Designer's Notebook: Thyristors

And so to solid state switches. In this month's Designer's Notebook Ian Sinclair looks at the basic techniques involving the thyristor and its close relatives.

TECHNICALLY, the thyristor is a four-layer diode, but as far as we are concerned, it's a silicon diode that is switched into conduction by a signal at a third electrode, the gate, as shown in Fig. 1. In many respects, however, the action is very much that of a normal silicon diode; for example, it will not conduct in the reverse direction (cathode positive), and it has about 0V6 forward drop across the anode-cathode terminal when it conducts. The distinguishing feature is that the start of forward conduction only occurs when the trigger pulse arrives at the gate and fires the thyristor. Whatever you subsequently do to the gate, the thyristor will continue to conduct until the forward current falls below a value known as the holding current, at which point the thyristor will turn off. However, while the thyristor is on, it is as fully conducting as a silicon diode would be.

Triggers Fingered

One point that is not always sufficiently understood is that the triggering requirements can vary enormously from one type of thyristor to another. A lot of small thyristors will trigger for a gate current of only a fraction of a microamp, so that interference signals will trigger the thyristor if the gate terminal is not grounded to the cathode by a low-value resistor. A lot of false triggering of burglar alarms seems to be due to thyristor circuits in which the gate has too high a resistance to the cathode, making the gate circuit a very efficient aerial for any radiated energy! Even when quite low resistance values are used, thyristors can trigger in lightning storms or because of static discharges, so that some careful design of the gate circuit and extensive testing is needed if you are in the alarm business. The combination of low resistance and a suppressor ferrite bead placed at the gate terminal helps a lot! Large thyristors need rather more in the way of gate current, but even these can be triggered by a fraction of a milliamp.

Thyristors are most at home in circuits which use DC or unsmoothed (but ...d) AC. The use of rectified AC is ...pular (Fig. 2) because the

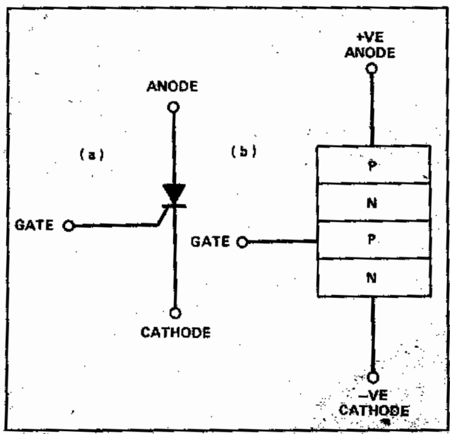

Figure 1. The thyristor: (a) circuit symbol, (b) arrangement of semiconductor layers.

thyristor will switch off each time the supply voltage reaches zero, and all that we need to concentrate our attention on is the triggering which switches it on again. Where a thyristor is used in a DC circuit, there is the extra complication of reducing the voltage across the thyristor to zero in order to switch it off (Fig. 3).

A Passing Phase

Down to configurations. The most useful basic triggering circuit is the phase-controlled thyristor fed with rectified AC as illustrated in Fig. 4. The load can be placed in the leads to the bridge rectifier, in which case the thyristor will control the average power dissipated in the load, despite the fact that the load is working on AC and the thyristor is controlling a rectified supply. An interesting option is to place a reservoir capacitor on the cathode side of the thyristor, giving a low-cost and low-dissipation form of voltage regulation (Fig. 5). The gate control can be obtained from a charging capacitor, as demonstrated in Fig. 6, or from a zener diode as in Fig. 5 — remember that there is no triggering until the gate voltage is about 0V6 above the cathode voltage.

Simple triggering from a charging capacitor is never entirely satisfactory, because the thyristor cannot be relied upon to fire at exactly the same stage of charging in each cycle. To get round this, the simpler circuits make use of a trigger diode or diac which ensures more reliable triggering. The trigger diode has the curious characteristic that it will remain non-conducting while the voltage across it in either direction builds up, suddenly conduct at some voltage level which is determined by its construction, and remain fully conducting until the voltage across it has dropped almost to zero (Fig. 7). A diac wired between a charging

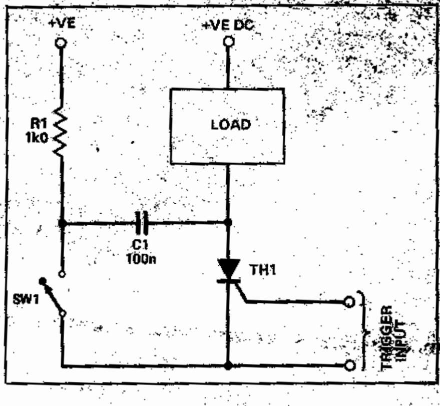

Figure 3. Turning off a thyristor which is operated from DC. Pressing the switch will discharge the capacitor, pulsing the anode of the thyristor and so stopping the current. This is enough to prevent conduction until the gate is pulsed again.

capacitor and the gate of the thyristor, with a load of a few hundred ohms connected between the gate and the cathode to avoid unwanted triggering will serve nicely to make the triggering much more reliable. What you then have to be sure of is that you have enough voltage around to operate the diac — depending on type, you may need up to 15 V across it before it starts to conduct.

