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applications and circuit design notes

DESIGN GUIDE FOR

RELIABLE TRIGISTOR CIRCUITS

3C SERIES TRIGISTORS

Bulletin D410-01, 7-59

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DESIGN GUIDE FOR RELIABLE TRIGISTOR CIRCUITS

DESCRIPTION

The Silicon Trigistor (triggered bistable transistor) is a PNPN semiconductor component with turn off as well as turn on pulse control at its base. The Trigistor is turned on by applying a positive current pulse to the base. Unlike a conventional NPN transistor, the Trigistor will remain on without the need for sustaining base current. To turn the Trigistor off, a negative trigger pulse is applied to the base. It will remain off until the next positive trigger pulse turns it on.

The Trigistor has the basic structure of a high gain, high speed diffused base NPN transistor with an additional junction at the collector of the NPN structure (Figure 1), which forms a low gain PNP transistor. The base region of the PNP transistor is also the collector of the NPN, and the collector of the PNP is the base of the NPN unit. The NPN and PNP are thereby intimately connected in an integrated complementary circuit arrangement and the resulting regenerative feedback is responsible for the bistable properties of the Trigistor.

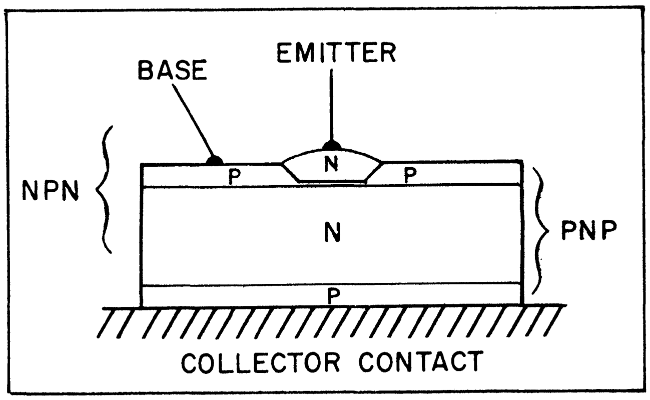

Fig. 1 Trigistor Construction

TRIGISTOR OPERATION

Several equivalent circuits for the Trigistor are shown in Figure 2. The circuit designer may find it more convenient to analyze Trigistor operation with the use of the equivalent two-transistor complementary circuit, 2(d), in which the collector of the NPN drives the base of the PNP and the collector of the PNP drives the base of the NPN. The resulting positive feedback loophas a loop gain equal to $\beta_1\beta_2$, the product of the current gains of the

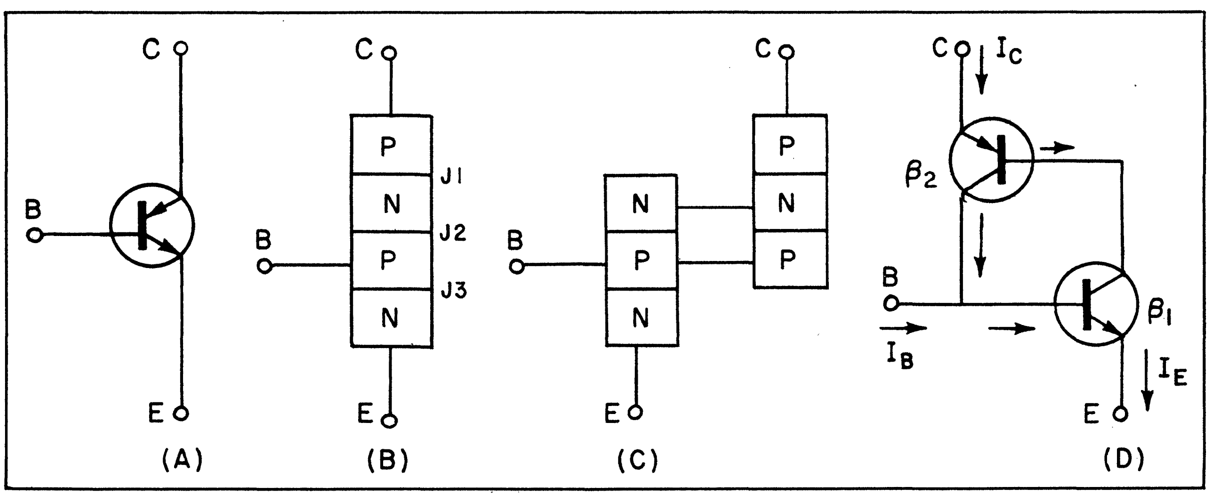

Fig. 2 Trigistor Equivalent Circuits

two transistors. The circuit is stable as long as $\beta_1\beta_2$ is less than unity. In the "off" state, with a positive voltage at terminal C, the collector junction of the two transistors (Junction 2) is biased in the reverse direction. Junction 1 is in the forward direction. A small negative bias applied to terminal B keeps the NPN unit biased off, preventing transistor action. Only collector dropout current can flow at terminal C, and the impedance between C and E is very high.

