SEMICONDUCTORS

PART 9: PRACTICAL THYRISTORS AND TRIACS

BY ANDREW ARMSTRONG

TRIGGERING CIRCUITS

In many triac applications, circuitry kept at earth potential for safety generates the mains control signal via a triac. Several ways of isolating the signal circuitry are possible, and in some cases isolation is not required at all.

Part 8 published last month considered only the theoretical aspects of thyristors and triacs. This month we shall look at some practical circuits and building blocks.

First of all, I shall return to the gto (gate turn off) thyristor. The triggering waveform shown last month was highly idealised, and in practice nobody would bother to generate such a waveform. The negative signal needed to switch off a gto can be generated easily and automatically by using a pulse transformer.

Switching on the current to the trigger transformer produces a positive signal on the secondary of the transformer, and this triggers the gto. When the gto must be switched off, the current to the primary of the pulse transformer is switched off, and the resulting back emf on the secondary switches off the gto. It is important to connect the pulse transformer with the correct polarity.

Fig.82 shows a horizontal deflection output stage for use with a small cathode ray tube. The section of circuitry is shown three times for comparison, with a bipolar transistor, a power mosfet, and a gto. The zener diodes to limit the voltage spike are beneficial in each case, but note that the power mosfet does not need an antiparallel catch diode.

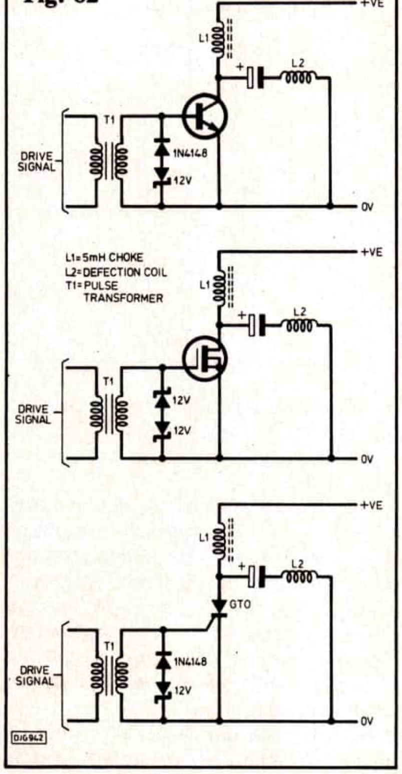
In each case the negative voltage generated on the output of the pulse transformer when the primary current is switched off is useful. It removes charge from the base region of the transistor, or discharges the gate capacitance of the power mosfet, or switches off the gto.

This is a particular application for which three very different devices are all suitable. It is likely, however, that for higher powered circuits of a similar type the gto would be most suitable. On the other hand, the switching speed of the gto is limited, so that at higher frequencies such as those encountered in switched mode power supplies the gto would not be suitable at all.

ISOLATION

A more important aspect of the pulse transformer is that it provides isolation between control circuitry and high voltage circuitry. Pulse transformers are often used to separate triggering circuitry from triacs connected to the mains. It is even possible to connect the triac in series with the live connection to the load instead of the neutral one, thus slightly enhancing the safety of the circuit.

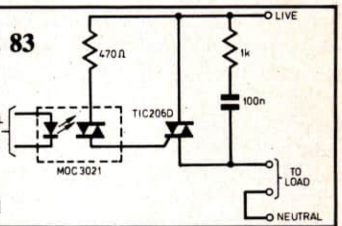
Fig. 82



A word of warning here. Though it is safer, if all else is equal, to connect a triac in the live rather than the neutral line, a triac cannot be relied on to isolate a load from the mains for safety purposes.

Another means of isolating control circuitry from the mains is to use an opto-isolated triac. For low currents the opto-isolated triac can do the work on its own, otherwise it may be used to trigger another, more substantial device. This application is illustrated in Fig.83.

Fig. 83



Some opto-isolated triacs incorporate zero level triggering circuitry, so that they will only switch on near to a mains zero crossing, and thus avoid generating interference. It is, of course, impossible to phase control a load using this type of isolator.

