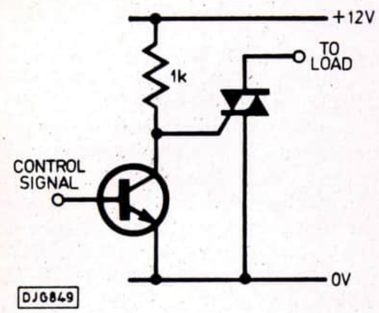
Though triacs can be triggered by a signal opposite in polarity to the voltage being controlled, not all types can be triggered with a positive gate voltage and a negative voltage on MT2. Many samples of triacs not specified to trigger in this quadrant will in fact trigger, but the triggering may be of such a nature as to damage the device because the current buildup is too slow to limit localised heating of the junction. Triacs used in this way may fail after many hours of operation.

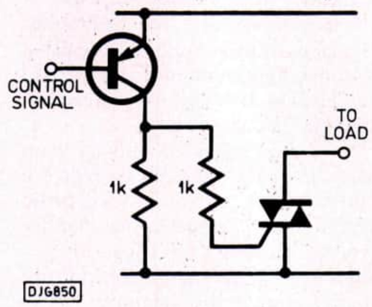
I have encountered a case in which equipment incorporating a substitute for the specified triac has shown over a 20% failure rate in the first month after installation due to this very cause. Apparently the specified device was temporarily unavailable, and someone experimented with various triacs in the bits box until one appeared to work. No one read the data sheet, and as a result items of equipment installed all over Europe started to fail, with high attendant repair costs.

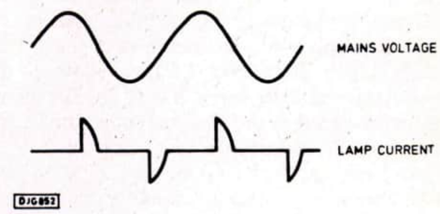
Admittedly the penalties for an amateur construction project are less severe, but it can be a serious embarrassment if your new disco lighting unit fails in the middle of a party. There is an immediate loss of street cred.

The rate of rise of current through triacs and of voltage across them must be limited for the same reasons as with thyristors. Because of the more complicated structure of the triac the limitations are more severe. In addition, because the gate can conduct in either direction, heavy fault currents can flow from the gate terminal if a voltage spike causes false triggering of the device.

This can be a problem, as illustrated by the triac triggering circuit shown in Fig.77. In this circuit, the resistor provides triggering current unless the transistor is switched on, in which case the current flows into the collector of the transistor rather than the gate of the triac. Spurious triggering of the triac can







Left: Fig. 77
Centre: Fig. 78
Right: Fig. 79

cause enough gate current to flow to destroy the gate structure of the triac and the transistor. On the other hand, a triggering circuit such as that shown in Fig.78 will not be damaged by occasional spurious triggering.

This point is not purely theoretical. In one particular industrial installation a series of control units employing the circuit of Fig.77 failed, most exhibiting transistors whose plastic case had cracked due to the heat of the break-down, and some with just three legs standing where the transistor used to be. Replacement of the unit with one using the circuit of Fig.78 halted the series of failures, even though severe voltage spikes were sometimes present.

MODES OF OPERATION

Perhaps of the most familiar use for triacs is in light dimmers. In this application the triac is retriggered each half cycle of the mains to adjust the amount of power received by a lamp, while minimising flicker. This is illustrated in Fig.79. A power level of considerably less than a quarter is illustrated, because the power delivered to the load is proportional to the area under a graph of V^2 bounded by the firing point.

The lamp current waveform shows very fast rise, and therefore contains very high frequencies capable of causing interference with radio reception. The normal way to minimise this problem is to connect an inductor in series with the load to limit the rate of change of current. A capacitor is often used as well to help filter out high frequencies. This arrangement is illustrated in Fig.80. Note that the capacitor connected between load and neutral is a class X capacitor, specially rated for use on 240V mains.

If short term constancy of power is not important, such as in a heater, then instead of using variable phase angle triggering to control the power, burst firing is used. This type of power control switches the power on and off for several half cycles at a time. A typical period for one switching cycle might be two seconds. To limit interference the triac is normally switched on only close to the mains zero crossing, so that there is no spike of current and hence no interference.

Burst fire control is ideally suited to controlling heating elements, but is useless for lighting control because the lights flash on and off. The average level is correct, of course, but that is like saying that with your head in the oven and your feet in the refrigerator you are comfortable on average.

SNUBBERS

To protect the triac from damage due to voltage spikes on the mains supply a snubber network is normally used. In Fig.80 the snubber network consists of C1 and R1. The value of R1 is chosen to damp the resonance of the inductor and capacitors. Without R1 in the circuit resonant ringing could cause false triggering of the triac.