A small positive current applied to terminal B biases the NPN transistor on and causes its collector current to rise, driving the base of the PNP. Figure 3 shows current gain of the two transistors as a function of collector current. Current gain of the PNP, β_2, is less than unity. Current gain of the NPN, β_1, is less than unity at low values of collector current but rises as collector current increases.

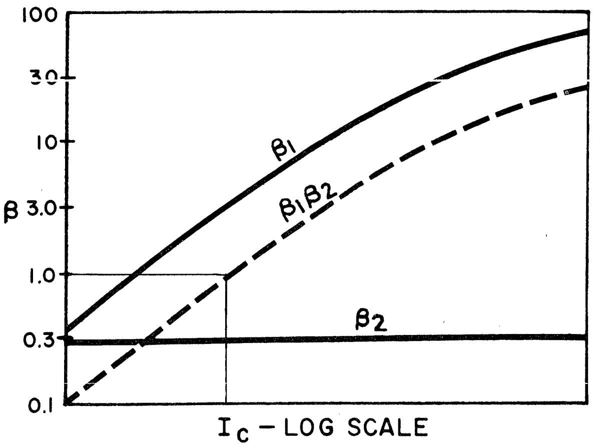

Fig. 3 B vs. Ic

At a particular value of collector current, the loop gain $\beta_1\beta_2$ reaches unity and the circuit becomes self regenerative. Collector currents of the two transistors rapidly increase to a total value through terminal C determined by the external circuit. The transistors drive each other into saturation and the impedance between C and E is very low. The positive current applied to terminal B which served to trigger the self-regenerative action is no longer required, since the collector of the PNP transistor supplies more than enough current to drive the base of the NPN.

The circuit will remain in this "on" state until it is triggered "off". Turn off is accomplished by applying a negative pulse at terminal B large enough to divert the collector current of the PNP transistor, cutting off the NPN unit. Regenerative action ceases, and the two transistors return to the "off" state.

With a negative voltage applied to terminal C, the emitter of the PNP transistor (Junction 1) is biased in the reverse direction, resulting in a high impedance characteristic between C and E. Regenerative switching action is not possible when terminal C is negative.

Operation of the Trigistor is identical to the above two-transistor analogy. Terminals B, C and E refer to Trigistor base, collector and emitter terminals.

TRIGISTOR CHARACTERISTICS

Ratings, specifications and characteristics of the 3C series Trigistor are given in Specification Bulletin C410-01, along with characteristic curves of key Trigistor parameters at various temperature-bias operating conditions. Test limits are indicated on the curves by a dot at the points where each parameter is controlled by the test specification.

Output Characteristics

The common emitter output characteristics of a typical Trigistor are shown in Figure 4. With collector to emitter voltage, V_{CE}, positive in polarity, the Trigistor has two stable states - the high conductance forward "on" state and the high resistance forward cutoff state. With V_{CE} negative, only the high resistance reverse cutoff state exists.