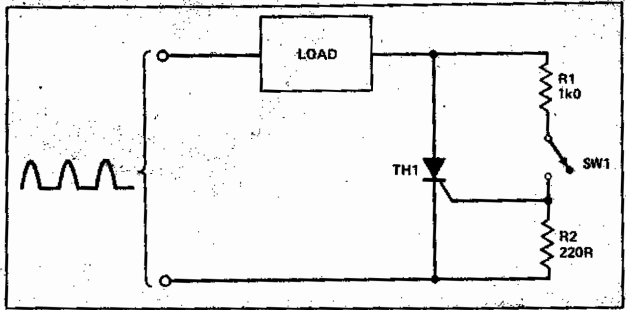

Figure 2. Elementary switching circuit for use with rectified AC. When the switch is on, current will flow through the load.

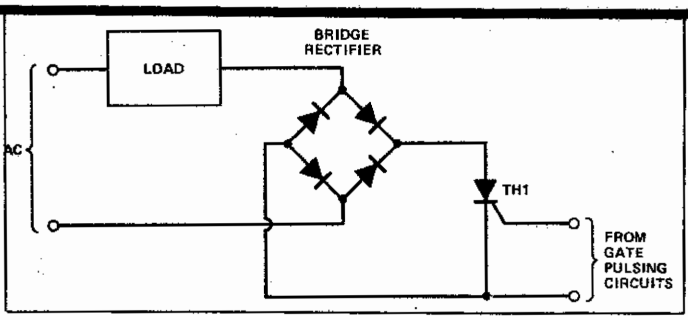

Figure 4. Basic cicruit for thyristor control of an AC circuit, using a bridge rectifier to supply the thyristor. The load, however, operates from AC.

The very simple phase-control system operates well enough for a lot of applications, particularly for light dimming, but more care is needed where electric motors are being controlled, mainly because of the back-EMF that motors of the AC/DC type will generate. When any motor of this type is spinning, it will act as a generator of DC (even if the supply to the motor is AC), and the thyristor must be capable of withstanding a reverse voltage which consists of the peak reverse AC plus this additional voltage generated by the motor.

The methods that are used for thyristor control of the larger motors, larger than your domestic power drill/food mixer motor, are a lot more specialised. For these circuits, charging capacitors are simply not precise enough as a method of triggering the thyristor at the correct point in the waveform: more elaborate trigger circuits, synchronised to the mains frequency, have to be used. These pulse-generating circuits can be coupled to the thyristor circuitry by using small pulse transformers, so that the timing circuits need not be connected to the circuits that the thyristor controls. This is particularly important when thyristors are used in high-voltage three-phase circuits, because the thyristors may be operating at voltages well above or below ground, yet the control box needs to be grounded.

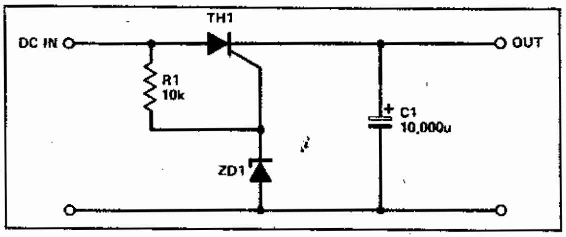

Figure 5. A thyristor regulator. This makes a very useful pre-stabiliser circuit, or can be used as a stabiliser in its own right where very precise stabilisation is not needed.

Radio interference is a continual problem for any thyristor circuit which makes use of phase control. Because the thyristor is being switched on when there is a substantial voltage across it, there are large current pulses which can be devastating for radio or TV receivers in the neighbourhood and which can also trigger other thyristors. It's essential, therefore, to design really effective pulse-transient suppression into the gate and anode circuits, and to ensure in the practical construction that the suppressors are placed as close as possible to the terminals of each thyristor. In general, small series inductors and parallel capacitors will do all that is needed, but they have to be capable of taking high peak currents, and must be wired close enough to prevent any wiring from acting as a radiating aerial.

The Zero Option

The other way of controlling thyristors in energy-control circuits is seen much less in the small-scale circuits that we tend to be more familiar with. This alternative is zero-voltage switching, and it involves switching the thyristors on at the instant when the voltage between anode and cathode is zero. This has the advantage of generating no more interference than a silicon diode would, which is very much less than is generated by the phase-control circuit: but it can be used only with loads like water-heaters which have very long time constants. If you switch your electric drill motor on for 100 mS in each second, the speed will be rather erratic to say the least, but a water or room heater switched in this way does not cause noticeable fluctuations of temperature because the temperature does not shoot up rapidly when the heater is on, nor shoot down when the heater is off. Figure 8 shows an outline of a typical zero-voltage control circuit — there is an IC which can be used to govern the whole operation.