To assist in choosing thyristors and triacs, three tables of data are included at the end of the text. Table 5 covers thyristors, Table 6 covers triacs, and Table 7 covers optoisolated thyristors and triacs.

DIMMERS

One application in which isolation from the mains is not normally a requirement is the light dimmer. In this application, safety isolation is provided by the plastic spindle of the control potentiometer. Most domestic light dimmers are housed in plastic cases which provide adequate protection from live circuitry.

Domestic lamp dimmers use an rc network to provide a phase shifted signal derived from the 50Hz mains. The signal is used to trigger the triac via a diac.

A diac is very much like a triac but without the gate terminal. It is made in such a way that it will break down and trigger itself when approximately 30V appears across it in either direction. The circuit shown in Fig.84 illustrates this principle. When the voltage on C1

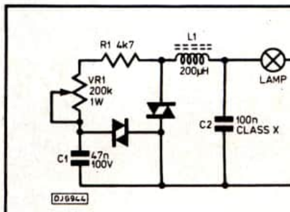


Fig. 84

reaches 30V the diac switches on and discharges C1 into the gate of the triac. This switches the triac on, which in turn switches on the lamp. Once the triac is switched on, no further current flows in R1 and VR1, so minimising their dissipation.

Clearly, the soonest that the triac can be triggered during a mains half cycle is when the mains voltage has risen to just above 30V. This means that there is a small part of the mains cycle during which the triac cannot be triggered. This is not a serious handicap, because very little energy is contained in this tiny fraction of a cycle. Furthermore, if the triac were to be triggered by a brief triggering pulse such as would be generated by the discharge of C1 via the diac, it would not remain on. At very low voltages the load current would not reach the holding current of the triac.

Note that this circuit includes suppression components to filter out interference which would otherwise be transmitted down the mains wiring. The time constant of L1 and C2 is chosen to reduce ratio interference to levels which would normally not cause a problem. Omission of these components would result in serious radio interference. The interference would be at its worst when the triac is triggered at the peak of the mains half cycle, ie approximately 340V.

This simple light dimmer circuit suffers from a hysteresis effect. The problem is that not all the charge is removed from C1 between one trigger pulse and the next. Consequently the trigger point on one half cycle affects that on the next and so on.

The amount of charge remaining on C1 at the end of a half cycle depends in part upon the load resistance. The load is a lamp whose resistance depends upon its temperature. You see the hysteresis effect in the following way: the lamp dimmer must be advanced to a substantial brightness setting before the lamp comes on. Then the dimmer may be backed off to achieve a lower brightness level.

The circuit shown in Fig.85 uses an extra rc time constant to improve the situation. This circuit provides smoother control.

