Electric Heater Control

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Three circuits are described which employ a triac to switch electric heaters for room temperature control and similar applications. In all the circuits zero voltage switching is employed to eliminate radio-frequency interference. One of the circuits is controlled by a thermostat, the second by a thermistor and the third, which also uses a thermistor, varies the thermal output of the heater. The result is that when the room has reached working temperature the output of the heater balances the heat losses from the room and very stable control of temperature is obtained.

Fig. 1 shows the circuit of a synchronous zero-voltage gating circuit, connected as a thermostat-regulated heater-controller. The circuit can control heater loads in the range 300W to 2.4kW using the specified triac. The circuit works as follows.

Transistors Tr_1 and Tr_2 are connected as a zero-voltage detector that is driven from the a.c. power line via current-limiting potential divider R_2 and R_3; Tr_2 is wired as a common-emitter amplifier, and is driven on whenever the line voltage is substantially positive; Tr_2 is wired as a common-base amplifier, and is driven on whenever the line voltage is substantially negative. The combined effect of Tr_1 and Tr_2 is thus such that one or other of these transistors is driven on whenever the instantaneous line voltage exceeds a certain 'reference' value and both transistors are off when the line voltage is below this value. The reference value approximates to:

$$V_{be}[(R_2+R_3)/R_3].$$

where V_{bc} is the forward base-emitt voltage of Tr_1 or Tr_2 ($\approx$600mV).

The collectors of Tr_1 and Tr_2 are coup to the base of the gating transistor Tr_3 via R_4 (R_5 is the collector load when the thermostat contacts are closed). Resistor R_5 provides base drive to the switching transistor Tr_4, which has R_6 and the triac gate as its collector load. Transistors Tr_3 and Tr_4 are powered from a zener diode regulated 10V d.c. supply derived from the a.c. line via R_1, D_1 D_2 and C_1. The thermostat contacts are closed at low temperatures and open at high temperatures. The combination R_7 and C_2 act as a simple suppression network to prevent the triac from being turned on by line transients.

To understand the circuits action, assume that S_1 is 'on' and that the instantaneous a.c. line voltage is at some value in excess of a reference value of, say 5V. Under this condition either Tr_1 or Tr_2 is driven on and Tr_3 is driven to saturation via R_4. The saturation voltage of Tr_3 is lower than the base-emitter turn-on voltage of Tr_4, so Tr_4 is cut off and no gate drive is applied to the triac.

Suppose now that the instantaneous line voltage falls below the 5V reference value (line voltage almost zero at the start or finish of one half-cycle). Transistors Tr_1 and Tr_2 turn off and remove the base drive from Tr_3 and Tr_4 is driven into saturation v R_5. As Tr_3 turns off current flows into the triac gate through R_6 which turns the triac on and causes it to self-latch for the duration of the half-cycle. Thus, gate trigger current is applied to the triac only in the brief periods when the line voltage is close to zero and negligible radio-frequency interference is generated.

With S_1 in the auto position the heater is controlled by the thermostat. When the correct temperature is reached the thermostat's contacts open circuit the collector of Tr_3 and prevent the triac from being turned on.

The circuit is useful in that it illustrates the use of a triac to control a heater without generating radio interference and enables a thermostat with very light contacts to be used.

The only adjustable component in the circuit is R_3, which controls the 'reference' voltage and the width of the triac's gate pulse. This pulse must not end until the current through the triac has risen above the minimum holding current otherwise the triac will fail to self-latch. However, the pulse must not be too wide, otherwisc r.f. interference may be generated when the thermostat's contacts close, or the low-voltage d.c. supply may be overloaded. The pulse width must be adjusted to suit th particular heater load that is used with the circuit. If a multi-value load (a two or three-bar heater) is used, R_3 must be adjusted with the heater in the minimum load position. To adjust R_3, proceed as follows.