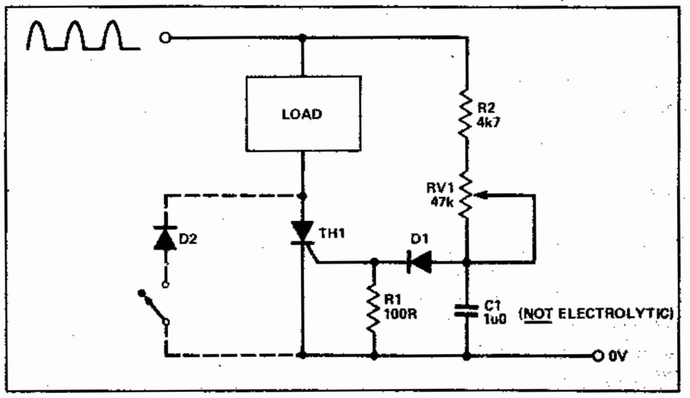

Figure 6. A typical phase control circuit for AC. The thyristor will conduct on only half of the input wave, so that a 'power-doubler' circuit, which switches a diode across the thyristor in the reverse conduction direction may be needed for a larger range of power control (shown dotted).

For My Next Triac . . .

The triac is a two-way equivalent of the thyristor, with the main circuit terminals labelled MT1 and MT2 rather than anode and cathode, since current can flow in either direction through the triac. Like the thyristor, the triac remains non-conducting until it has been triggered by a pulse at its gate terminal; the pulse can be of either polarity, but the minimum amplitude for firing is not the same for the two possible polarities. Again like the thyristor, the triac ceases to conduct when the current through it becomes too low to sustain conduction. Triacs are extensively

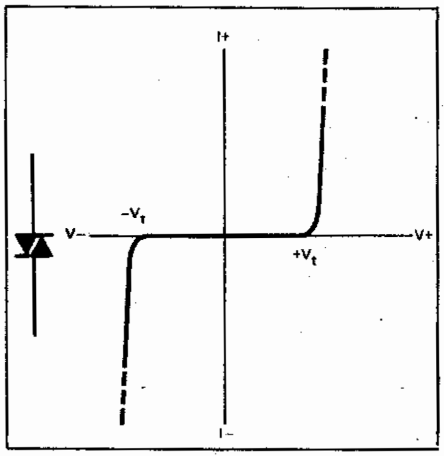

Figure 7. The diac, and its typical characteristic.

used to switch raw AC because a triac circuit represents a considerable saving on components as compared to a small thyristor circuit, even if the equivalent triac is more expensive than two thyristors. Figure 9 shows a typical triac circuit for AC use that can operate using a very small triggering input, such as from a microphone or photocell. The transformer supplies a low voltage for the gate circuit, and the rectifier bridge is arranged so that an unsmoothed full-wave rectified voltage is fed to the transistor amplifer circuit. When the transistor conducts, the current flowing in the bridge rectifier will also flow through the gate of the triac, triggering the triac on each half-cycle. The trigger current is AC because the gate is

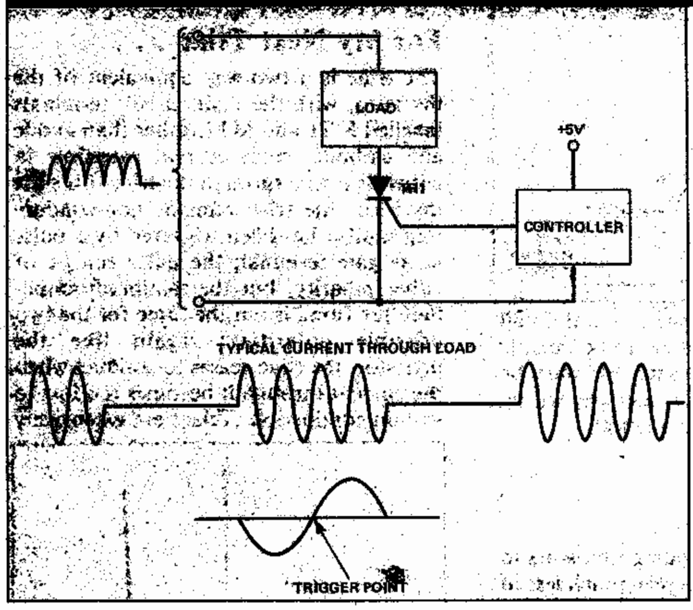

Figure 8. Principles of zero-voltage switching circuits. The controller (usually an IC) will switch the thyristor on at the point when the AC wave passes through zero. This ensures minimal RF interference, unlike the phase-control method.