In applications using burst firing or simply using a triac to switch a load the filtering components are not needed but the snubber network is still required. If the load to be switched is highly inductive, for example a relay or contactor, or a solenoid, then the choice of component values in the snubber network is important to prevent serious ringing. A snubber network with the wrong component values can be worse than none at all.

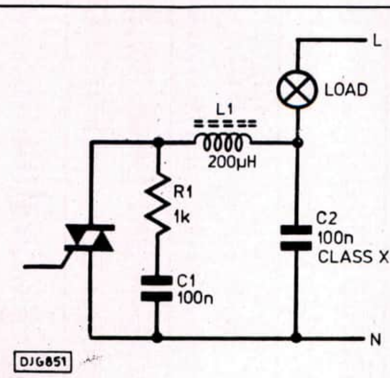
This may seem surprising, so consider the example of a triac controlling a solenoid load with 5H inductance and a power factor of 0.3. This means that the current phase lags the voltage by 60°. When the triggering current for the triac is switched off, the triac will switch off the next time the current reaches zero. As illustrated in Fig.81, the voltage is then at a value of approximately 295 volts positive or negative (assuming 240V mains). Because the current through the load is zero at this point, the situation is equivalent to suddenly applying 295V a series lcr circuit.

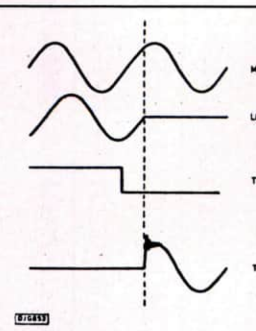
Clearly the voltage on the triac will rise to at least 295V, but it won't stop there. By the time the capacitor has charged to 295V a significant current is flowing in the inductor, and this current con-tinues to charge the capacitor. If the resistor value were very low then the peak capacitor voltage, and hence the peak voltage on the triac, would be 2*295 = 590V. This would definitely trigger a 500V rated triac into breaking down to protect itself, while the normal 400V rated devices used on the mains would not stand a chance.

If a suitable resistor value is used to damp the ringing caused by the sudden voltage step applied to the circuit, then the overshoot will be much less, though of course the resistor limits the ability of the snubber to prevent spurious triggering or damage in the presence of voltage spikes on the supply. If the load is highly inductive, however, this will serve as adequate protection.

One might imagine, therefore, that no snubber network at all would be a reasonable solution. This is not so because in the absence of a snubber network the rate of rise of voltage across the triac when it switches off and 295V appears across it almost instantly is enough to exceed its di/dt rating and cause false triggering anyway. A compromise of components is needed to avoid both these problems.

Here is a reasonable rule of thumb.





Left: Fig. 80
Right: Fig. 81

Choose the capacitor value so that the resonant frequency of the snubber capacitor with the load inductance is in the range 1000 to 10,000 Hz. Then calculate a resistor value to bring the Q of the resonant circuit of the snubber capacitor and the load inductance to 1, and then choose nearest preferred value.

The frequency of an lc resonant circuit is given by the formula:

$$f = \frac{1}{2 \times \pi \times \sqrt{L} \times C}$$

When the resonant frequency is known, calculate the resistance by using the formula Q = 2*π*f*L/R turned around to read R = 2*π*f*L/Q.

For example, if the load inductance is 1H, and the load is mainly inductive so that the resistive part can be ignored for rough calculations, a capacitor of 10nF would be suitable, giving a resonant frequency of approximately 1.5 kHz. The calculated resistor value to meet the stated criterion is 10k, and experiments have shown that this value is effective in the type of case described.

SUMMARY

The important practical rules for using triacs effectively are as follows. Always make sure that the device is specified to trigger under the conditions in which it is to be used. Make sure that the amount of trigger current is suitable, ideally a little above the minimum guaranteed trigger level, but below the maximum permissible gate current.

If the triac is triggered directly from a low level signal circuit, always feed the gate drive in via a resistor. This will avoid heavy gate fault currents in the event of overvoltage causing false triggering.

When using phase angle control, use a filter inductor to minimise radio interference, as well as a snubber network to protect the triac.

If the triac is to be used with an inductive load having a low power factor, choose the snubber network components carefully, and if necessary use a triac rated at a higher voltage than would normally be required for the mains voltage in use. This will enable it to withstand larger rings on the snubber network without false triggering.

Remember that some loads take a substantially greater surge current at switch on than they take when operating steadily. Make sure that the triac is rated to withstand the longest surge which the load will impose on it.

Next month I will show some practical circuit building blocks using triacs, including information on using pulse transformers and opto-triacs for triggering purposes. PE