Set S_1 to 'on' and R_3 to maximum

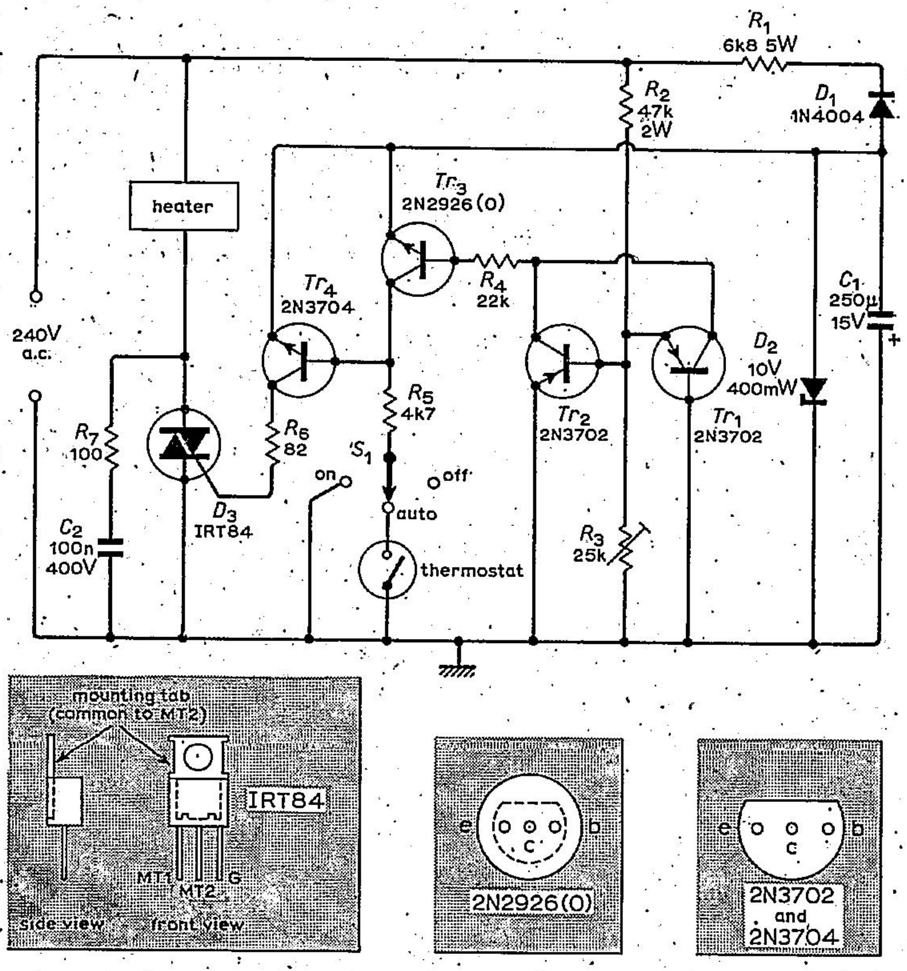

Fig. 1. Basic, zero voltage switching, triac heater control circuit. In this case the temperature sensing element is a thermostat.

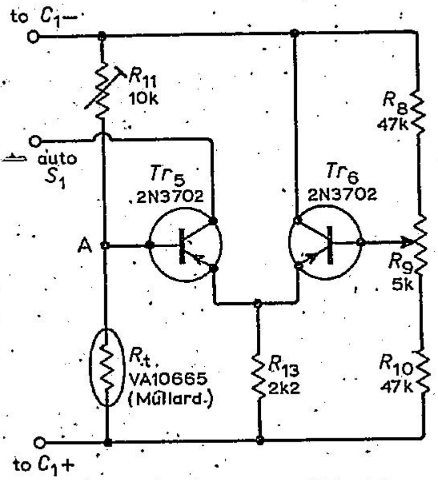

Fig. 2. When the thermostat of Fig. 1 is replaced by this circuit room temperature is measured by the thermistor which is part of a bridge. The bridge and long-tail pair control the triac and therefore the heater.

resistance. Connect a voltmeter across C_1, and apply power to the unit. A reading of approximately 10V should be obtained. Slowly reduce R_3 to the point at which the triac just turns on and applies full power to the heater (if the heater turns on with R_3 at the maximum value, increase R_3 to 50kΩ). Check that a reading of 10V is still obtained across C_1. Remove all power from the circuit and measure the value of R_3. Now set R_3 value to roughly half of the measured value. Finally, reconnect power to the unit and check that the heater turns on and that C_1 still gives a reading of 10V.

Note: The circuit is designed to operate with a minimum heater load of about 300W. If the voltage across C_1 falls appreciably below 10V it is probable that too low a heater load is being used. In this case the circuit should be used with an alternative triac, which should have a lower holding current rating that the device specified.