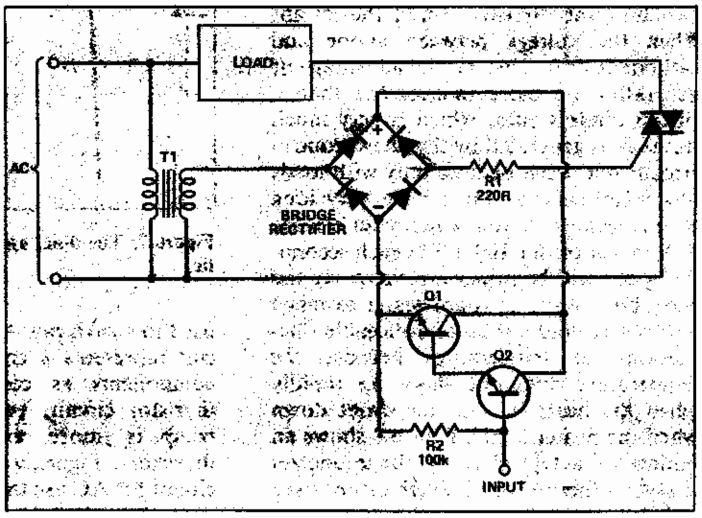

Figure 9. Using a triac in a circuit where the switching signals are very small. Note that the whole circuit is live to the line.

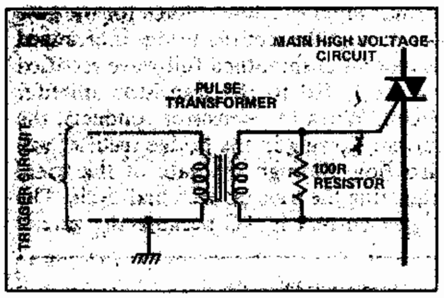

Figure 10. Isolating the line part of the circuit from the control part by using a pulse transformer.

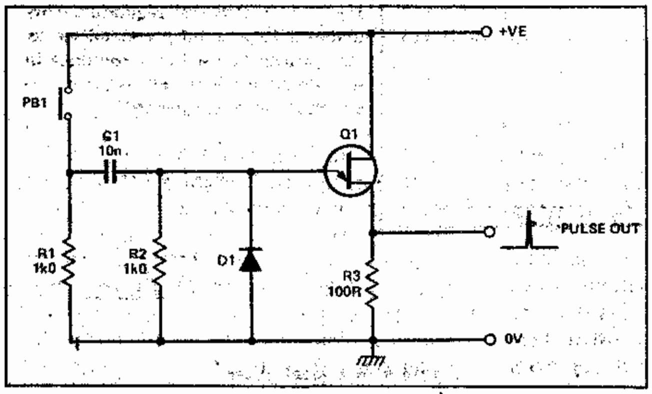

Figure 11. The unijunction connected to provide a short pulse when a switch is pressed.

wired in the AC side of the transformer. Note that the whole circuit is connected to the line — if an isolated low-voltage circuit is needed, then the gate must be triggered by a circuit using a pulse transformer rather than directly as in this example, and the part-circuit shown in Fig. 10 is needed.

Triggering thyristors or triacs via a pulse transformer needs a fairly sharp spike waveform, and one of the devices that has traditionally been used to provide this type of waveform is the unijunction. As the name suggests, this uses one junction on an N-type silicon base whose doping normally ensures that the conductivity is low (resistance high). The junction is placed so as to provide an emitter terminal, and when the emitter voltage is raised to the conducting level, the injection of holes into the bar will make it highly conductive. This is the triggered stage, which can be maintained only if a current continues to flow through the emittter. Unijunction circuits are arranged so as to prevent this continuous current, so ensuring a clean sharp pulse.

A unijunction 'one-shot' pulse generator is illustrated in Fig. 11. With the switch open, the emitter of the unijunction is grounded, and the device is non-conducting. Closing the switch contacts changes the voltage on one side of the capacitor from ground to the positive supply voltage, and the voltage on the other side will increase similarly, so triggering the unijunction. The conducting unijunction generates a positive-going spike at the grounded end of its circuit, and also charges the capacitor so that the end of the capacitor connected to the emitter is at about ground voltage. This process is very brief, and when the switch opens again, the emitter of the unijunction is protected from negative pulses by a diode.

The triggering voltage for a unijunction is a fixed fraction of the total voltage applied across the main terminals — the fraction is known as the 'intrinsic stand-off ratio,' and is usually around 0.6, implying that the device will trigger when the emitter voltage is about 60 per cent of the supply voltage. Because this ratio is fixed, changes in the supply voltage do not make much difference to the frequency of the output.

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