

The OM1682 is now obsolete and
has been replaced by the OM1682A.

This application note applies fully
to the OM1682A, without alteration.

Please read OM1682 as OM1682A.

Input sensing bridge design for the OM1682 triac controller IC

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Input sensing bridge design for the OM1682 triac controller IC

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1 SUMMARY

This application note describes the design of input sensing circuits for the OM1682 Precision Triac Controller IC. The sensor inputs of the OM1682 allow the use of simple very low power resistive bridge circuits, fed directly from the AC mains supply. Such sensing circuits eliminate the need for a separate DC supply, minimising power supply requirements and susceptibility to uncertain switching due to RFI or spurious mains-born signals. Examples show how signals derived from the triac or load can be used to generate hysteresis or “burst-mode” (variable duty cycle) operation. Having the sensing bridge external to the IC provides enormous flexibility, and enables the thermostat designer to provide any required thermostat characteristic.

2 INTRODUCTION

The OM1682 is a multi-purpose triac control IC, which together with a few peripheral components and external temperature sensor (NTC), performs the function of an electronic thermostat. It is suitable for a broad range of applications. In addition to the basic zero-crossing control of a heating element in applications such as water heaters, panel heaters, industrial temperature control (oil baths etc.) it is also capable of controlling inductive loads like fan motors, air conditioners, refrigerators and other more complex loads.

The OM1682 has a number of advantages over other types of triac controller ICs, the main features being:

- Very low supply current
- Low external components count
- Negative triac gate drive (avoids insensitive quadrant operation)
- Suitable for inductive or resistive loads
- Precise zero-crossing detection circuit
- Sensor can be AC powered, minimising DC supply filtering needs
- Hysteresis can be applied using external components, and can be configured easily to meet a wide range of temperature requirements.

This Application Note is the second in the OM1682 series, and covers the design of the input sensing bridge configuration only. The power supply and zero-crossing detection function of the OM1682 is specifically not discussed here, as it has already been covered in the Application Note AN001.

Power to the OM1682 can be derived from the zero-crossing sensing components, using a minimum of external components.

Control sense inputs (described in this report) are driven by a sensing bridge connected directly across the ac mains supply.

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3 SENSE INPUT CIRCUIT OF THE OM1682

3.1 Sensor inputs SA and SB

The OM1682 has two sensor inputs, SA and SB, which are symmetrical current inputs designed to accept signals referenced to common. The equivalent sensor input circuit is shown below in Figure 1. Each sensor input is effectively the emitter of a PNP transistor, and for the purposes of input circuit analysis can be considered to be at the same potential as V_{CC} . In other words inputs SA and SB can be considered to be at “virtual common”. Both inputs have back to back diodes connected to V_{CC} to protect against excessive voltages on the inputs.

Voltages signals derived from a sensing element (NTC, PTC or other) can be applied to inputs SA and SB via current setting resistors. The sensor inputs will accept both positive and negative going signals, although only positive signals contribute an input current to the capacitor

connected to the CAP pin, and the voltage level comparators.

Negative input signals are clamped to V_{CC} by the input diodes, and do not contribute input current to comparator circuit. Using this input configuration, both ac and dc input signals can be applied to the sensor inputs, although ac inputs are recommended for simplicity.

By not using a DC supply rail to drive the sensor inputs, problems associated with providing a power supply capable of supplying sufficient DC current to drive the sensor and associated networks over the full operating range are avoided. Also power supply ripple and filtering considerations are not relevant to the input measuring circuit. In addition by providing balanced differential inputs operating at close to the V_{CC} rail potential, control signals which either increase or decrease with the parameter to be regulated (temperature, pressure, humidity etc.) can be handled.

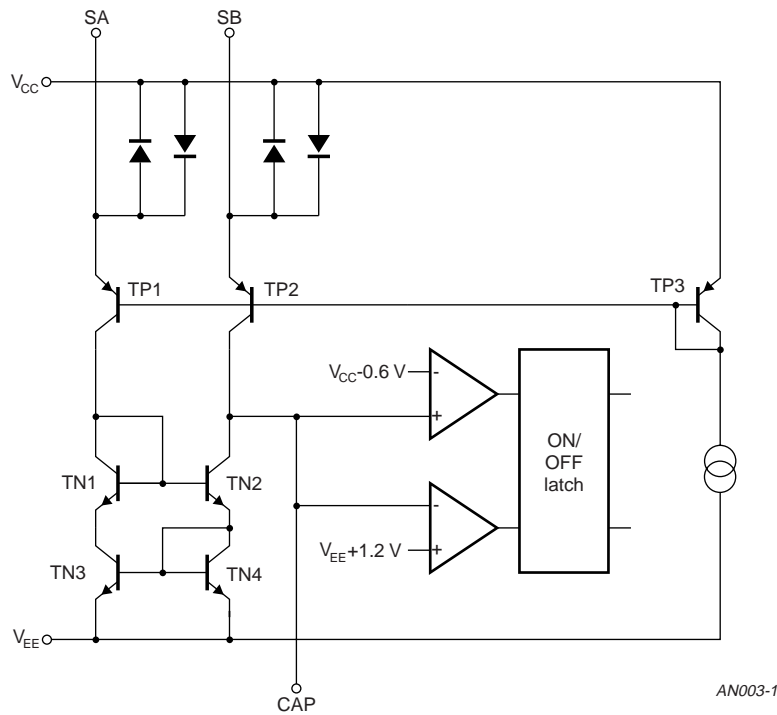


Fig.1 OM1682 sensor input circuit

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In the typical application a resistive sensor, together with a level setting variable resistor, is used in a bridge arrangement as shown in the basic input bridge circuit of Figure 2. The resistor R4, applies a current proportional to the voltage across the AC sensor to one of the two sensing inputs, and another equal resistor R3, gives a current derived from the voltage on the setting resistor to the other input. The circuit will be balanced when the two input currents are equal, and any change in the sensor resistance will generate a difference signal between the input currents to SA and SB. This difference current is integrated in a capacitor connected to pin CAP.

When the current into pin SA is greater than the current into pin SB, the voltage on pin CAP will be driven negative towards the OFF threshold comparator. When the current difference is reversed, and the current into SB is the greater, then the current difference will charge CAP positively towards the upper ON threshold.

A typical circuit will power this sensing circuit via a high value resistor taken from the AC supply. While the circuit is in balance the timing capacitor voltage remains steady, but once the sensed parameter changes and causes an

imbalance, then the capacitor will charge or discharge as a result of the imbalance depending on which input current is the greater. After a delay resulting from the time needed for the capacitor on CAP to charge to the threshold voltage, it initiates a change from ON to OFF or vice-versa. The charging or discharging current is the difference between the two current input signals applied to SA and SB.

The use of the timing capacitor connected to the CAP terminal provides inherent filtering of the sensing signal, and as the SA and SB inputs are driven by AC signals, filtering of transient interference signals is inherent in this circuit. However they may also be driven from a positive DC source; for example, from a remote sensor with its own power supply, and still have the advantage of the inherent interference rejecting characteristics of the timing capacitor.

Only the positive half of the input AC signal is used to generate the difference signal between SA and SB; on the negative half cycle the voltage is clamped to one V_{BE} below the V_{CC} rail.

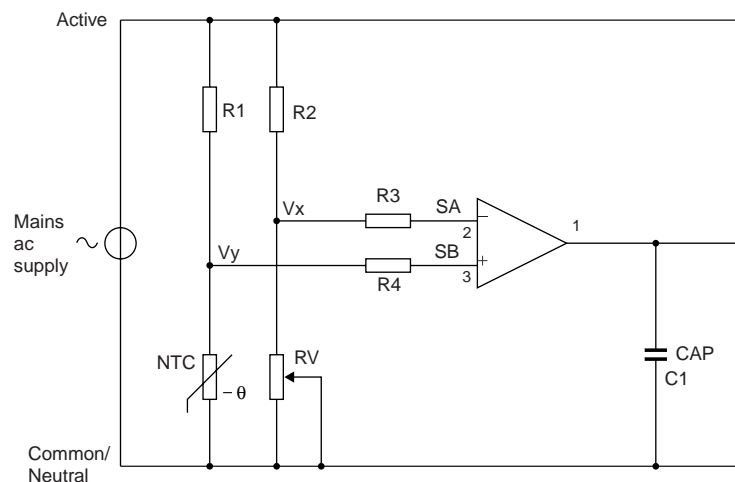


Fig.2 Basic sensor input bridge circuit (heating)

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3.2 CAP – Timing capacitor

The timing capacitor is connected from CAP to either V_{EE} (substrate, -ve) or to V_{CC} (common, +ve). The charge and discharge times of this capacitor limit the ON and OFF cycle times, and give minimum cycle times proportional to the capacitance value as well as to the maximum difference in current levels at the two sensor inputs SA and SB.

The capacitor connected to the CAP pin can be returned to either V_{EE} or to V_{CC} . Generally the power supply rises slowly, and by the time it has reached its operating voltage, the voltage on CAP will have already been determined as OFF or ON by the currents generated in the input circuit.

If the power supply rises quickly, by connecting the capacitor to V_{EE} the condition after switching on, once the power supply has reached its working voltage, is for the triac to be off, and for it to only turn on when the input sensing circuit generates a charging current to bring the timing capacitor to its upper threshold. If connected to V_{CC} , then the first period after switch-on is ON.

The charging and discharging periods, that is the ON or OFF times, vary with the magnitude of the difference in input currents applied to SA and SB from the sensor. When the capacitor charges towards the V_{CC} rail, and reaches an upper threshold of one V_{BE} below the V_{CC} rail, then the “request for firing latch” is set in the ON condition; the control circuit is ready to start an ON cycle at the next appropriate zero-crossing of the mains supply. (see Figure 1, OM1682 sensor input circuit).

The ON period is synchronised with the mains zero-crossing signals, as sensed by the TS and LS inputs. Internal logic ensures that with a resistive load an integral number of full cycles makes up the ON period, and no DC signal is generated in the supply line. With an inductive load every ON period starts by conducting in the opposite direction to the first half cycle of the previous ON period in order to minimise magnetising inrush current in transformer or motor loads.

During the ON cycle, the imbalance in the input signal currents that caused the capacitor to charge to the upper threshold voltage, will change, and the new difference between the signals into SA and SB discharge the capacitor, with the voltage on the CAP pin approaching the V_{EE} rail. The lower threshold is two V_{BE} above V_{EE} , and when this threshold is reached the latch which was set by the request for an ON cycle is reset. When the “request for firing latch” is reset, the timing circuit stops driving the gate only after the programmed even or odd number of conducting half cycles.

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4 INPUT SENSING BRIDGE DESIGN

4.1 Basic input bridge circuit

A simple sensing bridge circuit is shown in Figure 2. The bridge is normally connected directly across the ac mains supply, with a temperature sensing thermistor (NTC) in one branch of the bridge, and a level setting variable resistor in the other. The bridge circuit shown is configured for a heating application, with the NTC branch of the bridge feeding input SB via R4, and the voltage on the variable resistance branch feeding input SA via R3.

The circuit could be configured for a cooling application swapping the connections of the NTC and variable resistor arms to the SA and SB inputs to the OM1682. That is by connecting R4 to the SA input, and R3 to SB.