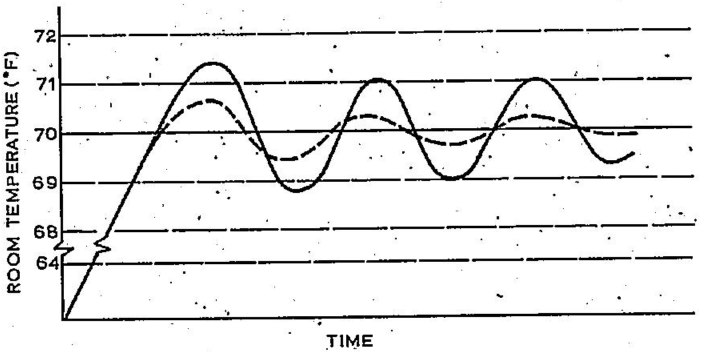

Fig. 3. A comparison of the performance of the thermostat and thermistor controlled circuits of Figs 1 and 2.

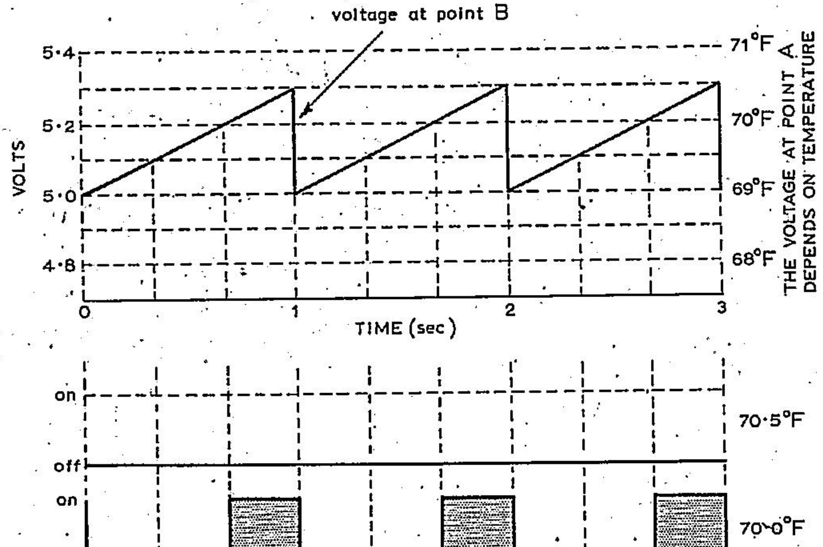

Fig. 4. Showing how a sawtooth waveform impressed on the base voltage of Tr_6 allows proportional control of the heater to be obtained.

Thermostat controlled heater switch

Fig. 2 gives the extra circuitry needed to replace the thermostat of Fig. 1 with a thermistor. The basic synchronous zero-voltage gating circuit remains unchanged except that the thermostat is omitted and the auto position of S_1 is connected to the collector of Tr_5 (Fig. 2). Resistors R_8, R_9, R_{10} and R_{11} and the thermistor R_t are wired as a temperature-sensitive bridge with Tr_5 and Tr_6 bridge-balance detector. Resistor R_5 of Fig. 1 (the inhibit resistor) is used as the collector load of Tr_5.

When the room (thermistor) temperature is low Tr_5 is driven hard on and current is available to R_5, turning the triac, and therefore the heater, on synchronously. When temperatures are high Tr_5 is cut off and no current flows in the heater.

When the temperature is close to the pre-set value Tr_5 is driven partially on, and the magnitudes of the current in both R_5 and the triac gate are proportional to the difference between the actual and the pre-set temperatures. The operating condition of the circuit in this circumstance depends on the magnitudes of these currents, as follows.

The triac in the Fig. 1 circuit is gated on during positive and negative half cycles but the gate drive stays negative. Under these conditions the IRT84 triac has typical gate sensitivities of 35mA for the positive half cycle and 15mA for the negative half cycle. Consequently, if the thermistor temperature is low and the bridge is out of balance sufficiently to cause the application of a gate current in excess of 35mA, the triac is driven on for both (positive and negative half cycles and applies full power to the heater. As the temperature rises the bridge goes closer to balance and the triac gate current decreases. When the gate current falls to a value less than 35mA but greater than 15mA the triac ceases to trigger during positive half cycles and it applies half power to the heater. When the temperature-sensitive bridge is nearly balanced the triac gate current falls to less than 15mA; all power is removed from the heater.