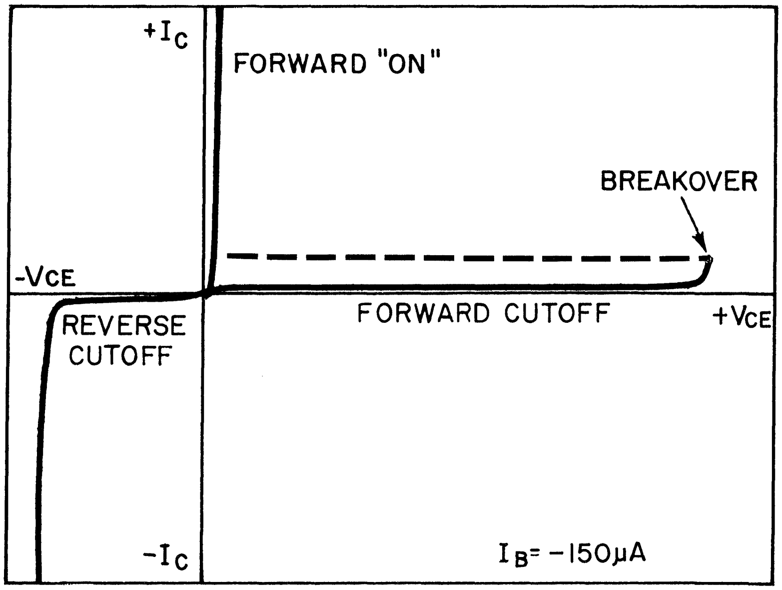

Fig. 4 Output Characteristic

Forward collector cutoff current, I_{CBO}, is shown at several junction temperatures in Curve 1 of the Trigistor Specification Bulletin. I_{CBO} is by definition measured with a voltage applied between collector and base, V_{CB}, and with the emitter open circuited. If the Trigistor is operated in the common emitter connection with the base open, I_{CBO} acts as a positive base current source and is multiplied by the current gain, β_1, of the equivalent NPN transistor. This may cause the Trigistor to turn on, particularly at elevated temperatures where I_{CBO} is greatest. In order to insure stability of the forward cutoff characteristic and prevent undesired turn on, the base must be biased off with a negative current source greater than I_{CBO} (in the same manner that a conventional transistor is stabilized in switching applications). Under this condition, I_{CBO} is not multiplied, and the common emitter cutoff collector current equals I_{CBO}.

I_{CBO} is controlled by the specification to a maximum value of 100 μA at 125° C and at maximum rated V_{CB}. The common emitter characteristics of Figure 4 are with a negative base bias current of 150 μA which provides an adequate margin for stability at the highest temperature extreme.

Forward breakdown voltage occurs at a voltage substantially above rated V_{CB}. If forward collector voltage in excess of ratings is applied to the Trigistor, reaching the breakdown voltage level, the rapid increase in I_{CBO} will overcome the negative base bias, causing the Trigistor to turn on. This "breakover" effect, shown in Figure 4, affords protection against forward overvoltaging, since collector voltage drops to a low value, reducing power dissipation.

The forward V_{CB} rating is 5 volts greater than the V_{CE} rating, allowing the Trigistor to be operated at full V_{CE} rating in common emitter circuits when the base is driven negative (during turn-off) to the full 5 volt emitter-base voltage rating.

The reverse cutoff characteristic (negative V_{CE}) is similar to the forward cutoff characteristic. Reverse breakdown voltage is greater than the reverse V_{CE} rating (-15 volts for all Trigistor types). All voltage ratings apply over the entire operating temperature range (-65° C to +125° C).

Curve 2 in the Trigistor Specification Bulletin shows the collector characteristic in the "on" state at several different junction temperatures. Collector to emitter "on" voltage, $V_{C_{on}}$, is approximately 1 volt, so that collector "on" current, $I_{C_{on}}$, is generally determined by the collector supply voltage and load impedance. Although $I_{C_{on}}$ must be within the 1 to 8 ma range for reliable turn off control at the base, the Trigistor is capable of carrying much higher sustained or pulsed collector current, limited by power dissipation.

As indicated in Curve 2, when the collector current is decreased to a certain value, collector voltage rapidly increases. Below this "dropout current" level, regenerative action is not maintained and the Trigistor turns off. The dropout current level is similar to the "breakover" current level, shown as a dash line in Figure 4. The dropout current level increases as negative base bias current is increased.

Input Characteristic

The Trigistor input characteristic is shown in Figure 5. The collector is connected to a positive supply voltage through a load resistor which establishes $I_{C_{on}}$ at 4 ma.