Using this type of input bridge with the OM1682 simplifies the design of the thermostat characteristic. The sensor input section of the OM1682 is quite similar to conventional differential amplifiers. The main difference is that we work with current inputs and not voltage inputs. This is done for several reasons, but the most important reason is that it allows the use of large value (typically > 100 k Ω) resistors in series with each input, providing protection against transients. Once large value resistors have been included at each input, we can consider the voltage ahead of each input resistor, which is then very similar to ordinary differential amplifier.

The fact that the bridge is driven by an AC voltage is of no consequence when analysing the bridge. Assuming $R_1 = R_2$, and $R_3 = R_4$, all we need to do is establish whether, for a given temperature (and therefore NTC resistance value) R_{NTC} is greater or less than the potentiometer resistance, RV, to determine whether the OM1682 will turn the triac ON.

4.2 Guidelines for bridge component selection

There are a few considerations to be taken into account when choosing component values for R1, R2, R3, R4, RV and the sensing element (NTC or PTC etc.) to ensure reliable and safe operation over the full operating range, and simplifying circuit analysis of the bridge. These are as follows.

4.2.1 RESISTORS R1 AND R2

1. Use mains rated resistors.

Remember that these circuits are connected directly across mains voltages, and can therefore be subject to large spurious signals and transients up to several kV. Suitable resistors should be used that will withstand

these voltages without failing, or creating dangerous conditions.

Philips VR25 and VR37 resistors are specifically designed for this purpose, and their use in this application is recommended.

2. Let R_1 and $R_2 > 10 \times$ (max) NTC resistance.

This produces almost constant current into the NTC over the expected operational temperature range, and ensures that the voltage across the NTC is virtually proportional to its resistance.

It also limits the voltage on the NTC to < 1/10 of the mains voltage, to prevent self-heating effects of the NTC from creating errors in switching temperatures.

3. For simplicity let $R_1 = R_2$.

This simplifies the analysis of the bridge, but otherwise is not absolutely necessary. Sometimes it is necessary to give R1 and R2 different values in order to provide a sensible value for the potentiometer RV. If R1 and R2 have different values, the relationship of point 2 above should still be used.

4.2.2 RESISTORS R3 AND R4

1. Use series resistors at inputs SA and SB (R_3 and R_4) of at least 100 k Ω .

This provides good immunity to transients on the mains. Both inputs SA and SB are internally diode protected, so when suitable resistors are used transients of more than several kilovolts would be needed before there is any chance of damage to the OM1682.

2. Make R_3 and $R_4 > 2 \times$ NTC resistance.

This is to minimise the loading effect on the voltage across NTC.

For ease of analysis of the bridge circuit, and also to balance the OM1682 SA and SB input circuits for greater accuracy, it is also preferable to let $R_3 = R_4$.

4.2.3 NTC SENSOR

1. Select a suitable voltage across the sensor.

Design the voltage across the sensor (NTC) and variable resistor (RV) so that the LARGEST voltage in normal operation will cause a current in the input resistor of LESS than 200 μA_{rms} .

With an NTC the largest voltage occurs when the NTC is coldest. In heating applications that is at first switch-on from the coldest expected ambient.

Strictly the OM1682 data requires that the peak total input current (the sum of SA and SB input currents)

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does not exceed 500 μA peak. In practice usually only one of the two inputs has a large enough range of values (the NTC input), so the rough rule of 200 μA_{rms} each is in most cases good enough.

It is possible to work with input currents as low as 10 μA at SA and SB, giving a 20:1 range of acceptable input current values.

4.2.4 CONTROL POTENTIOMETER RV

1. Choose RV to match the resistance change of the NTC.

The value of the potentiometer has to be chosen to match the change in resistance of the NTC so that switching occurs over the entire operating range. If the potentiometer is too small the operating temperature range will be decreased. The NTC values for either end of the temperature range are determined initially, and thus the size of the potentiometer can be determined. It is assumed that the temperature vs potentiometer setting is linear between the two end points.

2. Choose series resistor for minimum potentiometer setting.

A resistor is normally placed in series with the potentiometer so that the bridge can always be balanced. Without a series resistor, when the potentiometer is at minimum the NTC would have to be close to zero ohms in order to balance the bridge. For most NETs such a low resistance can not be achieved, so the thermostat will be ON all of the time at this end of the potentiometer range.

3. Using different values of R1 and R2 to allow suitable RV value.

The size of the potentiometer required can be changed by altering the value of R1 and R2. Making R2 larger than R1 will result in a larger potentiometer being required and making R2 smaller than R1 requires a smaller potentiometer. This allows the size of the potentiometer to be adjusted so that a standard value potentiometer can be used. This is preferable otherwise mechanical stops would have to be used to ensure that the required operating range is not exceeded.

4.2.5 SENSOR INPUTS SA AND SB

1. Relation of SA and SB.

To maintain the correct relation of the input currents it is worth bearing in mind that current input SA is trying to turn the triac OFF, and current into SB is trying to

turn the triac ON. SA and SB are differential inputs, so the net difference between the current into SA and SB (i.e. $I_{\text{SB}} - I_{\text{SA}}$) determines whether the triac will be turned ON or OFF.

The difference of the two input currents is fed to the capacitor C1 on pin CAP. Capacitor C1 filters the difference signal so that there will be no spurious switching should large transients cause one input to exceed the other input for short times.

2. If the two input currents I_{SB} and I_{SA} are EQUAL, then the differential current is zero.

i.e. If $I_{\text{SB}} = I_{\text{SA}}$, then $I_{\text{SB}} - I_{\text{SA}} = 0$.

Thus when the input bridge is balanced such that the input currents are equal, there is no net charge or discharge of capacitor C1 – and so the state of the triac (either ON or OFF) will not change. This means that in order for the state of the triac to change, the bridge must be taken past its balance point.

An imbalance in the currents into sensor inputs SA and SB will result in the capacitor C1 being charged up or charged down. A larger current into SA will result in capacitor C1 being charged down towards the (triac) OFF threshold. The OFF signal indicates to the output driver that a triac gate pulse is no longer required. When the capacitor is charged up and reaches the ON threshold the gate pulses resume upon detection of the next mains voltage zero-crossing.

The temperature at which the bridge is balanced ($I_{\text{SA}} = I_{\text{SB}}$) depends on the resistors R1, R2, R3, R4, the setting of the potentiometer, and the NTC sensor resistance. The potentiometer is used so that the balance point can be changed easily, and so that the customer can set it the required control temperature. Changing the balance point changes the temperature at which the gate pulses are activated or removed.

3. Forced bridge Imbalance.

A further imbalance between the currents applied to SA and SB (apart from that resulting from the action of the sensor) can be created by an additional resistive path that introduces another AC signal. For example if this signal is taken from the AC signal across the triac when it is off, it will add to the signal already present in SA or SB.

This additional imbalance can be used to create hysteresis around the control point (see Section 7. It can also be applied in a manner to decrease hysteresis to force more frequent cycling around the control point: ultimately more of this kind of feedback determining the cycling rate and overriding the sensor signal.

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In one application circuit the sensing bridge is powered from across the triac during the OFF period, and from across the load in the ON time, then suitably chosen fixed resistor values give this electronically induced imbalance. This is the circuit where the triac T1 and the load are connected (see AN001): the common connection between the triac and the load is also the common reference for the OM1682 control IC. When the triac is ON, this common connection is almost at active potential, and while the triac is OFF, via the load it is at neutral.

4. Connection for cooling applications.

For an application requiring cooling the NTC is connected to SA and the potentiometer to SB. This is done so that an ON condition is in effect while the NTC temperature is above the balance point temperature. Increasing the setting of the potentiometer will result in more current flowing into SB. This moves that the balance point to a lower temperature. An ON condition will remain until the temperature decreases to a point where the bridge becomes balanced. Any increase in temperature, to above the switching point will result in the current into SA being larger than SB and thus an ON condition is achieved.

For cooling, if feedback is taken from the triac to give hysteresis, this is applied across the sensor arm of the bridge.

5. Connection for heating applications.

Heating applications require the NTC to be connected to SB and the potentiometer to SA. This needs to be done so that once the temperature rises above the switching point an OFF condition is achieved. Increasing temperature results in the NTC resistance decreasing until the current into SB falls below that of SA. The capacitor will then be charged down until the OFF condition is reached and heating stops until the next heating cycle when the NTC sensor has cooled.

For heating, if feedback is taken from the triac to give hysteresis, this is applied across the setting arm of the bridge.

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5 SIMPLE ON/OFF CONTROL

5.1 Fixed sensing bridge

With single temperature switching the gate pulses are activated and removed at the same NTC resistance value. That is, at the same temperature. Once the temperature reaches this point the status of the sensor inputs is changed from ON the OFF or vice versa depending on whether the temperature is rising or falling and the type of application. The temperature at which the switching occurs depends on the characteristics of the NTC and the value of R5.

This single temperature ON/OFF arrangement is a rather trivial one, but still helps to understand the operation of the sensing bridge. In this arrangement no adjustment of the switching temperature is required, and in Figure 3 below, RV is replaced by a single fixed resistor R5.

For the purpose of analysis the input bridge circuit can be redrawn as shown in Figure 3.

Clearly using the assumptions listed in 4.2 (i.e. let R1 = R2 and R3 = R4), then the bridge is balanced when R5 = R_{NTC}. Therefore the value of R5 is chosen to be equal to the NTC resistance R_{NTC} at the switching temperature.

5.2 Example 1: ON/OFF heater at fixed temperature

A simple ON/OFF controller using the OM1682 is required to control the temperature of water in a coffee-maker at 94 °C. The controller is powered from 230 V_{ac} mains. A suitable NTC sensor for this temperature is the Philips type 2322 633 83303, which has a value of 30 kΩ at 25 °C, and a β value of 3977.

5.2.1 NTC RESISTANCE AT THE SWITCHING TEMPERATURE

We can calculate the resistance value of the NTC sensor at the desired switching temperature using the equation given in appendix 1 (where 94 °C = 367 °K).

$$R_{T2} = 30 \cdot e^{3977 \cdot \left(\frac{1}{367} - \frac{1}{298} \right)}$$

$$= 2.44 \text{ k}\Omega$$

If R1 = R2, and R3 = R4, then the sensing bridge will be in balance when R5 is to equal the NTC resistance at the switching temperature. Therefore choose R5 = 2.4 kΩ, with a tolerance of ±1%.