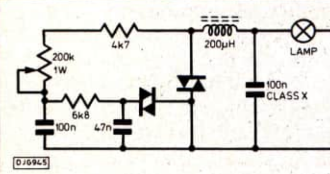


Fig. 85

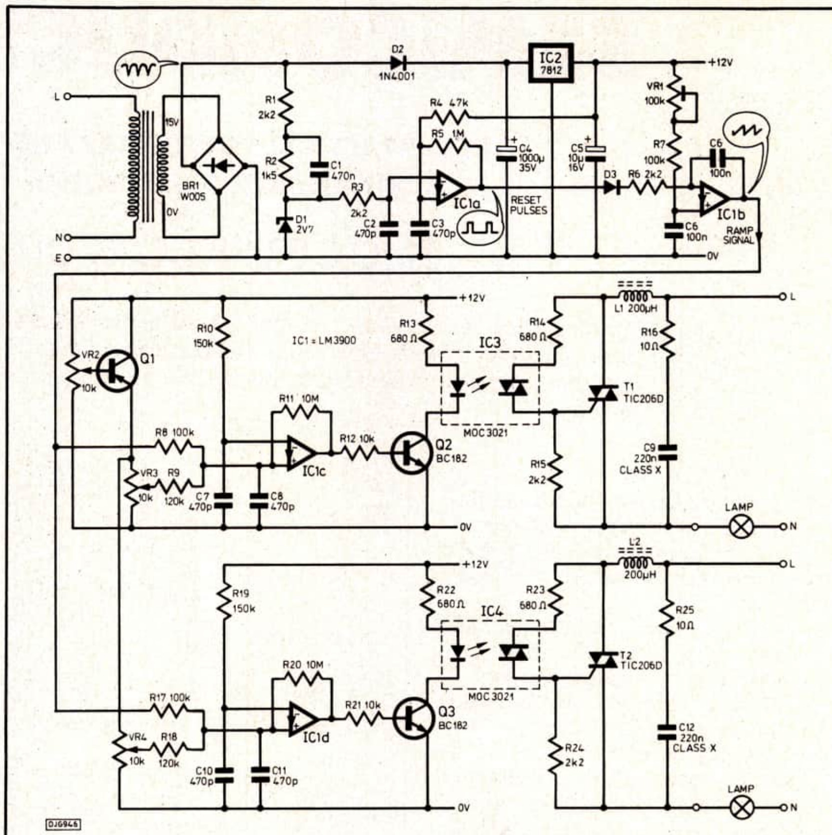


Fig. 86

ISOLATED CONTROL

As mentioned earlier, it is often necessary to operate control circuitry at earth potential, while the triacs being controlled are connected to the mains. There are many different approaches to the problem, depending on the precise application, but the method with the widest usefulness is probably the opto-isolated triac.

The circuit shown in Fig.86 illustrates this principle, using opto-triacs to phase control two lamps. This design features two channels in which the brightness is controlled by a voltage. In the circuit shown the control voltage is provided by two potentiometers, with a master control provided to dim both channels simultaneously.

If this principle were extended to further channels it could provide a simple stage lighting unit. If instead the control voltages were derived from audio signals then the design could provide a very effective sound controlled light unit.

The principle on which the unit operates is to generate a repetitive ramp waveform synchronised to the mains. The ramp generator is reset around the mains zero crossing, and continues to ramp up until the next reset pulse. The ramp and the brightness control signal are added together via two resistors to produce a current to feed into the input of a Norton opamp. This current is compared with a current fed into the other input of the opamp. The size of the ramp is adjusted so that the ramp on its own does not quite switch the comparator, even at its tip. The addition of just a small brightness control signal causes the comparator to switch near the tip of the ramp, and bigger brightness control signals cause earlier triggering.

The top part of the circuit is the power supply and ramp generator. IC1a is used as a comparator to generate reset pulses whose timing is determined by the rectified but unsmoothed dc on the output of the bridge rectifier. D2 serves as a blocking diode to permit smooth dc on one side and unsmoothed on the other.

Because the timing information is derived via a mains transformer, rather than straight from the mains, this is not necessarily in perfect phase with the mains. Typically mains transformers give between 5° and 10° phase lag. This can cause problems if a very narrow reset pulse is used, because the tip of the ramp can trigger the triac on the mains half cycle *after* the one on which the ramp started. To avoid this problem a certain amount of phase advance is given by C1.

D1 limits the voltage excursion to a level which will not damage the input of IC1a and both inputs of the opamp are protected from interference by 470pF capacitors. The net result is a clean ramp reset pulse with the correct timing. This pulse is used to reset an integrator which ramps up to approximately 7V during one half cycle.

At first sight the integrator may look a little strange; this is because the circuit is using a Norton opamp, whose inputs operate on current rather than voltage. That is to say that the output voltage of the opamp is equal to its gain times the difference between the two input currents.

The inputs both have the characteristics of silicon diodes with the cathode connected to 0V. While the opamp is operating linearly with negative feedback, it acts to maintain equal currents into its two inputs. Thus the charging current for C6 must equal the current fed into the positive input by R7 and VR1.

When the reset pulse arrives, a very large current is fed into the negative input which causes the capacitor to discharge rapidly and the output to go to 0V. Once all the charge is removed from the capacitor the diode effect on the opamp light terminal prevents reverse charging from occurring. This means that the integrator starts to ramp up as soon as the reset pulse finishes. Norton opamps will be covered more fully later in the series.