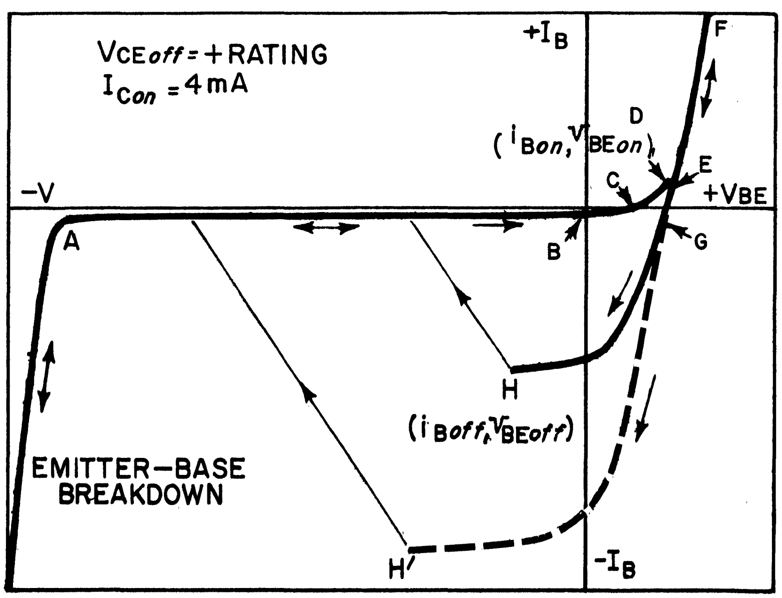

Fig. 5 Input Characteristic

Between points A and B on the input characteristic, the Trigistor is in the "off" state. The Trigistor cannot turn on because its base-emitter voltage, V_{BE}, is negative, preventing transistor action. The small negative base current, I_B, is essentially equal to I_{CBO}. At B, V_{BE} equals zero. I_{CBO} must still flow out of the base, since the base-emitter junction is zero biased and no current can flow in the emitter circuit.

Turn On

As V_{BE} is raised in the positive direction from B to D, the base-emitter junction begins to conduct with the typical exponential characteristic of a forward biased silicon junction. Transistor action begins and I_c and β_1 start to rise. At C, I_B equals zero and I_{CBO} acts as an internal source of base current. Beyond C, I_B aids I_{CBO} as a positive base current source. At point D, β_1 β_2 reaches unity and the Trigistor turns on. Base trigger-on current, i_{Bon}, and base trigger-on voltage, v_{BEon}, are the discrete instantaneous values of base current and voltage at which the Trigistor turns on.

i_{Bon} and v_{BEon} are shown as a function of junction temperature in Curves 3 and 4 in the Specification Bulletin. These curves define the "spread" in these characteristics and provide essential circuit design information. All Trigistors will turn on within the shaded areas of these curves. The upper limit of the shaded areas establishes minimum requirements for the base trigger-on pulse to insure that all Trigistors turn on. Equally important, the base must be biased below the lower limit of the shaded areas to insure that all Trigistors will remain in the stable "off" state until a trigger-on pulse is applied.

The lower i_{Bon} limit shown in Curve 3 represents the maximum I_{CBO} allowed by the test specification. Although the Trigistor requires a negative base stabilizing current, I_{BS}, greater than maximum I_{CBO}, it does <u>not</u> require negative V_{BE} to prevent undesired turn on. As shown in Curve 4, no Trigistor can turn on at junction temperatures up to 125^{o} C until V_{BE} reaches a minimum positive voltage which corresponds to the "knee" in the forward characteristic of the base-emitter junction. Thus a resistor connected from base to emitter is a practical method of bias stabilization up to 100^{o} C junction temperature. Turn on base current and voltage requirements are independent of the $I_{C\,on}$ level established after turn on, and essentially independent of V_{CE} prior to turn on.

Referring back to the Trigistor input characteristic, Figure 5, when the Trigistor turns on at point D, collector current suddenly rises to the $I_{C\,on}$ level. This increase in current flowing through the base-emitter junction causes its voltage drop to rise by a few millivolts, and the input characteristic shifts from D to E.

As I_B is increased above the i_{Bon} level, the input characteristic proceeds toward F. The Trigistor input characteristic from A to F is similar to a conventional NPN silicon transistor except for the discontinuity from D to E where the Trigistor turns on.

With the Trigistor in the "on" state, when I_B is reduced, the input characteristic does not retrace its original path through points D and C. At the conclusion of the base trigger-on pulse, Trigistor base current returns to the negative stabilizing bias level, and the input characteristic moves through E to G. V_{BE} remains positive because the base-emitter junction is in the forward direction. Emitter current is almost equal to I_{Con} (4 mA). The Trigistor input characteristic remains at G, in the "on" state, until it is turned off.

Turn Off

With the Trigistor in the "on" state, a substantial proportion (12 to 50%) of the I_{Con} current is available to drive the base of the equivalent NPN transistor from the collector of the PNP, which keeps the Trigistor solidly "on".

As I_B is increased in the negative direction, the drive available to the NPN is reduced. When I_B equals the feedback current from the PNP, at point H, the NPN is cut off. The Trigistor turns off and the input characteristic returns to the "off" state between A and B along a path determined by the base driving impedance.

Base trigger-off current, i_{Boff}, and base trigger-off voltage v_{BEoff}, are the discrete values of base current and voltage at H, where the Trigistor turns off. i_{Boff} is directly proportional to I_{Con}. Although the base-emitter junction is in the forward direction up to the moment of turn-off, v_{BEoff} may be negative because of the voltage drop caused by I_{Boff} flowing through internal series base resistance.

The dash line portion of the input characteristic indicates the larger values of i_{Boff} and v_{BEoff} at H' associated with an I_{Con} current level of 8 mA.