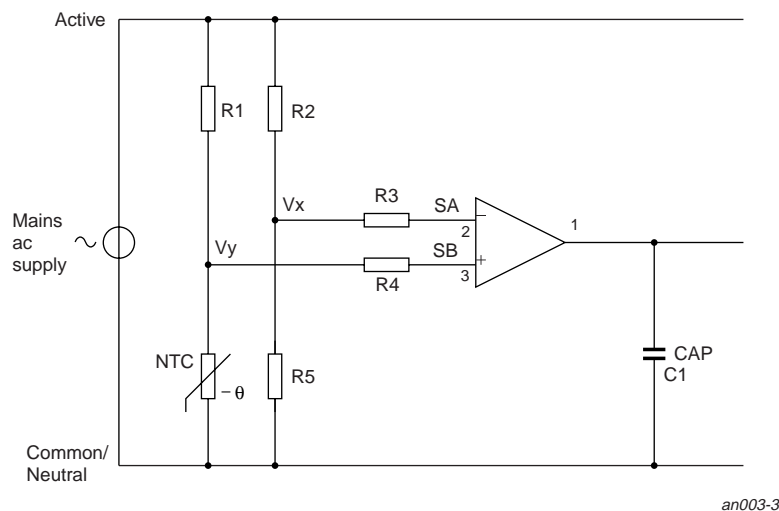


Fig.3 Sensor bridge for simple ON/OFF control (heating)

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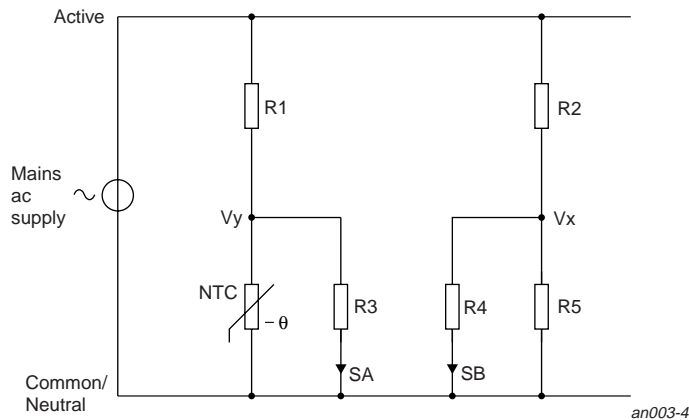


Fig.4 Equivalent bridge circuit (cooling)

5.2.2 SELECTION OF BRIDGE COMPONENTS

Choose $R1 = R2 = 220\text{ k}\Omega$.

This value of $R1$ and $R2$ is sufficient to limit the power dissipation in each resistor to less than 0.25 W , so that low cost VR25 (mains rated) resistors can be used, rather than more expensive VR37.

It also satisfies section 4.2.1 (i.e. $R1$ and $R2 > 10 \times R_{NTC}$).

Choose $R3 = R4 = 100\text{ k}\Omega$ in accordance with section 4.2.2.

5.2.3 VOLTAGE ACROSS THE NTC

The voltage across the NTC at the switching temperature of $94\text{ }^\circ\text{C}$ is given by:

$$V_o = V_i \cdot \frac{R_{NTC} \parallel R3}{R1 + R_{NTC} \parallel R3}$$

Where:

$$V_i = 230\text{ V}_{ac}$$

$$R_{NTC} = 2.4\text{ k}\Omega$$

$$R1 = 220\text{ k}\Omega$$

$$R3 = 100\text{ k}\Omega$$

$$V_o = 230 \cdot \frac{2k44 \parallel 100k}{220k + 2k44 \parallel 100k} = 2.46\text{ V}_{ac}$$

It can be seen that the value of $R3$ (i.e. $100\text{ k}\Omega$) is much greater than the resistance value of the NTC sensor at the switching temperature, so that it provides very little influence on the voltage across the sensor.

5.2.4 SENSE INPUT CURRENTS INTO SA AND SB

1. RMS input currents.

The sense input currents into SA and SB are equivalent to the currents through resistors $R3$ and $R4$ respectively. Since SA and SB are effectively at the same potential as "common", the rms currents in to SA and SB can be simply calculated from the ac voltages across $R3$ and $R4$.

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When the input bridge circuit is balanced (i.e. when the NTC resistance value is 2.4 kΩ at 94 °C), the currents into SA and SB will be equal, and will be given by:

$$I_{SA} = I_{SB} = \frac{V_o}{R3} = \frac{2.46 \text{ V}}{100 \text{ k}\Omega} = 25 \text{ }\mu\text{A}_{\text{rms}}$$

2. Effective average input currents

When driven with ac signals (as per the above example) only “positive” currents flowing into the OM1682 (i.e. when the voltage across R3 and R4 is positive with respect to common) have any significant effect on control sensing and supply circuit loading. On negative half cycles these currents return directly to the common rail (V_{CC}) via diodes internal to the OM1682, and therefore do not contribute to the input sensing current, and do not load the OM1682 supply.

Therefore the effective average sense currents into SA and SB (i.e. only the positive half cycle) when the bridge is balanced is given by:

$$I_{SA(\text{avé})} = I_{SB(\text{avé})} = \frac{\sqrt{2}}{\pi} \cdot I_{SA(\text{rms})} = 11.3 \text{ }\mu\text{A}(\text{avé})$$

3. Maximum input sense current

It should be remembered that the voltage across the NTC is inversely dependent upon the temperature, so that the voltage across the NTC will be greater at lower temperatures, resulting in a much larger current into input SA (only) in this application. Therefore when considering the loading on the OM1682 supply circuit, the lowest expected operating temperature should be used to determine the maximum effective control sense input current.

For example, assume that this circuit might be expected to operate when the NTC is at -10 °C (i.e. at first turn-on (power up) of the control circuit).

From 5.2.1 above the resistance value of the NTC at -10 °C is 177 kΩ

The voltage across the NTC (from 5.2.2) would be 51.76 V_{ac}.

From 5.2.3 the rms sense current into SA will be 517 μA_{rms}.

From 5.2.4, the effective input current into SA will be 233 μA ave.

The loading effect that this sense input current will have on the OM1682 supply circuit should be taken into account when designing the supply circuit components (as per Application Note AN001).

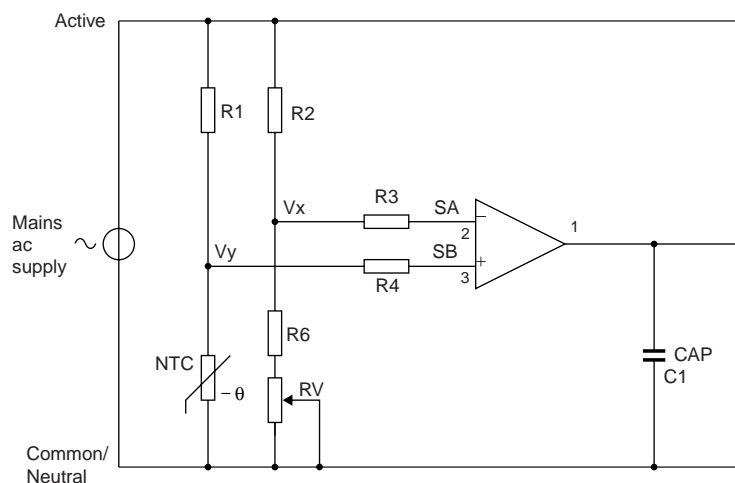


Fig.5 Sensor bridge with variable set point (heating)

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6 VARIABLE ON/OFF CONTROL

With a variable ON/OFF control the switching temperature point is able to be adjusted by varying one of the resistors in the bridge. At any given setting of the adjusting potentiometer (variable resistor), the operation is the same as for the fixed sensing bridge discussed in Section 5.

6.1 Variable sensing bridge

In Figure 2 a variable resistor was shown which in Figure 3 was changed to a fixed resistor R5. If it is wished for the user to be able to adjust the regulating temperature R5 can be returned to being a variable resistor (potentiometer) which is shown in Figure 5 with a potentiometer RV and a fixed resistor R6 in series.

For analysis the input bridge has been redrawn in Figure 6.

Again assume $R1 = R2$ and $R3 = R4$, then the bridge is balanced at that temperature when the sum of the potentiometer resistance and R6 is equal to the NTC resistance.

In this case the calculations are the same as those carried out in Section 5.2, except that new temperature answers will need to be calculated at least for the end points where the potentiometer is at its maximum position, and where it is set to its minimum setting.

If intermediate points are calculated then a graph can be drawn which gives the switching temperature for that application.

The potentiometer can be connected so that the set temperature either increases with clockwise rotation, or decreases, whichever is preferable for style and function.

While a linear potentiometer is usually used, there may be good reason to select a control with a logarithmic (or anti-logarithmic) curve.

An example of the method of calculation follows in the next section, although IES can provide examples of typical applications where the bridge calculations are carried out in an Excel spreadsheet, together with more accurate mathematical representations of the temperature characteristics of the NTC thermistor.

It is therefore necessary to determine the relationship between the NTC resistance and the setting of the potentiometer to find the balance point at the temperature(s) of interest.

Switching will occur when the currents I_{SA} and I_{SB} are equal and the bridge is balanced. This will result in the voltages at points X and Y are equal, assuming that $R3 = R4$.

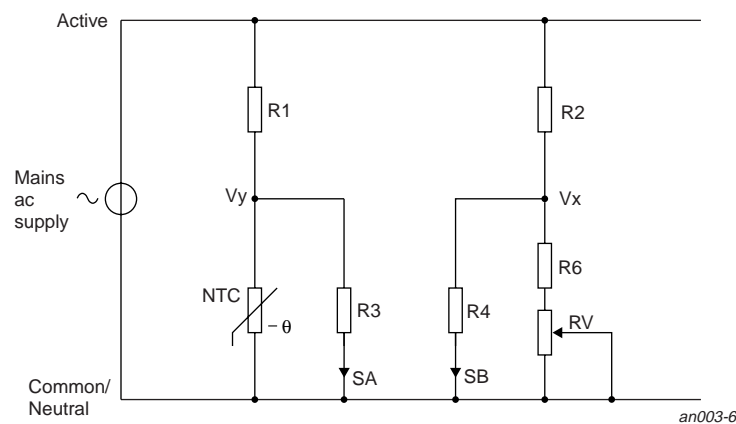


Fig.6 Equivalent circuit: variable bridge (cooling)

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The resistance of an NTC increases exponentially with temperature as is explained in Appendix 1. However over a small temperature this can be approximated to a reasonably straight line. By taking the values of the resistance of the NTC at each end of the required temperature range, a suitable potentiometer resistance can be chosen.

6.2 Example 2: Adjustable ON/OFF heater control.

In this example the ON/OFF controller uses the OM1682 to control the temperature of room heater covering the temperature range of 15 to 35 degrees. The controller is powered from 230 V_{ac} mains. A suitable NTC sensor for this temperature is the Philips type 2322 640 64103, which has a value of 10 kΩ at 25 °C, and a β value of 3977.

6.2.1 NTC RESISTANCE AT THE SWITCHING TEMPERATURE

We can calculate the resistance value of the NTC sensor at the desired switching temperature using the equation given in appendix 1 (where 15 °C = 288 °K).

$$R_{NTC(15)} = 10 \cdot e^{3977 \cdot \left(\frac{1}{288} - \frac{1}{298}\right)}$$

$$= 15.9 \quad k\Omega$$

and 35 °C = 308 °K)

$$R_{T2NTC(35)} = 10 \cdot e^{3977 \cdot \left(\frac{1}{308} - \frac{1}{298}\right)}$$

$$= 6.5 \quad k\Omega$$

If R1 = R2, and R3 = R4, then the sensing bridge will be in balance when R6 + RV is to equal the NTC resistance at the switching temperature. Therefore choose a potentiometer with a resistance of RV = 10 kΩ, in series with a resistor for R6 = 6.8 kΩ with a tolerance of ±1%. These are the closest standard values to give a range of 6.8 to 16.8 kΩ.