Thus, with the combined circuits of Figs 1 and 2 controlling a heater, room temperatures can be accurately controlled. The procedure for setting up the circuit is as follows.

First adjust R_3 in the same way as described earlier. Turn S_1 to the auto position and set R_9 to mid-value. Raise the thermistor to the required turn-off temperature, and adjust R_{11} so that the heater goes into half-wave operation. All adjustments are then complete, and the circuit is ready for use. Potentiometer R_9 enables the turn-off temperature to be varied a few degrees about the value pre-set by R_{11}.

Fig. 3 shows the typical performance (temperature-regulation) graph of the Figs 1 and 2 circuits when set to maintain a room temperature of 70°F. Room temperature rises fairly rapidly at first and then fluctuates about the pre-set level. There are two basic causes for the fluctuations. One cause is the thermal backlash of the electronic control system or the temperature sensor. The other is the thermal time constant of the room and/or the heater. Heat output does not fall abruptly when power is removed from the heater, so the room temperature continues to rise for a short period after the heater is turned off. This heat permeates slowly through the room, and takes time to warm up the thermistor on thermostat.

The thermal over- and under-shoots of the thermostat-regulated circuit are dictated primarily by the backlash of the actual thermostat, which is assumed to be ±1°F in Fig. 3. The performance of the thermistor-regulated circuit is dictated primarily by the thermal time constants of the room and the heater, but typically, it will hold room temperature to within ±0.3°F of the pre-set level.

Integral-cycle heater controller

Very precise room temperature control can be obtained by varying the output of the heater. Phase-controlled variable-power systems can not be used for heater control, due to the severe radio frequency interference problems that are involved at high power levels.

Fully variable interference free control of heater output can, however, be obtained using synchronous, internal-cycle, switching, in which power is applied to the heater for only a definite integral number of half-cycles. Thus, if power is applied for only fifty half-cycles in each hundred the heater will operate at 50% of full power, and if power is applied for ninety half-cycles in every hundred it will operate at 90% of full power, and so on.

Thermistor-regulated synchronous circuits can be designed to give fully automatic integral-cycle variable power control of electric heaters. Such circuits give very accurate regulation of room temperatures. The operating principle of a self-regulating integral-cycle heater controller can be understood with the aid of Figs 2 and 4.

A repetitive sawtooth waveform, with an amplitude of 300mV and a period of one second, is applied to the base of Tr_6 (point B) via a capacitor, and the circuit action is such that an inhibit signal is fed to the synchronous triac on-off circuit whenever Tr_5 turns off as the instantaneous voltage at point B goes negative to that at A.

Fig. 4 shows the voltages that appear at points A and B under different temperature conditions when the circuit is set to maintain a room temperature of 70°F, and shows the resulting heater output levels at four different temperatures. It can be seen that a low-amplitude saw-tooth waveform is superimposed on a fixed reference potential of 5V at point B in the circuit, and that a steady potential appears at point A but has an amplitude that varies with temperature. Variable resistor R_{11} is adjusted so that its resistance is slightly greater than that of the thermistor at 70°F, so that a potential of 5.2 V appears at point A under this condition.

Thus, when the room temperature is below 69°F the thermistor resistance is high and point A is always negative to point B, so Tr_5 is biased on and full power is applied to the heater, as shown in Fig. 4. As the room temperature rises the resistance of the thermistor decreases, and the potential at point A falls. Consequently, the circuit passes through an area (between 69°F and 70.5°F) where Tr_5 is turned on and off once every second by the sawtooth waveform at point B. When the temperature rises to 69.5°F, Tr_5 and the heater are turned off for one third of each one-second sawtooth period, so the heater output falls to two-thirds of maximum. At 70°F Tr_5 and the heater are turned off for two-thirds of each one-second period, so the heater output falls to one-third of maximum. Eventually, when the room temperature rises to 70.5°F, the voltage at point A becomes positive to that at point B, so Tr_5 and the heater are turned off.