Curves 5 and 6 in the Trigistor Specification Bulletin give i_{Boff} and v_{BEoff} as a function of junction temperature at an I_{Con} level of 4 mA, Curves 7 and 8 show i_{Boff} and v_{BEoff} as a function of I_{Con} at 25° C junction temperature.

DESIGN CONSIDERATIONS FOR TRIGISTOR CIRCUITS

Cutoff Bias Stabilization

Bias stabilization is required for reliable Trigistor operation to prevent turn on until a trigger-on pulse is applied to the base. Some of the spurious sources of base current that may cause the Trigistor to turn on have been mentioned previously— I_{CBO}, particularly at high temperatures, and collector breakdown. Another internal base current source is caused by rapid rise in collector voltage coupled through capacitance within the Trigistor.

With the Trigistor in the "off" state and V_{CE} positive, Junction 2 (Fig. 2) is reverse biased. If V_{CE} is made suddenly more positive, a positive current is coupled into the base through the capacitance of Junction 2, according to the relationship:

$$I = C \frac{dV}{dt}$$

Junction capacitance of 25 $\mu\mu$f results in an effective turn-on base current of 25 μA per volt/μsec rate of rise of collector voltage.

This effect is often caused by transients in the collector supply voltage, particularly when collector voltage is applied directly to the Trigistor through mechanical switch or relay contacts. It can be easily overcome by reducing the rate of rise of collector voltage with an RC filter in the supply lead. In gating, coincidence, and other circuit applications, a rapidly rising collector voltage is often deliberately applied to the Trigistor. It may not be desirable to slow down the rate of rise because the circuit response is also slowed down. In such cases, the Trigistor can usually be prevented from turning on by increasing the negative stabilizing bias on the base.

The bias stabilizing network is one of the most important factors in reliable Trigistor circuit design. Negative stabilizing bias current, I_{BS}, must be large enough to prevent any Trigistors from turning on spontaneously, but it must not be large enough to turn off any Trigistor that has been triggered on.

The minimum requirement for I_{BS} is established at the highest operating junction temperature, where I_{BS} must be greater than I_{CBO} (Curve 3). Maximum I_{BS} is established at the low temperature extreme with $I_{C_{on}}$ at its lowest value (Curves 5 and 7).

For example, refer to the two circuits on Page 2 of the Trigistor Specification Bulletin that are presented as recommended operating conditions for bias stabilization. In circuit A, designed for reliable operation over an operating junction temperature range of -25° C to +125° C, stabilizing bias is derived from a negative voltage source.

Curves 3 and 4 show that I_{BS} must be greater than 100 μA and V_{BE} less than 0 volts to prevent any Trigistor from turning on at 125° C. With an R_B of 10K and V_{BB} of -1.5V, I_{BS} of -150 μA is available at 0 V_{BE} which provides a suitable margin of stability.

Curves 5 and 6 show that with $I_{C_{on}}$ of 4 mA and at -25° C, no Trigistor will be turned off if I_{BS} is less than -300 μA. Note that when the Trigistor is "on", the base is a voltage source, and if series base resistance is low enough, the Trigistor can be turned off at a positive value of V_{BE}. At a V_{BE} of 0.8 volts the total voltage across R_B is 2.3 volts. The resulting I_{BS} of -230 μA cannot cause any Trigistors to turn off.

The bias stabilizing network does not affect the trigger-on and trigger-off voltage requirements since it is in parallel with the base. To turn on all Trigistors, 1.0 volts minimum is required at -25° C (Curve 4). A capacitor coupled trigger-on pulse must have a minimum voltage swing of +2.5 volts, since the base may be at -1.5 volts initially with the Trigistor in the "off" state. To turn off all Trigistors, -3.0 volts minimum is required at +125° C (Curve 6).

Trigger-on and trigger-off current requirements are affected by the bias stabilizing network. With $v_{BE_{on}}$ of +1.0 volts at -25° C, R_B requires 250 μA in addition to $i_{B_{on}}$ of 100 μA for a net minimum trigger-on current requirement of 350 μA. With $v_{BE_{off}}$ of -3.0 volts at +125° C, R_B requires -150 μA in addition to $i_{B_{off}}$ of -2.5 mA for a net minimum trigger-off current requirement of -2.65 mA.

In Circuit B the stabilizing resistor is returned directly to the emitter instead of to -1.5 volts as in Circuit A. This circuit is attractive because it does not require a negative bias supply voltage. It cannot, however, operate over as wide a temperature range.