From the thermistor data sheet, an NTC resistance of 6k8 corresponds to about 34.0 degrees. At 50% of potentiometer rotation the resistance is = 6.8 + 5 = 11.8 kΩ, corresponding to a temperature of about 21.2 °C, and at the coldest setting 16.8 kΩ, the temperature is approximately 13.6 °C. These values can then be plotted as temperature against potentiometer rotation (Figure 7), giving a graphical representation of the control curve of this control. Note that the NTC response with temperature is logarithmic and non-linear; so there is a little curvature in the expected graph. This may be preferable in any case, as differences in temperature are more evident at the cooler end of the scale.

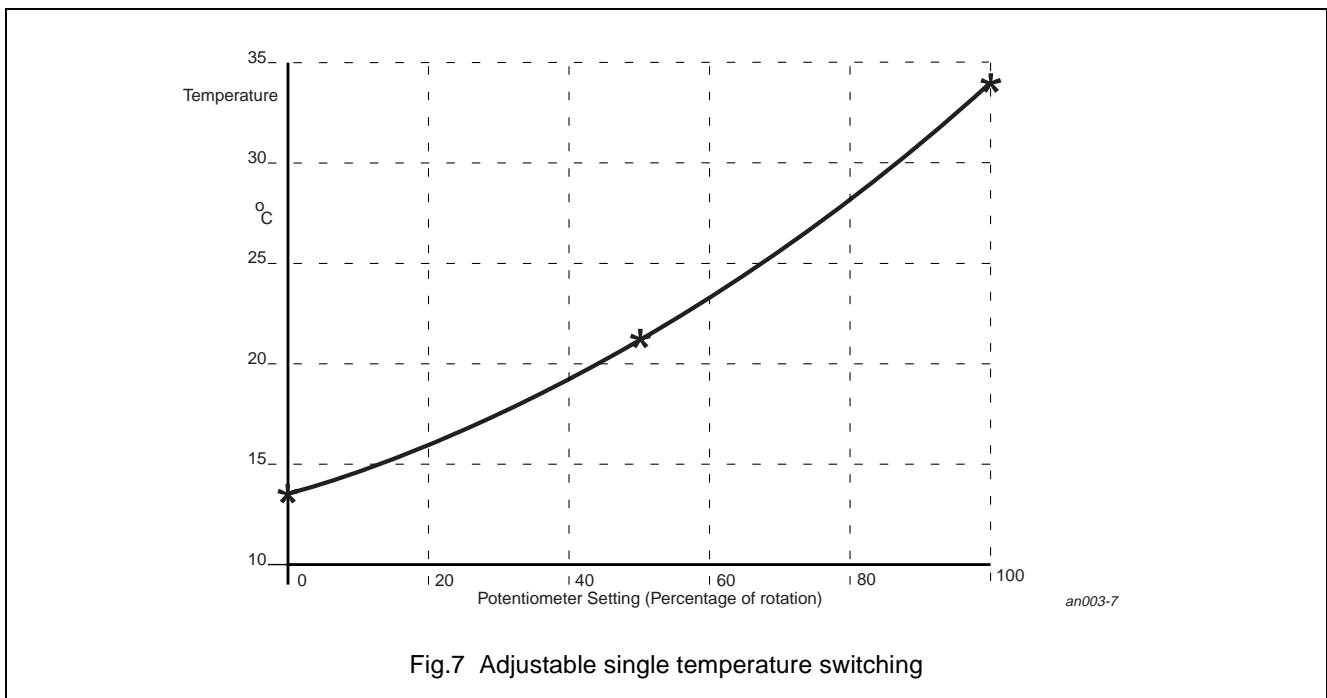


Fig.7 Adjustable single temperature switching

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6.2.2 SELECTION OF BRIDGE COMPONENTS

Choose $R_1 = R_2 = 220\text{ k}\Omega$.

This value of R_1 and R_2 is sufficient to limit the power dissipation in each resistor to less than 0.25 W , so that low cost VR25 (mains rated) resistors can be used, rather than more expensive VR37.

It also satisfies section 4.2.1 (i.e. R_1 and $R_2 > 10 \times R_{NTC}$).

Choose $R_3 = R_4 = 220\text{ k}\Omega$ in accordance with section 4.2.2.

6.2.3 VOLTAGE ACROSS THE NTC

The voltage across the NTC at the lower switching temperature of $15\text{ }^\circ\text{C}$ is given by:

$$V_o = V_i \cdot \frac{R_{NTC} \parallel R_3}{R_1 + R_{NTC} \parallel R_3}$$

Where:

$$V_i = 230\text{ V}_{ac}$$

$$R_{NTC} = 6.5\text{ k}\Omega\text{ (hot setting), } 10\text{ k}\Omega\text{ (mid), } 15.9\text{ k}\Omega\text{ (cold)}$$

$$R_1 = 220\text{ k}\Omega$$

$$R_3 = 220\text{ k}\Omega$$

$$V_o = 230 \cdot \frac{6\text{ k}\Omega \parallel 220\text{ k}\Omega}{220\text{ k}\Omega + 6\text{ k}\Omega \parallel 220\text{ k}\Omega} = 6.42\text{ V}_{ac}\text{ (hot setting)}$$

$$= 9.58\text{ V}_{ac}\text{ (mid range setting)}$$

$$= 14.2\text{ V}_{ac}\text{ (coldest setting)}$$

It can be seen that the value of R_3 (i.e. $220\text{ k}\Omega$) is much greater than the resistance value of the NTC sensor at the switching temperature, so that it provides very little influence on the voltage across the sensor.

6.2.4 SENSE INPUT CURRENTS INTO SA AND SB

1. RMS input currents.

The sense input currents into SA and SB are equivalent to the currents through resistors R_3 and R_4 respectively. Since SA and SB are effectively at the same potential as "common", the rms currents into SA and SB can be simply calculated from the ac voltages across R_3 and R_4 .

When the input bridge circuit is balanced at the coldest set temperature (i.e. when the NTC resistance value is

$15.9\text{ k}\Omega$ at $15\text{ }^\circ\text{C}$), the currents into SA and SB will be equal, and will be given by:

$$I_{SA} = I_{SB} = \frac{V_o}{R_3} = \frac{14.2\text{ V}}{220\text{ k}\Omega} = 65\text{ }\mu\text{A}_{rms}$$

2. Effective average input currents

When driven with ac signals (as per the above example) only "positive" currents flowing into the OM1682 (i.e. when the voltage across R_3 and R_4 is positive with respect to common) have any significant effect on control sensing and supply circuit loading. On negative half cycles these currents return directly to the common rail (V_{CC}) via diodes internal to the OM1682, and therefore do not contribute to the input sensing current, and do not load the OM1682 supply.

Therefore the effective average sense currents into SA and SB (i.e. only the positive half cycle) when the bridge is balanced is given by:

$$I_{SA(ave)} = I_{SB(ave)} = \frac{\sqrt{2}}{\pi} \cdot I_{SA(rms)} = 29\text{ }\mu\text{A(ave)}$$

3. Maximum input sense current

It should be remembered that the voltage across the NTC is inversely dependent upon the temperature, so that the voltage across the NTC will be greater at lower temperatures, resulting in a much larger current into input SA (only) in this application. Therefore when considering the loading on the OM1682 supply circuit, the lowest expected operating temperature should be used to determine the maximum effective control sense input current.

For example, assume that this circuit might be expected to operate when the NTC is at $-10\text{ }^\circ\text{C}$ (i.e. at first turn on of the control circuit).

From section 6.2.1 above the resistance value of the NTC at $-10\text{ }^\circ\text{C}$ is $55\text{ k}\Omega$

The voltage across the NTC (from section 6.2.2) would be 38.3 V_{ac} .

From 6.2.3 the rms sense current into SA will be $174\text{ }\mu\text{A}_{rms}$.

And from 6.2.4, the effective input current into SA will be $78\text{ }\mu\text{A ave}$.

The loading effect that this sense input current will have on the OM1682 supply circuit should be taken into account when designing the supply circuit components (as per Application Note AN001).

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6.2.5 MORE ACCURATE CALCULATIONS

The temperature calculation for an NTC thermistor is more accurate if the extended Steinhart and Hart formula is used with the figures given in the Philips data sheet. These constants and calculations are available in an Excel spreadsheet from IES offering a more accurate answer either calculating the resistance for a given temperature, or vice versa.

In addition a spreadsheet can be written which will allow resistance values to be inserted into table cells, and the resulting characteristic curve plotted within the spreadsheet. This allows standard resistance values to be tried in the various positions in the bridge to seek to find optimum values giving an acceptable curve and end points.

Usually a new spreadsheet is written for each circuit; if there is not one already available based on the circuit which is best suited to a given application, an approach to IES will find guidance and help in solving a specific circuit.

The adjustable single temperature thermostat has been calculated using the target temperatures used above in

this section. The resulting characteristic graph is shown below in Figure 8. Increasing temperature corresponds to a decreasing potentiometer resistance, so that the potentiometer would usually be wired so that the user's control panel is marked with increasing temperature for clockwise rotation corresponding to decreasing RV.

While the thermistor and fixed resistors are available to reasonably close tolerances (2% and 1% respectively), potentiometers generally have much greater tolerances.

Thus in this example, at the highest set temperature, we can expect the temperature accuracy to be very good (typically better than 1 °C, with about 2 °C for worst case tolerancing). At the cold end of the curve where the full value of the potentiometer resistance is included in the bridge, this tolerance error can be taken into account by allowing the coldest temperature to go a few degrees below the minimum required set temperature. Hence in this example, to ensure that regulation at the minimum temperature is still achievable, component values have been chosen to reach a lowest temperature of 13.6 °C at minimum setting with the nominal potentiometer value.

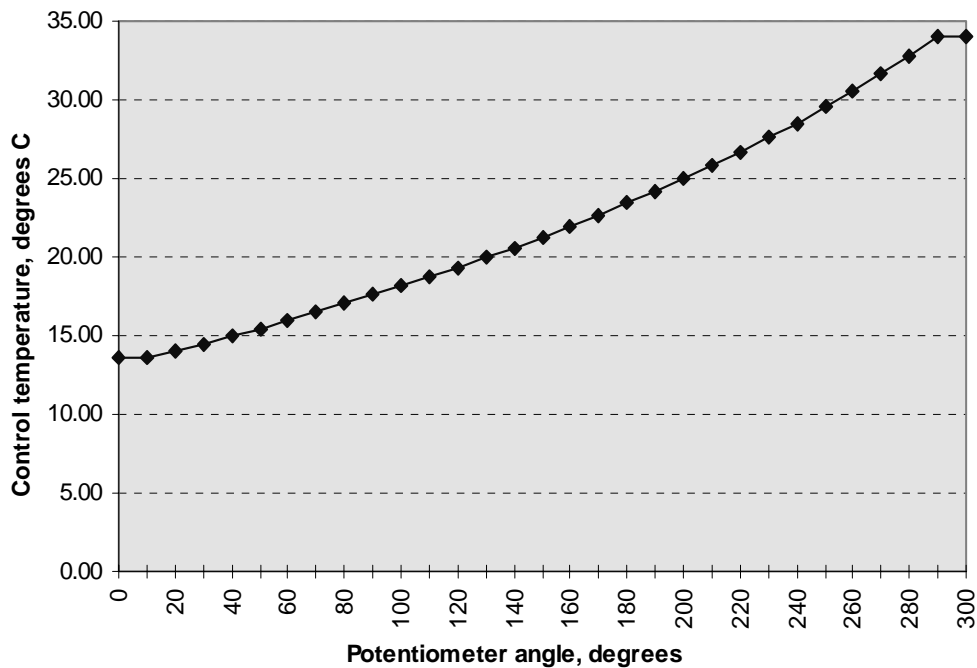


Fig.8 Accurate spreadsheet graph of single temperature switching heater thermostat (an003-8.xls)

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7 CONSTANT HYSTERESIS

Electromechanical thermostats are generally unable to switch ON and OFF at the same temperature, even if this would give more desirable and more accurate performance. Their operation is usually such that the switch is only actuated when they have passed through the desired switching point by more than a few degrees.