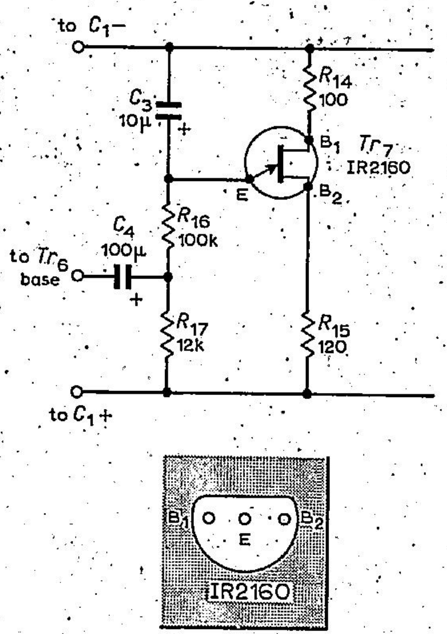

Fig. 5. Sawtooth oscillator which converts the circuits of Figs 1 and 2 to an integral cycle heater controller.

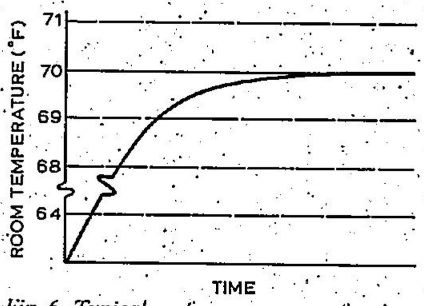

Fig. 6. Typical performance curve for the integral cycle controller.

The important point to note about the self-regulating integral-cycle heater control system is that it applies full power to the heater until the room temperature rises to within a degree or so of the pre-set level, and that the heater output then reduces progressively as the pre-set level is approached, the heat output being proportional to the thermal requirements of the room. Eventually, when the pre-set temperature is reached, the heater is not switched fully off, but gives just sufficient output to counterbalance the natural heat losses of the room. The heater is switched off only when the room temperature is raised slightly above the pre-set level by an external cause, such as a rise in outside temperature. The system gives very good regulation of room temperature.

Fig. 5 shows the practical circuit of the sawtooth generator which must be added to the circuits of Figs 1 and 2 to form the self-regulating integral-cycle heater controller.

The output waveform of the unijunct oscillator (Tr_7) is fed to the base of Tr_6 C_4. The sawtooth is inverted in relation to the waveform shown in Fig. 4 but the basic theory of operation is unchanged. The procedure for initially setting up this circuit is quite simple, and is as follows.

First, connect the selected heater in place, turn S_1 to the 'on' position, and adjust R_3 in the same way as described before. Turn S_1 to the 'auto' position, set R_9 to mid-value, raise the thermistor to the required 'normal' room temperature level, and then adjust R_{11} so that the heater output drops to roughly one third of maximum. All adjustments are then complete, and the circuit is ready for use. Room temperatures can be varied several degrees about the pre-set level with R_9.

Fig. 6 shows the typical performance of the unit. When first switched on the room temperature rises fairly rapidly to within a degree or so of the pre-set level. The temperature then slowly settles down to the pre-set level, with negligible overshoot or undershoot.

Practical points

Construction of the units should present few problems. The layouts are not critical, and the circuits can be wired up on Veroboard o on specially designed printed circuits. Resistor R_1 is a 5W type, and R_2 is rated at 2W; these two resistors should be mounted well above the surface of the board, and should be separated from all semiconductors and from C_1. Triac D_3 dissipates roughly 8W per kilowatt of heater load, and must be mounted on a suitable heat sink.

The triacs used in the prototype circuits are the recently introduced IRT84 types, manufactured by International Rectifier. This is a 10A; 400V plastic device, and is available from a number of suppliers. Other triacs may be suitable for use in place of the IRT84, but they must have low holding-current values. Unmarked triacs are to be avoided in these circuits. Unijunction transistor Tr_7 is another International Rectifier device.

When installing or testing the circuits remember that they are 'live', and that they should be screened so that they cannot be touched by children or other inquisitive individuals. The thermistor or thermostat should be placed remote from the main unit and positioned so that it responds to mean room temperature. It should be mounted two or three feet above ground level, and must be out of the way of draughts and sources of direct heat. The temperature-sensing 'head' should be mounted in a we ventilated but tamper-proof box, and should be connected to the main unit via a screened lead that is safe for use at mains voltages. Do not use the flimsy screened cable sometimes used for microphones and other low-level sources.