Curve 9 shows the effect of base-emitter bias stabilizing resistance, R_{BE}, *vs.* junction temperature. R_{BE} cannot be too large or some Trigistors may turn on. Maximum R_{BE} is determined by dividing $v_{BE_{on}}$ by $i_{B_{on}}$ at the lower limit of the shaded areas in Curves 3 and 4. If R_{BE} is too small, some Trigistors may be turned off. Minimum R_{BE} is determined by dividing $v_{BE_{off}}$ by $i_{BE_{off}}$ at the upper limit of the shaded areas in Curves 5 and 6.

R_{BE} of 2K in Circuit B will not allow any Trigistors to turn on at 100° C junction temperature and will not cause any to turn off at 0° C. An R_{BE} value of 3K would allow Trigistor operation over a temperature range of -25° C to +90° C.

It is apparent that as V_{BB} is reduced from -1.5 volts to 0 volts, the smaller value of R_B that is necessary to prevent turn on at high temperature is more likely to cause turn off at low temperature. Smaller R_B also increases the net minimum trigger-on and trigger-off current requirements.

If V_{BB} is made larger, towards -5 volts (max. V_{BE} rating), the bias stabilizing network tends toward a constant current source. I_{BS} does not increase as much at low temperature and has less effect on turn off.

If the bias stabilizing network is designed so that I_{BS} decreases at low temperatures, a greater margin is provided and the Trigistor may be operated at lower $I_{C_{on}}$ levels. This characteristic can be achieved using a thermistor as one of the elements of the bias stabilizing network.

Figure 6 shows the resistance *vs.* temperature characteristic of a thermistor-resistor parallel combination that can be substituted for the 2K bias stabilizing resistor in Circuit B. The fixed resistor is 50K ohms and the thermistor is 10K at 25° C (Fenwal GB41L1, Gulton 41CB2, or Veco 41A2). The lower operating temperature of Circuit B is extended to -55° C with wider stability margin at 100° C. Thermistors can also be used effectively in bias stabilizing networks designed to operate from a negative supply voltage, as in Circuit A.

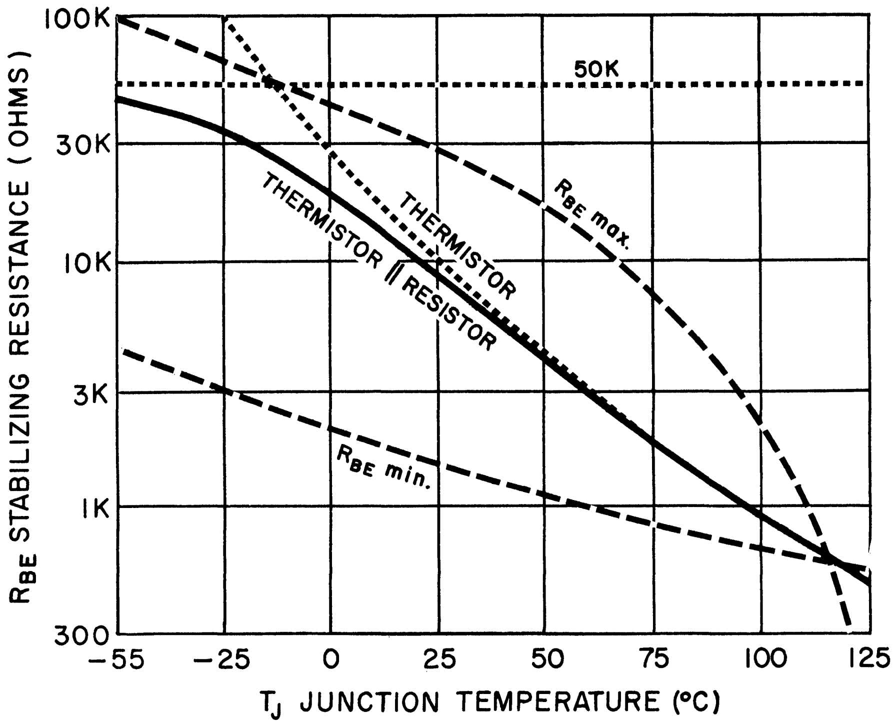

Fig. 6 Thermistor Bias Stabilization

When Trigistor circuits are designed for reliable operation at temperatures above 100° C, a negative voltage source must be used for bias stabilization. If a negative source is not available, a forward biased silicon junction diode or a low voltage zener diode inserted between emitter of the Trigistor and ground will serve the same purpose. Before the Trigistor can turn on, its emitter must be above ground by a voltage equal to the diode drop. With the bias stabilizing resistor returned to ground, the diode voltage drop is equivalent to a negative voltage source with respect to the emitter.