While the set temperature may be specified by a single control temperature, the characteristic of the control is usually such that for a heater there is an upper cut-out temperature where the heating action is turned off; followed by the sensing point cooling to below the set point where the heating action starts again at the cut-in temperature.

For a cooling thermostat, the cooling action (compressor, or cooling fan) runs until a cut-out switching point below the set temperature is reached, when the cooling action is switched OFF. It then warms to above the set point to cut-in, when the cooling starts again.

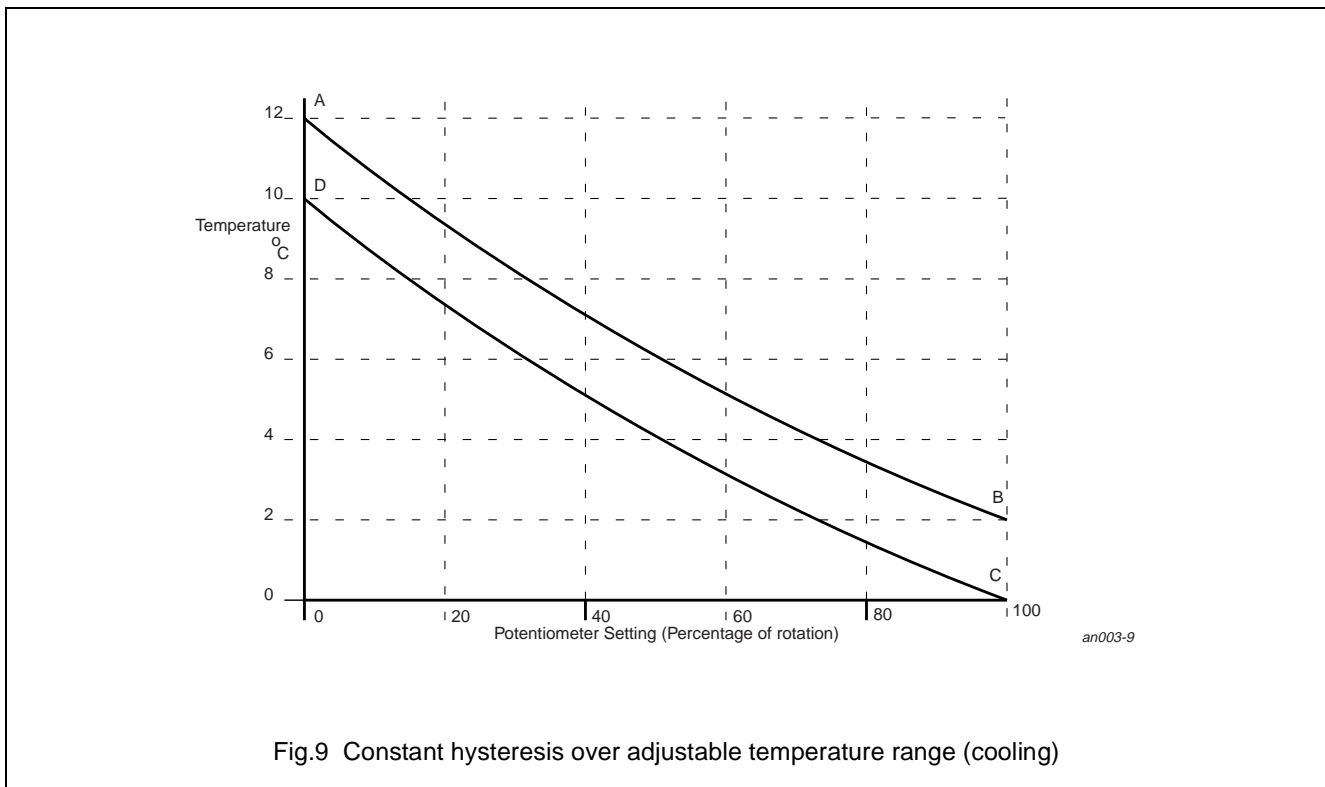
The difference between these two temperatures is called "hysteresis".

In the majority of heating and cooling applications the difference between cut-in and cut-out temperatures means

that the device has a range of temperatures in which it normally operates. If the temperature goes beyond these bounds the controller acts to ensure that the temperature remains within the selected bounds. For example a refrigerator runs until it is cooled to a certain temperature (cut-out), and the compressor stops. It is then allowed to rise to another temperature (cut-in) before the cooling action starts again. This difference in turn on and turn off temperature is the hysteresis. Figure 9 shows the temperature vs potentiometer setting for a refrigerator control with hysteresis.

In this graph, which has been drawn for a cooling application with the potentiometer connected so that clockwise rotation corresponds to a lower temperature, it can be seen that above or below the upper or lower limits the gate pulse will either be ON or OFF respectively (for cooling). For heating it will be OFF when it is above the upper line, and ON below the bottom line. In these areas it is not possible for both modes to be active.

In the middle region both ON and OFF modes occur regardless of the application. Under normal running conditions it is between these upper and lower bounds that the temperature controller operates.



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7.1 OM1682 applications with hysteresis

Unlike with a mechanical controller, hysteresis is only achieved with the OM1682 by providing feedback signal from the load. This signal is applied to the arm of the bridge which drives the SA input to the OM1682. Thus for cooling circuits it is applied to the arm that contains the NTC. While for heating, the feedback from the triac needs to be applied to the setting arm of the bridge, as it is this side that drives the SA input when in a heater configuration.

When the triac is off there is no current flowing in the load and since resistor Rh is much larger than the load resistance, Rh is effectively connected to mains. The equivalent circuit for this can be seen in Figures 10 (cooling), or 12 (heating).

Therefore adding Rh has increased the current into the SA sense input while the triac is OFF. This increases the difference between the cut-in and cut-out temperatures for both heating and cooling applications. When cooling, the NTC arm of the bridge is applied to the SA input of the OM1682. The NTC resistance has to decrease further before I_{SB} exceeds I_{SA} –thus requiring a higher temperature before the compressor or fan cuts in.

For a heating load the increased AC voltage applied to the setting side of the bridge again increases the sense current into SA: this increase allows I_{SA} to only exceed I_{SB} at a higher NTC resistance, thus it is at a lower temperature that the OM1682 senses balance and switches into the heating state, turning the triac ON.

When the triac is ON, Rh is connected directly to common through the conducting triac. This puts Rh is parallel with the NTC (cooling), or with the adjustment section of the circuit (heating), decreasing the current into the sense

input. For cooling loads the cut-out temperature is decreased; and for heating loads it is increased.

Thus the feedback resistor Rh modifies the bridge equivalent circuit for the single temperature sensor shown in Figure 4, and instead for cooling has as equivalent Figure 10 while the triac is OFF, and Figure 11 while the triac is ON. For heating Figure 12 shows the OFF equivalent, and Figure 13 the ON condition.

The analysis of these circuits is the same as for the single temperature switching except for the additional resistor in parallel in different parts of the circuit depending on whether the triac is ON or OFF.

The initial starting point for the calculation of the resistors is the amount of hysteresis and the maximum and minimum temperature settings. The amount of hysteresis is the difference in temperature between the cut in and the cut out temperatures. The hysteresis will be almost constant over the entire operating range. This gives the four end points shown in Figure 9. From these four points the resistance of the NTC at each of the four temperatures can be calculated.

For the cooling circuit the potentiometer arm of the bridge gives a fixed voltage for any set potentiometer position. This voltage is not dependent on whether the triac is conducting.

Therefore for a cooling example the target cut-in and cut-out temperatures can be chosen for a given setting of the potentiometer. This will assist in calculating the hysteresis resistor needed to achieve the desired result.

Note that for a resistive load the calculation is a little more difficult, but follows a similar process.

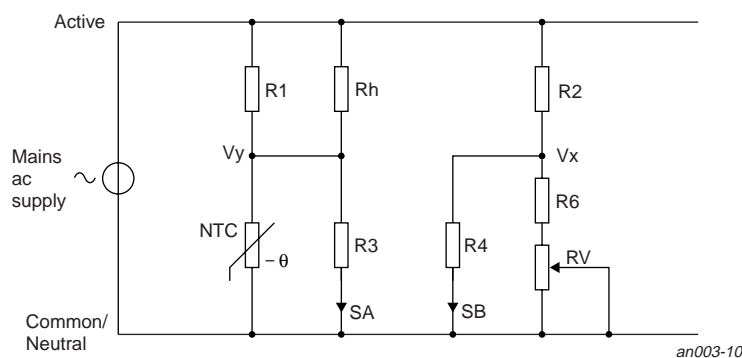


Fig.10 Equivalent circuit: hysteresis via Rh, triac OFF, cooling

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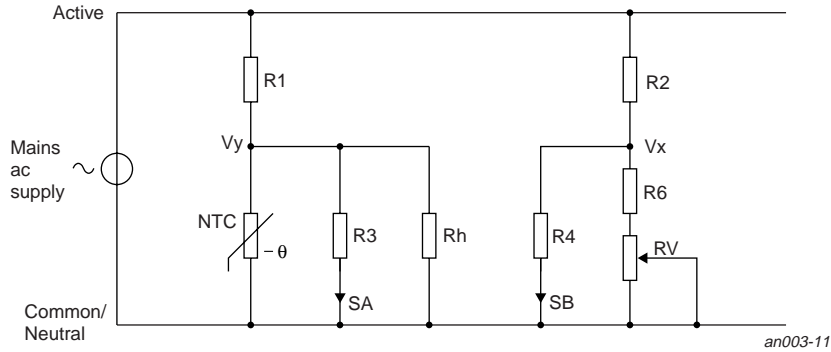