MASTER CONTROL

As mentioned above, the ramp signal is added to the brightness control signal. The brightness control signal itself is derived from a potentiometer whose top end is fed from another potentiometer via a transistor to increase the current capability. This method can be used to feed any reasonable number of secondary control pots from one master pot.

The ramp and brightness control signals are fed to a Norton opamp connected as a comparator. Its inputs are protected from interference by 470pF capacitors as with the reset pulse comparator.

When the comparator output switches high, the transistor, Q2 or Q3, is turned on, and this switches on the opto-triac, IC3 or IC4. This in turn triggers on the main triac which carries the load current. Because this is a phase control circuit, it can generate a lot of interference, so inductors are used in series with the output to filter out radio frequency interference. A 10μ resistor is included in series with the filter capacitor, to damp the circuit and prevent possible resonance problems.

The TIC206D triac is guaranteed to trigger with a gate current of 5mA, except in quadrant four, when it may require 10mA. It will not be used in quadrant four in the circuit, but only in quadrant one and three, so it is capable of being triggered via its gate current limiting resistor, even when the mains is near to the zero crossing point. To prevent leakage in the opto-triac from spuriously triggering the TIC206D, a gate leakage resistor, R15 or R24, is included.

This circuit has not been tested as it is drawn, but all the element of it have been used in other contexts in the past. Should you wish to build this circuit on Vero board, take care that a stray uncut Vero track does not nullify the isolation of the opto-triacs. If in doubt, cut holes in tracks adjacent to tracks carrying mains for extra safety.

The rfi filtering inductors L1 and L2 may be made by winding about fifty turns of 0.5mm diameter wire onto a piece of ferrite rod salvaged from an old radio set. A better alternative would be to use a T94-40 toroidal iron dust core available from Cirkit.

Because the timing for the reset pulses is derived from the mains transformer, this component should not be too heavily loaded. For the current consumption of the circuit as shown, a 6VA transformer would be adequate, though a higher rated one would be preferable. If any other circuitry is to be powered from the same transformer, then a higher rated component should definitely be used.

To adjust the circuit for correct operation, set the brightness controls to minimum and adjust VR1 until one or both of the lamps light dimly, then back it off until both lamps are completely extinguished. At the very least this circuit will make a suitable starting point to experiment further with lighting control.

possible circuit for a simple zero level triggered lighting control unit is shown in Fig.87.

This circuit shows a simple sound controlled light which will flash a lamp in time with the bass line of the music. The isolation between the audio input and the triac is provided by a transistor-type opto-isolator. The signal circuitry is operated from an ordinary transformer power unit, but the triac triggering circuitry is powered via a mains dropper resistor. The current available from this sort of circuit is given by the formula I(average) = V(peak)/(pi*R). The peak of the mains voltage is 340V and the resistor value is 22k, so a current of 4.9mA is available. This is plenty to power the logic and trigger the triac.

The triac is triggered only on mains zero crossings. Two Schmitt nand gates are used, IC1a and IC1b. When the mains voltage is close to zero, the biasing resistors set the output of IC1a to logic 1 and the input of IC1b not connected to IC1a *also* at logic 1, which means that the output of IC1b is at logic 0. Positive mains voltage in excess of approximately 60V will switch the output of IC1a to logic 0, thus forcing the output of IC1b