Diode drop must be considered at both high and low operating temperature extremes. The zener diode is preferable to the forward biased diode because of its larger voltage drop and smaller variation with temperature. Zener diodes with small positive temperature coefficients can be connected in series with the emitter or the base to compensate for the negative temperature coefficient of the base trigger-on voltage, v_{BEon}.

Collector ON Current

The Trigistor is designed for trigger-off control at the base with I_{Con} in the 1-8 mA range. An I_{Con} level of 4 mA is recommended for operation over the temperature range of -25° C to +125° C with I_{BS} derived from a negative bias source through a fixed R_B.

If the Trigistor is operated at an I_{Con} level below 4 mA, Curve 7 shows that i_{Boff} is reduced. I_{BS} must therefore be reduced to avoid causing any Trigistor to turn off. This will limit the maximum operating temperature unless the bias stabilizing network is thermistor compensated.

As the I_{Con} level is raised above 4 mA, v_{BRoff} requirements increase, particularly at high temperature, to the point where v_{BEoff} exceeds the -5 volt V_{BE} rating (Curves 6 and 8).

When the Trigistor is operated at I_{Con} levels above the 1-8 mA range, turn-off can be accomplished by driving the anode voltage negative, as with a conventional PNPN Controlled Switch.

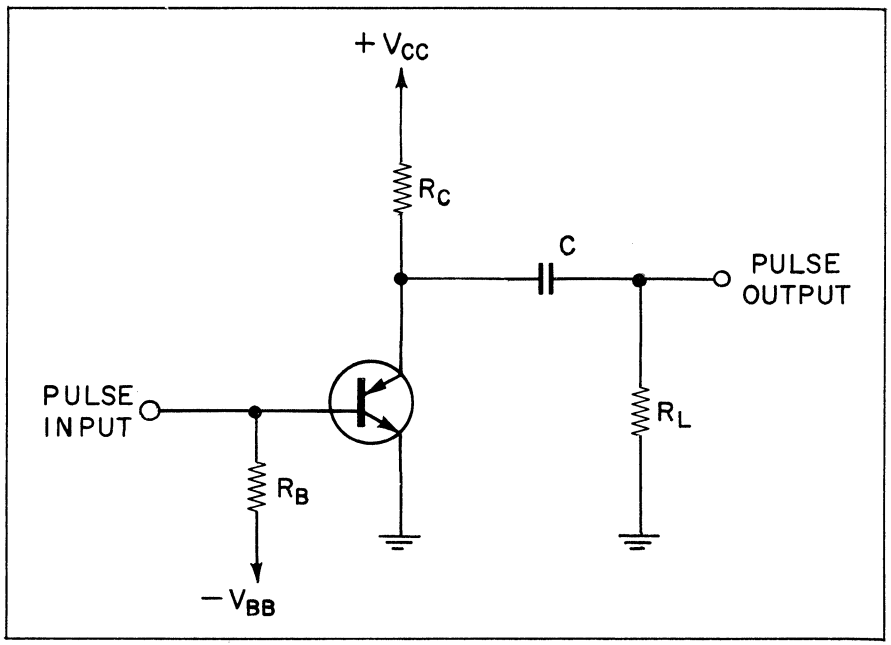

Fig. 7 Trigistor Pulse Generator

The Trigistor is uniquely suited for a wide variety of circuit applications wherein it is used to generate high current pulses (up to 1 ampere) and can subsequently be turned off at the base. Fig. 7 is an example of this type of circuit. When the Trigistor is "off", C charges through R_C until the collector is at $+V_{CC}$. When a trigger-on pulse is applied to the input, the Trigistor turns on and its collector voltage drops to approximately +1 volt. The energy stored in C discharges through the Trigistor into R_L. As C discharges, $I_{C_{on}}$ declines toward a steady-state level determined by R_C and V_{CC}.

If the steady-state $I_{C_{on}}$ level is approximately 4 mA and I_{BS} equals -150 μA, the Trigistor will remain "on" until it is turned off by a negative trigger-off pulse at the gate. C then recharges toward $+V_{CC}$ to complete the cycle.

If steady-state $I_{C_{on}}$ is below the collector dropout current level, the Trigistor will automatically turn off after C discharges. The dropout current level can be raised in the 1-8 mA range by increasing negative D.C. base bias above the I_{BS} value required for stabilization.

Referring to the Trigistor Specification Bulletin, the axes of Curve 7 could be relabeled "Base DC Bias Current vs. Collector Dropout Current". For example, a bias current of -1 mA establishes the dropout current level between 2 to 8 mA.