Fig.11 Equivalent circuit: hysteresis via Rh, triac ON, cooling

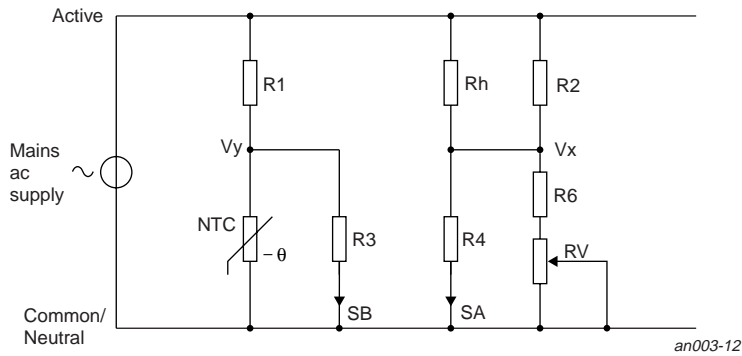


Fig.12 Equivalent circuit: hysteresis via Rh, triac OFF, heating

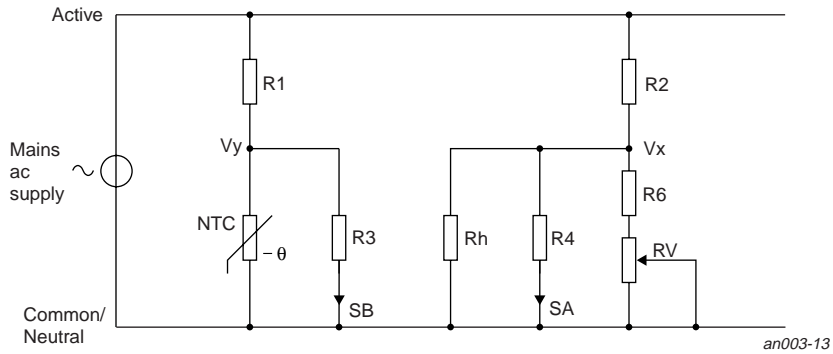


Fig.13 Equivalent circuit: hysteresis via Rh, triac ON, heating

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The two bridge circuits will always be balanced when the currents I_{SA} and I_{SB} are equal, thus voltages V_{Xon} and V_{Yon} will be equal (seeing we have chosen $R3 = R4$). Voltages V_{Xoff} and V_{Yoff} will also be equal for the same reason. The value of RV is the same for both the cut-in and for the cut-out circuits. This means that voltages V_{Yon} and V_{Yoff} , and V_{Xon} and V_{Xoff} will be the same. This allows a value of R_h to be determined.

Looking at a cooling application, from Figure 10 first calculate $V_{y(off)}$ for the chosen NTC resistance values at the cut-in temperature R_{t1} :

$$V_{y(off)} = \frac{V_i \cdot \left(\frac{1}{R_{t1} + R_3} \right)}{\left(\frac{1}{R_{t1} + R_3} + \frac{1}{R_1 + R_h} \right)} = \frac{V_i \cdot \left(\frac{1}{R_1 + R_h} \right)}{\left(\frac{1}{R_1 + R_h} + \frac{1}{R_{t1} + R_3} \right)}$$

Then from Figure 11, calculate $V_{y(on)}$ for the NTC resistor at the cut-out temperature R_{t2} :

$$V_{y(on)} = \frac{V_i \cdot \left(\frac{1}{R_h + R_{t2} + R_3} \right)}{\left(\frac{1}{R_h + R_{t2} + R_3} + R_1 \right)} = \frac{V_i}{\left[1 + R_1 \cdot \left(\frac{1}{R_h + R_{t1} + R_3} \right) \right]}$$

As $V_{y(off)}$ and $V_{y(on)}$ are equal, by equating these they can be solved for R_h by substituting the cut-in and cut-out temperatures for that potentiometer setting.

These equations can be simplified by assuming that since $R3 \gg R_{t1}$, and $R3$ and R_h are both $\gg R_{t2}$, they have little affect in determining the value of R_h . The solution can then be simplified to:

$$R_h = \frac{R_{t1} \cdot R_1}{R_{t2} - R_{t1}}$$

The value of RV needed to accommodate the range of temperature settings can be calculated from the voltages for V_x above at each end of the desired temperature range. V_x can then be calculated with a value of RV and $R6$ to give these voltages to simplify the equations R_h and $R3$ can be left out.

$$\frac{\left(\frac{1}{\left(\frac{1}{R_4 + R_6 + RV} \right)} \right)}{\left(R_2 + \frac{1}{\left(\frac{1}{R_4 + R_6 + RV} \right)} \right)} = \frac{1}{\left(1 + \frac{R_2}{R_4} + \frac{R_2}{R_6 + RV} \right)} = \frac{R_t}{R_1 + R_t}$$

$$\therefore RV + R_6 = \frac{R_2 \cdot R_t \cdot R_4}{R_1 \cdot R_4 - R_2 \cdot R_t}$$

7.1.1 OTHER DESIGN CONSIDERATIONS

7.1.1.1 Triac considerations

When using an inductive load the triac must be chosen so that the rate of change of voltage induced when the triac switches off does not affect the triac operations. When an inductive load is turned off there is a voltage spike that lasts for a certain time. A rapidly changing voltage across the T2-gate junction of a triac can cause enough current to flow in to the gate of the triac and fire it. The triac chosen must have a high enough dV/dt so that the voltage induced when the load is turned off does not fire the triac. Often a snubber circuit is used to limit the dV/dt but this adds to the component count, although it will also help a little in rfi (radio frequency interference) suppression.

The load current that the triac is able to handle must be sufficient to withstand load failures. For example if the load is a compressor for a refrigerator then the triac must be able to withstand the locked rotor current. Adequate heatsinking must be provided to ensure that the triac will continue at high currents and not overheat.

7.1.1.2 Power supply considerations: supply current

The mains has to supply the current drawn by the OM1682 and associated resistors as well as the current drawn by the load and the triac. the current required for the OM1682 can be divide into the following parts.

- Quiescent current: 200 μA (max)
- Current for gate drive: Average current = duty cycle of gate pulse x (gate current + 2 mA). The extra 2mA is required to supply the gate driver circuitry
- Current into sense inputs SA and SB: Approx 500 μA (max)

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7.1.1.3 Power dissipation

The total power dissipated by the OM1682 and associated circuitry is the sum of the following:

- Power in the bridge resistors
- Power in any feedback resistors
- Power in resistors to LS,TS or PWR
- Power dissipated in triac

Note: Power is only dissipated in feedback resistors when the triac is off.

The triac only dissipates power when on.

The power in the resistors to LS,TS,PWR can be halved by placing a diode in series with them as the current flows into the chip in the negative half cycle only.

7.2 Example 3: Adjustable cooling control with hysteresis (refrigerator)

Determine the components needed to provide the sensing circuitry for a temperature range of cut-in 2 °C, cut-out 0 °C up to cut-in 12 °C and cut-out of 10 °C. That is the hysteresis should be 2 °C

Using the basic range of the Philips 2322 640 5... series NTC thermistors which have an operating temperature range of -40 to 125 °C. This series has a number thermistors with different resistances at 25 °C. The thermistor chosen for this application has an R25 value of 10 kΩ. This R25 value was chosen as it provided realistic values of resistance at the end points of the operation range. An NTC with a small R25 value could result in the power rating of R2 and R1 having to be increased as their resistance decreases to satisfy the suggested conditions listed above. A very large R25 value would result in R2 and R1 having to be very large.

Therefore use a 2322 640 53473 NTC with $\beta = 3977$.

7.2.1 NTC RESISTANCE AT THE SWITCHING TEMPERATURES

Figure 9 shows a cut-in and cut-out temperature for any position of the potentiometer. At the low resistance end of the potentiometer (anti-clockwise), the A and D positions are shown at 12 and 10 °C respectively. The cold high resistance end of the potentiometer travel shows the B (2 °C) and C (0 °C) positions. The NTC resistance is calculated as follows:

$$A \quad R_{12} = R_{25} \cdot e^{\beta \cdot \left(\frac{1}{285} - \frac{1}{298} \right)} = 10 \cdot e^{3977 \cdot \left(\frac{1}{285} - \frac{1}{298} \right)} = 18.38 \text{ k}\Omega$$

$$B \quad R_2 = R_{25} \cdot e^{\beta \cdot \left(\frac{1}{275} - \frac{1}{298} \right)} = 10 \cdot e^{3977 \cdot \left(\frac{1}{275} - \frac{1}{298} \right)} = 30.53 \text{ k}\Omega$$

$$C \quad R_0 = R_{25} \cdot e^{\beta \cdot \left(\frac{1}{273} - \frac{1}{298} \right)} = 10 \cdot e^{3977 \cdot \left(\frac{1}{273} - \frac{1}{298} \right)} = 33.94 \text{ k}\Omega$$

$$D \quad R_{10} = R_{25} \cdot e^{\beta \cdot \left(\frac{1}{283} - \frac{1}{298} \right)} = 10 \cdot e^{3977 \cdot \left(\frac{1}{283} - \frac{1}{298} \right)} = 20.29 \text{ k}\Omega$$

These resistance values give the NTC resistance at the end points of the temperature against potentiometer setting curve. From these figures the potentiometer resistance, and the value of the hysteresis feedback resistor can be calculated.

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7.2.2 SELECTION OF THE BRIDGE AND POTENTIOMETER COMPONENTS

Using these values of NTC resistance and using R1, R2, R3 and R4 all equal to 220 kΩ, calculating the potentiometer values for the A,B, C and D points gives the following values for the sum R6 + RV.

- A 40 kΩ =R6 +RV
- B 22 kΩ =R6
- C 20 kΩ =R6
- D 35 kΩ =R6 +RV

This suggests a design value of R6 = 20 kΩ with a 15 kΩ potentiometer

It is of interest to compare these figures with the result from the more accurate spreadsheet calculation. This is shown in the graph below in Figure 14. The differences are a result of the more accurate NTC calculation, together with exact figures for the use of all of the resistor values. The spreadsheet allows standard resistor values to be used to check the result of using preferred values, rather than exact calculated values.

This does highlight a further difficulty in that this is not a commonly available value for the potentiometer

resistance. It may therefore be necessary to change R1 or R2 to a value that allows the use of a standard potentiometer.

In the HM169 general purpose precision thermostat module a 4.7 kΩ potentiometer is used on all versions, with choice of NTC resistor and the other bridge components being regarded as being more easily obtained for different values. The HM169-02 which has the same A, B, C and D points as this example, R1 = 270 kΩ, R2 = 330 kΩ, R3 = R4 = 220 kΩ, R6 = 5.4 kΩ, Rh = 2.7 MΩ, RV = 4.7 kΩ with 13 kΩ in parallel across it, and RNTC = 2.2 kΩ.

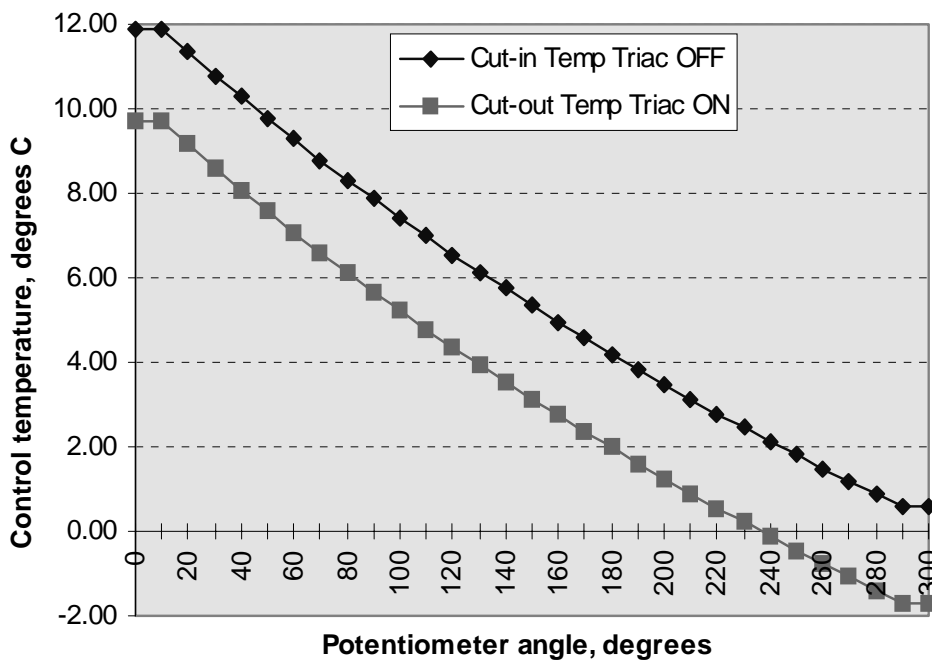


Fig.14 Cooling curves with hysteresis from spreadsheet model

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8 BURST MODE OPERATION

To give hysteresis, feedback is taken from the ac signal across the triac and applied to the arm of the sensing bridge that drives input SA. This moves the switching point by a fixed amount depending on whether the triac is ON or OFF. If a large feedback signal is applied to the arm of the bridge connected to the SB input sense terminal instead of to SA, then it is possible to set up the bridge voltages so that it is forced to behave as an oscillator. By varying the potentiometer the duty cycle can be varied from being full ON to being fully OFF.