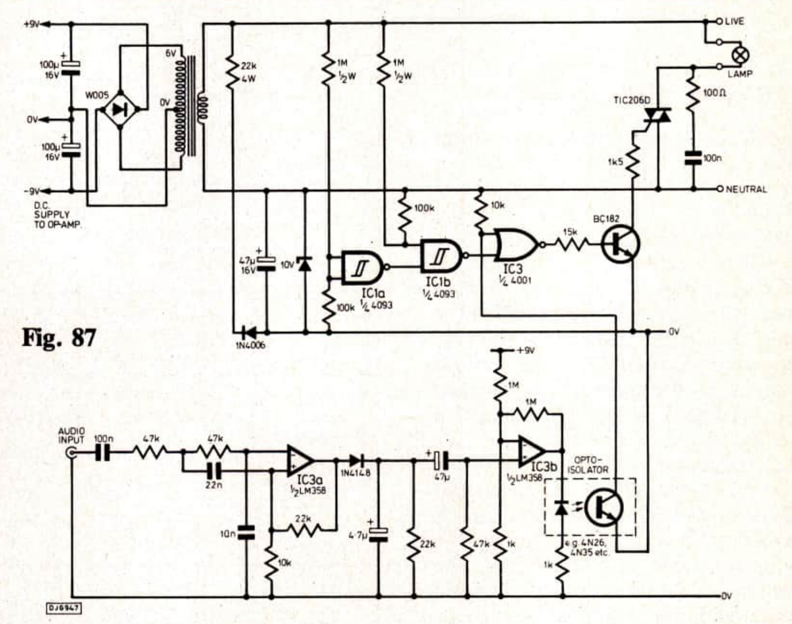


Fig. 87

Some sound controlled lighting units flash the lights in time with the music rather than varying their brightness. If these units are designed only to trigger the triacs near the mains zero crossing, no significant radio frequency interference is generated. A filter indicator is not required in such a circuit, though a snubber network is required in order to afford some protection for the triac.

This style of lighting control has the advantages of being sufficiently coarse and obvious for the most hardened disco goer, of not interfering with sensitive sound equipment, and being slightly simpler and therefore more reliable. A

to logic 1. Negative mains voltages of greater than 60V will register as logic 0, on the other input of IC1b, thus forcing its output to logic 1.

All this means that on the output of IC1b is a series of brief negative pulses synchronised to the mains zero crossings. These pulses are gated together with an opto-isolated signal derived from the audio signal in order to trigger the triac.

Note that the input protection diodes of the 4093 protect the input of this gate from signal levels which would otherwise significantly exceed the power supply rails. Note also that half watt resistors

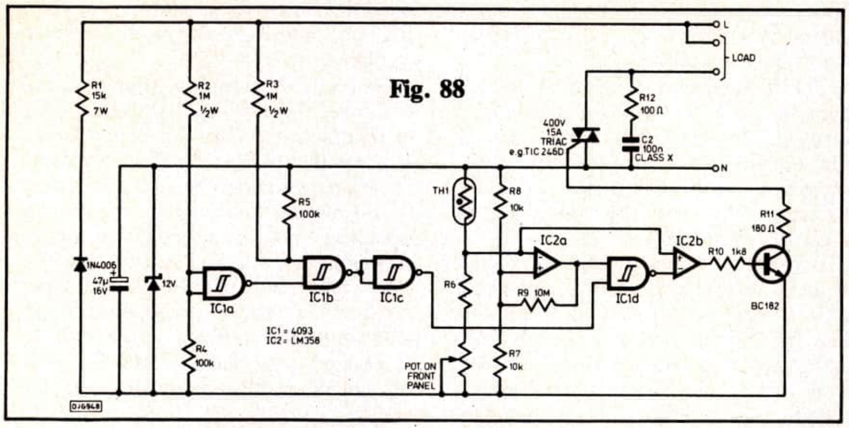


Fig. 88

are used to take a signal from the mains live terminal because most quarter watt resistors are not rated at mains voltage.

The audio signal processing itself is very simple. IC3a is connected as an active low pass filter with gain set at a frequency of 228Hz. Positive half cycles of signal are rectified to generate a varying dc level. This varying dc level is ac-coupled to a comparator, via a longer time constant than that which stores the dc voltage. The effect of this is to provide a sort of automatic gain control in that the comparator will always switch at approximately the average dc signal.