The high current output capability of the Trigistor can be used to turn on PNPN Controlled Switches or Controlled Rectifiers and can turn them off by applying a negative pulse to the anode. In pulse logic circuits, a single Trigistor can trigger-on and trigger-off many other Trigistors. "Treeing" is possible to an extent never realizable with transistors. In addition, logic circuits can be designed so that the Trigistor either remembers or does not remember when it has delivered a pulse.

Maximum Trigistor collector current is determined by the maximum power dissipation rating -- 125 mW at 100° C ambient temperature, derated 4 mW/$^\circ$C above 100°C. Power dissipation can be calculated by multiplying $I_{C_{on}}$ by $V_{CE_{on}}$ (Curve 2). At 100° C ambient, the Trigistor can carry 125 mA continuous DC or RMS current at peak current levels up to 1 ampere.

Switching Speed

Trigistor switching speed specifications and test circuit are given in the Trigistor Specification Bulletin. Curve 10 illustrates typical variation in switching parameters as a function of junction temperature.

When a positive trigger-on pulse is applied to the base of the Trigistor, the equivalent NPN transistor is turned on (Fig. 2d). Since the PNP transistor is much slower than the NPN, regenerative feedback is delayed. The initial collector response is determined solely by the NPN transistor. As in a conventional NPN transistor, collector rise time, t_r, is reduced by increasing base drive. If base drive is not sufficient to drive the NPN transistor into saturation, collector current will not rise to the maximum value determined by V_{CC} and R_C.

If the base trigger-on pulse is terminated before the PNP starts to supply regenerative feedback current to the base of the NPN, the Trigistor will turn off. In order for the Trigistor to turn on and remain in the "on" state, the trigger-on pulse duration must be longer than the "base time to hold", t_{BH}, which is essentially the time required for regenerative action to take place.

When a negative trigger-off pulse is applied to the base of the Trigistor, the equivalent NPN transistor is driven off quite rapidly. The PNP is not driven off, and turns off more slowly. As the NPN is turned off, Trigistor collector current falls to the level carried by the PNP prior to turn-off (12 to 50% of I_{Con}). From this point, the PNP turns off, and collector current diminishes gradually to the I_{CBO} level. Because of this "knee" in the turn-off time characteristic, collector current fall time, t_f, is defined at 60%, rather than at the 90% point.

If the trigger-off pulse is terminated before the PNP recovers, the Trigistor will not remain in the "off" state because collector current from the PNP transistor will turn it back on. Minimum trigger-off pulse width for the Trigistor to remain "off" is the "base time to recover", t_{BR}. The Trigistor recovers when its collector current falls below the I_{BS} level, so that t_{BR} is less if negative base bias is increased.

Trigistor circuit response is indicated by t_r and t_f. The maximum repetition rate is determined by t_{BH} and t_{BR}.

TRIGISTOR DEFINITIONS

I_{CBO} — Collector cutoff current. Collector current with positive or negative collector to base potential and with emitter open. I_{CBO} is essentially equal to the collector current in the forward "off" state with positive potential applied between collector and emitter terminals and with the base biased off.

I_{BEO} — Emitter cutoff current. Emitter current with positive emitter to base potential and collector open.

$I_{C\,on}$ — Collector "on" current. Collector current with the Trigistor in the forward "on" state. $I_{C\,on}$ is determined by the external circuit.

$V_{C\,on}$ — Collector "on" voltage. Collector to emitter voltage drop associated with $I_{C\,on}$.

I_{BS} — Base bias stabilizing current. Negative base bias current which prevents the Trigistor from turning on due to spurious causes.

$i_{B\,on}$ — Base trigger-on current. Instantaneous base current required to turn Trigistor on.

$v_{BE\,on}$ — Base trigger-on voltage. Instantaneous base-emitter voltage with $i_{B\,on}$ flowing immediately prior to turn on.

$i_{B\,off}$ — Base trigger-off current. Instantaneous base current required to turn Trigistor off.

$v_{BE\,off}$ — Base trigger-off voltage. Instantaneous base-emitter voltage with $i_{B\,off}$ flowing prior to turn off.

t_r — Rise time. Time required during turn on for collector current to rise to 90% of $I_{C\,on}$ level.

t_f — Fall time. Time required during turn off for collector current to fall to 40% of the $I_{C\,on}$ level.

t_{BH} — Base time to hold. Time required during turn on for regenerative action to sustain Trigistor in the "on" state.

t_{BR} — Base time to recover. Time required during turn off for regenerative action to cease, allowing Trigistor to remain in the "off" state.