If required an NTC thermistor can still be used to provide some temperature compensation to the duty cycle, although care needs to be taken that it does not force the operating condition into a fully ON or fully OFF condition.

8.1 Selection of bridge component values

Referring to Figure 15, we have the equivalent circuit while the triac is OFF, and in Figure 16 the equivalent circuit for the triac ON. If the voltage V_y is calculated for both of these two conditions, then we have the limits between which the voltage V_x must operate.

If the voltage V_x never reaches the upper voltage V_y while the triac is OFF, then it will not switch ON, and will remain OFF for 100% of the time. Likewise, if V_x cannot be adjusted down to the lower value of V_y , then at that end of the adjustment range the triac will stay turned ON.

Therefore, having calculated the two values for V_y , then equating these voltages to V_x allows the value of $R_6 + RV$ to be calculated. This will correspond to the values when the simmerstat is fully ON, and fully OFF.

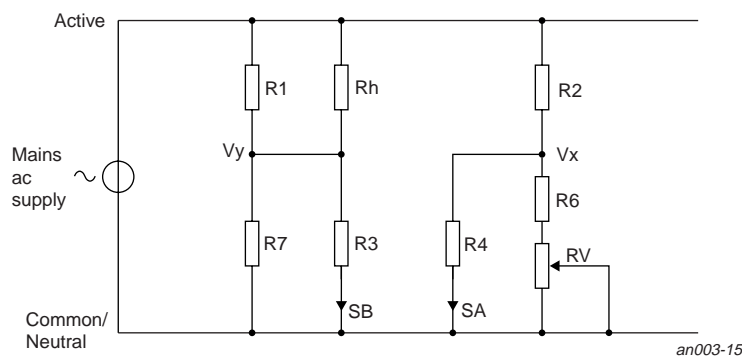


Fig.15 Simmerstat equivalent circuit, triac OFF

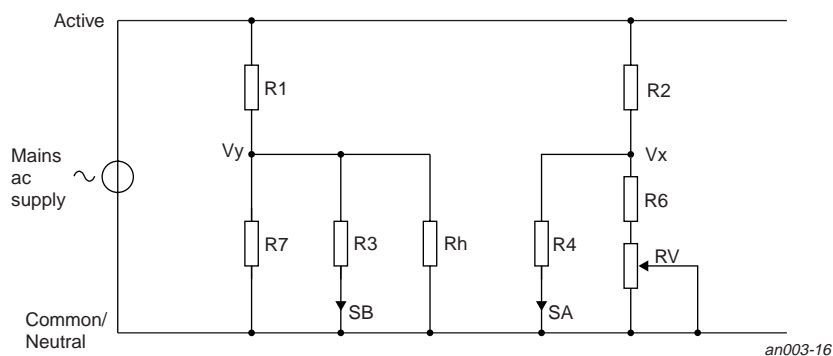


Fig.16 Simmerstat equivalent circuit, triac ON

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From these resistance values $R_{(upper)}$ and $R_{(lower)}$ it is reasonable to allow 10% of the potentiometer range at each end of its travel to be fully ON and fully OFF. Therefore 10% of the potentiometer value should be subtracted from the low resistance figure to give a value for R6. And for the upper V_y voltage, RV should be increased by 10%. This will give a 10% band fully ON at the lower end of the potentiometer range, and 10% fully OFF at the upper end.

Thus:

$$R6 + 0.1 \cdot RV = R_{(lower)}$$

$$R6 + 0.9 \cdot RV = R_{(upper)}$$

Giving:

$$R6 = \left(\frac{9 \cdot R_{(lower)} - R_{(upper)}}{8} \right)$$

$$RV = \frac{R_{(upper)} - R_{(lower)}}{0.8}$$

To calculate an estimated switching frequency, the input currents to SA and SB can be calculated with the potentiometer in mid-range, and the frequency calculated from the charging rate of the filter capacitor on the CAP pin. As the potentiometer is moved away from this centre position the frequency will decrease as either the ON or the OFF time will become larger as the voltage difference between V_x and V_y becomes less, and the current difference between the input currents to SA and SB decreases, making the duty cycle change towards fully ON or fully OFF.

There may be statutory limits on how frequently a load may be switched (mains flicker). If so then the capacitor on the CAP pin will need to be increased, together with larger resistors from V_x and V_y to SB and SA respectively.

8.2 Example 3: Simmerstat

Using values from the HM169-11 simmerstat circuit as an example, first calculate V_{yOFF} and V_{yON} .

Use values of $V_i = 230$ V, $R1 = 220$ k Ω , $R7 = 3.6$ k Ω , $R3 = 1$ M Ω , and $R_h = 220$ k Ω .

$$V_{yOFF} = V_i \cdot \frac{1}{\left(1 + \frac{\left(\frac{1}{R7} + \frac{1}{R3} \right)}{\left(\frac{1}{R1} + \frac{1}{R_h} \right)} \right)}$$

$$= 7.26 \quad V$$

And:

$$V_{yON} = V_i \cdot \frac{1}{\left(1 + R1 \cdot \left(\frac{1}{R7} + \frac{1}{R3} + \frac{1}{R_h} \right) \right)}$$

$$= 3.63 \quad V$$

These two voltages should be equal to V_x at the two extremes of the potentiometer range.

Use $R2 = 220$ k Ω , $R4 = 1$ M Ω , and $R_v = 4.7$ k Ω . The next step is to apply the V_y voltages to find R6 and RV.

$$(R6 + RV) = \frac{R2}{\left(\frac{V_i}{V_x} - 1 - \frac{R2}{R4} \right)}$$

Giving:

$$R_{(lower)} = 3,542 \quad \Omega$$

$$R_{(upper)} = 7226 \quad \Omega$$

$$R6 = 3081 \quad \Omega$$

$$RV = 4605 \quad \Omega$$

Therefore use 3 k Ω for R6, and 4.7 k Ω for the potentiometer.

To calculate the frequency, the voltage at V_x on mid potentiometer setting will be the average of 3.63 V and 7.26 V. That is 5.5 V. Across 1 M Ω for R4 this gives an input current to SA of 5.5 μ A. The voltage V_y will be 1.82 V greater or smaller than the mid value of 5.5 V. Thus the current difference will be 1.82 μ A_(rms).

The nominal power supply voltage of the OM1682 is 6.4 volts, and the voltage excursion of the capacitor on the CAP pin is therefore 6.4 - 0.6 - 1.2 = 4.6 V. If the capacitor is 1 μ F, then it needs $C \times V = 4.6 \times 1E-6 = 4.6$ μ C (microcoulombs) of charge to charge from one threshold to the other.

The 1.82 μ A provides an average charge or discharge current into the capacitor of $I \times 0.5 \times 2.808 / \pi$ C/s. Or for a

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current of 1.82 μA a charging rate of 0.818 $\mu\text{C/s}$ (microcoulombs per second). This charge must charge the capacitor from the OFF threshold to the ON threshold and back again in one cycle, so $2 \times 4.6 = 9.2 \mu\text{C}$ is needed for each cycle, which at the rate of 0.818 $\mu\text{C/s}$ gives a cycle time of 11 seconds, or a frequency of 0.09 Hz.

This is most effectively shown from the spreadsheet calculation for a simmerstat which shows the linear

relationship between duty cycle and potentiometer setting in Figure 17, and also in another graph Figure 18, shows frequency against potentiometer setting. As can be seen the frequency is at its maximum at mid potentiometer setting, and decreases as the OFF or ON time increases as the potentiometer is moved away from this mid position, falling to a frequency of zero when it is fully ON or OFF.