EXPENSIVE THERMOSTAT

Fig.88 shows an electronic thermostat intended for an electric heater. It uses zero crossing detection circuitry just like that of Fig.87. The power to run the circuit comes via a mains dropper resistor, which is a very cheap means of powering a circuit but gives very limited current. Consequently, the design of the circuit has been chosen to use the minimum of current. Brief high current pulses are used to trigger the triac, but these average to a low current over a mains cycle.

The triggering of the triac is turned on or off under control of an opamp wired as a comparator which is caused to switch one way or another by the varying resistance of a thermistor. The output of this comparator is gated together with the zero crossing signal by IC1d. IC2b simply serves as an inverter to get the signal to the correct polarity. Note that a negative power supply is used so that negative trigger pulses are applied to the triac. This avoids operating the triac in quadrant four, where some devices will not trigger.

This circuit must be more expensive than a mechanical thermostat, but it is also more accurate, faster responding, and can be arranged to give less hysteresis. While it is unlikely to be justified for most domestic uses, there may be some occasions on which it is justified. In any event, it serves to illustrate a fairly economical way of designing triac control circuitry.

SOLID STATE RELAY

There is a device available which combines the requirements of isolating the control circuitry from the mains and providing zero level triggering. This device is the ssr (solid state relay). Very often these devices use thyristors connected in an anti-parallel configuration, rather than triacs, to control the mains. This gives a lower voltage drop than an equivalent current rated triac. The voltage drop can be very significant in some ssr applications, not because of loss of power, but because of power dissipation, causing a need for large and efficient heat sinks.

Table 5

Thyristors Type	Cont. current	Surge current	Trigger current	Voltage Notes
TIC106	5A	30A	200μA	Suffix denotes voltage. eg. A=100V, E=500V, M=600V, N=800V.
TIC126	12A	100	20mA	Suffixes as TIC106
BT145-500R	16	300	35mA	500V (Suffix denotes voltage)

Table 6

Triacs Type	RMS current	Surge current	Trigger current	Voltage Notes
TIC206	4A	25A	5MA (quadrants 1 to 3) 10 ma (quadrant 4)	Suffix denotes voltage as TIC106
TIC226	8	70	50mA (quadrants) 1 to 3)	Suffix denotes voltage as TIC106
TIC246	16	125	50mA (quadrants 1 to 3)	Suffix denotes voltage as TIC106
BT134-500G	4	25	50mA (quadrants 1 to 3) 100mA (quadrant 4)	500V Suffix denotes voltage

Table 7 Thyristors & Triacs

Opto Type	Trigger current	Output current	Voltage	Remarks
H11C4	11mA	300mA	400V	Thyristor
H11M1	7mA	300mA	800V	Thyristor
MOC3020	30mA	300mA	400V	Triac driver
MOC3021	15mA	300mA	400V	Triac driver
MOC3041	15mA	300mA	400V	Triac driver with built in zero crossing triggering

For example, if the voltage drop across an ssr is 1.5V, and it is controlling a 30A circuit, the power dissipation will be 45W. A device of this nature is likely to be used in an industrial situation where the ambient temperature may be as high as 40°C. Typically, a maximum case temperature of 80°C may be specified, to achieve which requires a heat sink of better than 1°C/W heat sinking capacity.

One more device which we must mention is the Chipswitch made by International Rectifier. This is a type of solid state relay which uses back to back optically coupled high voltage switching ics whose switching element is a power mosfet. These devices can withstand higher voltage slew rates than triacs without breaking down. They are available in a range of currents and voltages, but the majority are rated for mains operation. These devices are still rather expensive for amateur use, but can be valuable industrially because they can often be used without a snubber network.

This concludes the section on thyristors and triacs. After a month's break, I shall continue the series in the October issue with a look at the design and usage rules which apply to the more common logic families.

PE

BOSFET SSRS

Just as we go to press on Andrew's article on Triacs, International Rectifier have announced the release of two miniature photovoltaically coupled solid state relays. The PVA10 series of SSRS use IR's bosfet power ics and can switch current up to 160mA. They have output capacitances as low as 3pF and switching speeds of less than 25μs, making them ideal for situations ranging from thermocoupling to data transmission. **Ed.**