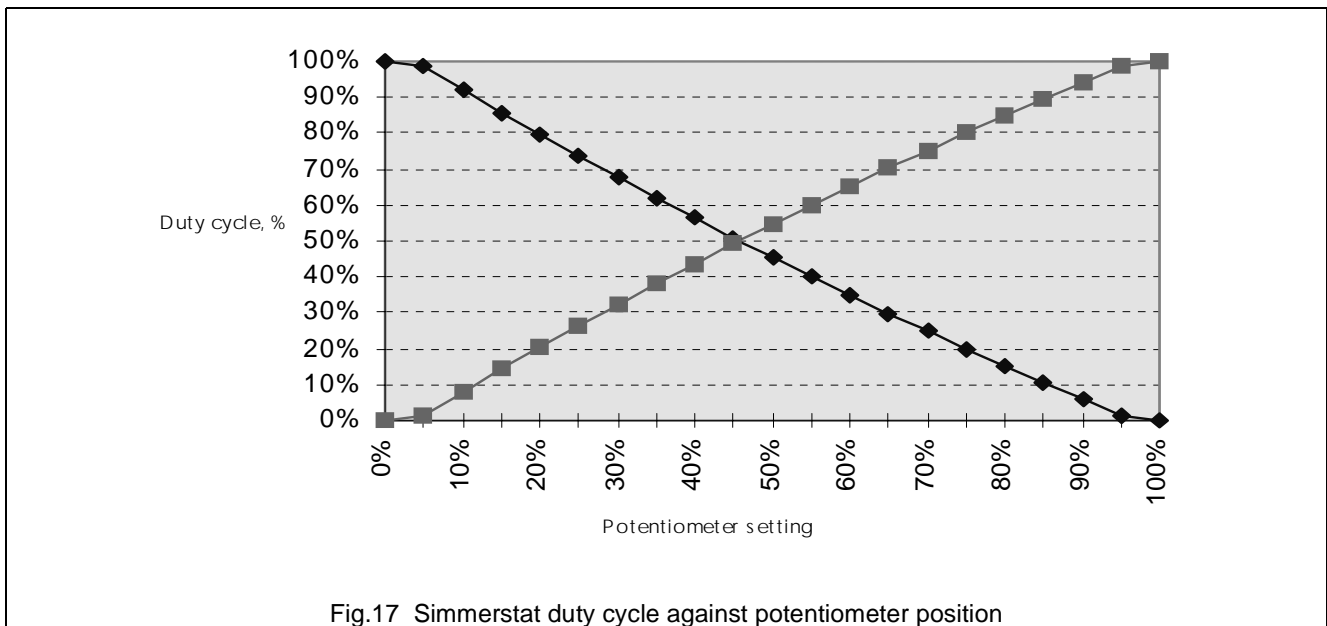


Fig.17 Simmerstat duty cycle against potentiometer position

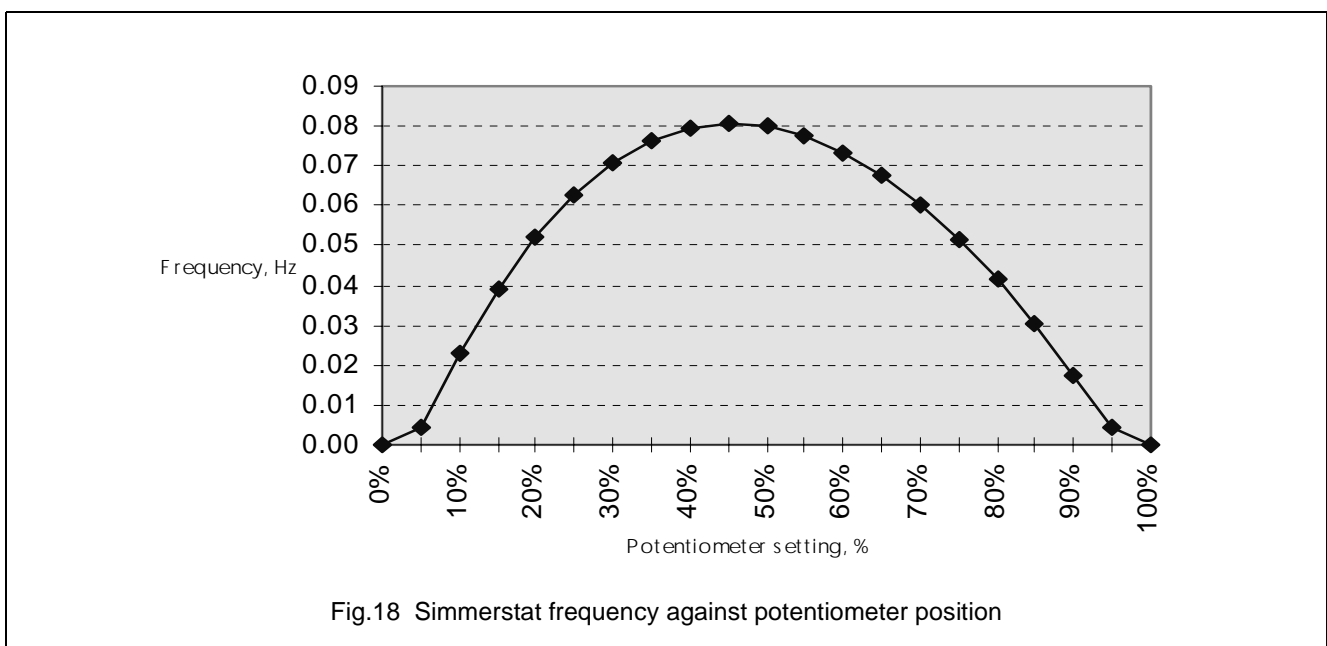


Fig.18 Simmerstat frequency against potentiometer position

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9 CONCLUSIONS

In this report an attempt has been made to describe the design process for a number of the more straight forward applications in which the OM1682 precision thermostat can be used. Other possibilities become evident as a user acquires understanding of the accuracy and repeatability of these designs.

IES can support customers in the design process, and suggest different approaches which enable more flexible approaches with additional features to be designed. In particular for all of these applications the design process can be greatly facilitated if a spreadsheet is built up that allows the values of resistors to be adjusted, and which shows graphically how the resulting thermostat will perform over its setting range.

These circuits are all available for easy component change to permit custom versions to be made in the HM169 series of thermostat demonstration modules. These are based on the use of a standard printed board layout with positions for optional resistor placement to permit any of the circuits described in this report to be easily built up. Because the use of a triac with reasonable current capability needs a heatsink of adequate size to dissipate the triac heat to ensure that at all times its junction temperature remains below 125 °C, the HM169 has not been miniaturized unnecessarily. The printed circuit board fits in the folded heatsink, and has room for easy placement of resistors suited to individual specific applications.

This report has not discussed the issues involving thermal mass associated with the heating or cooling mechanism, and the thermal resistance and time delays needed for the heat (or cooling action) from the load to reach the sensing point of the NTC thermistor.

When power is applied to the load, for example, a heating element (although similar issues arise in looking at a fan, or refrigeration compressor, the heating element starts to dissipate heat, and its temperature is raised above the ambient. Its sheath, and the surrounding air is then also heated and raised in temperature, and it may over time reach a steady state where there is a heat gradient from the hottest point on the heating element itself, to the enclosure or item being heated, and then ultimately from that to the surrounding ambient air. Somewhere along this gradient the thermistor is monitoring and controlling the temperature at that point of measurement. It is the temperature at this point that the OM1682 is trying to regulate.

Even with the simplest controller (the fixed ON/OFF controller), the thermistor will be placed at the control point, and the heating element will be further up the thermal gradient, storing heat which will continue to flow out towards the ambient even after the sensing point has reached the trip level and turned off the power to the load.

This stored heat will cause the temperature at the sensing point to overshoot, and move on above the set temperature by an amount that will depend on the stored energy along the heat gradient back to the heating element itself.

A short time after the controller turns OFF, it cools without further power input, and once the overshoot has finished the temperature at the measuring point starts to fall. It turns back ON when the temperature at the thermistor again reaches the trip level. This time it undershoots until the heat in the element re-establishes the heating gradient and starts increasing the temperature at the measuring point.

With an ON/OFF controller, there can still be a significant gap between the peak and the trough of the temperature at the measuring point. Adding hysteresis will serve to increase this gap, and lengthen the cycle time. Opposing feedback may help reduce it, although in this case care must be taken in the design. The result of even more feedback in this way is explained in the Section describing the simmerstat application where a large negative feedback is applied to force cycling. Ultimately the cycling becomes almost independently of the temperature sensor.

IES have a lot of experience in using the OM1862, and are very happy to help and support a designer seeking to use this extremely flexible and accurate control IC.

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10 APPENDIX 1: CHARACTERISTICS OF NTC SENSORS

10.1 General expression for NTC resistance

Negative Temperature Coefficient thermistors (NTCs) are resistive components, for which the resistance decreases as the temperature increases. They are generally made from polycrystalline semiconductors, the compositions of which are a mixture of chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co) and nickel (Ni).

The following general expression for the resistance (R) of an NTC can be derived from basic principles:

$$R = A \cdot e^{\frac{\beta}{T}}$$

where A and β are considered constants of the NTC type, and T is the temperature in degrees Kelvin (°K). In practice A and β are not perfectly constant with temperature. However, over a wide range of temperatures, it may be assumed that these parameters are constant.

10.2 Determination of β by measurement

If the operation of the NTC is considered between two temperatures T1 and T2, the value of β can be determined by measurement of the resistance at each of these temperatures:

$$R_1 = A \cdot e^{\frac{\beta}{T_1}} \quad \text{and} \quad R_2 = A \cdot e^{\frac{\beta}{T_2}}$$

Dividing R1 by R2 gives:

$$\frac{R_1}{R_2} = e^{\left(\frac{\beta}{T_1} - \frac{\beta}{T_2}\right)}$$

or:

$$\ln\left(\frac{R_1}{R_2}\right) = \beta \cdot \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

solving for β gives:

$$\beta = \frac{\ln\left(\frac{R_1}{R_2}\right)}{\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

In practice, β varies slightly with increasing temperature.

10.3 Calculation of the temperature coefficient

The temperature coefficient α of an NTC may be derived from:

$$\alpha = \left(\frac{1}{R}\right) \cdot \left(\frac{dR}{dT}\right) = -\frac{\beta}{T^2}$$

For different materials, the constant β may vary between 200 and 5500 K: e.g. a value of 3600 K yields $\alpha = -4\%$ per K at a temperature of 300 K.

In practice, most NTCs are specified with a reference value at 25 °C and a constant β value between 25 °C and 85 °C.

10.4 Calculation of the NTC resistance Rt

From the equation above, the resistance of an NTC at a temperature T2 can be expressed as:

$$R_{T2} = R_{T1} \cdot e^{\beta \cdot \left(\frac{1}{T_2} - \frac{1}{T_1}\right)}$$

Therefore the resistance of the NTC can be calculated for any temperature T2, given the value of the NTC resistance at some reference temperature T1.

Alternatively NTC resistance at various temperatures can be calculated using the "Steinhart and Hart" equation:

$$R_T = \frac{R_{25}}{R_{REF}} \cdot e^{\left\{ \frac{3\sqrt{E^2 \cdot D - E} - 3\sqrt{E^2 \cdot D + E}}{R_{REF}} \right\}}$$

Where E, D and R_{REF} are constants for a given NTC.

10.5 Determination of resistance/temperature deviation

The complete resistance deviation is obtained by combining the 'R25 tolerance' value with the 'resistance deviation due to β tolerance' value.

Let: X = R_{25} tolerance
 Y = resistance deviation due to β tolerance
 Z = complete resistance deviation.

Then,

$$Z = \left\{ \left[1 + \frac{X}{100} \right] \times \left[1 + \frac{X}{100} \right] - 1 \right\} \times 100$$

Or: Z = X + Y (approximation).

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TC = temperature coefficient

 ΔT = temperature deviation

so:

$$\Delta T = Z/TC$$

10.6 Example

Let: X = 5%

Y = 0.89%

TC = 5.08%/K

Then:

$$\begin{aligned} Z &= \{[1 + (5/100)]x[1 + (0.89/100)] - 1\} \times 100 \\ &= \{[1.05 \times 1.0089] - 1\} \times 100 \\ &= 0.0593 \times 100 \\ &= 5.93\% \end{aligned}$$

Or, (by approximation)

$$\begin{aligned} Z &= X + Y \\ &= 5 + 0.89 \\ &= 5.89\% \end{aligned}$$

$$\begin{aligned} \Delta T &= Z/TC \\ &= 5.93/5.08 \\ &= 1.167 \quad (1.17) \end{aligned}$$

So around zero °C, an NTC having a R25 value = 10 k Ω has a value of 32.51 k Ω between ± 1.17 °C.

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11 REFERENCES

1. OM1682 Precision Triac Controller Thermostat. IES Data Sheet.
2. AN001 Application note: Power supply design for the OM1682 IC.
3. HM169 Precision Thermostat data sheet.

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Notes:

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12 DEFINITIONS

Data sheet status	
Engineering sample information	This contains draft information describing an engineering sample provided to demonstrate possible function and feasibility. Engineering samples have no guarantee that they will perform as described in all details.
Objective specification	This data sheet contains target or goal specifications for product development. Engineering samples have no guarantee that they will function as described in all details.
Preliminary specification	This data sheet contains preliminary data; supplementary data may be published later. Products to this data may not yet have been fully tested, and their performance fully documented.
Product specification	This data sheet contains final product specifications.
Limiting values	
Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.	
Application information	
Where application information is given, it is advisory and does not form part of the specification.	

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13 IES INFORMATION

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