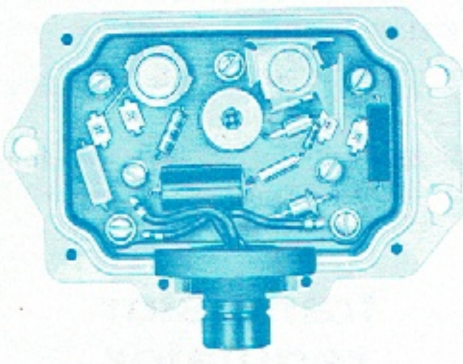
training chart manual

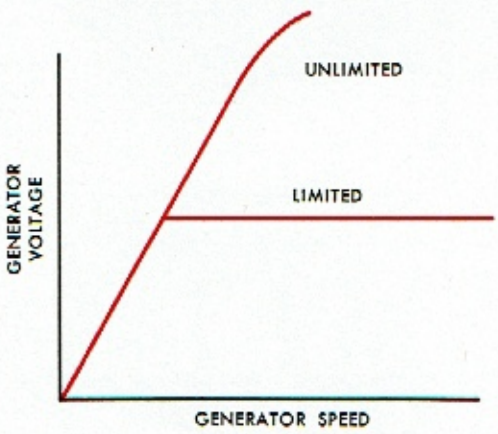
SECTION L

TRANSISTOR REGULATORS

Delco Remy



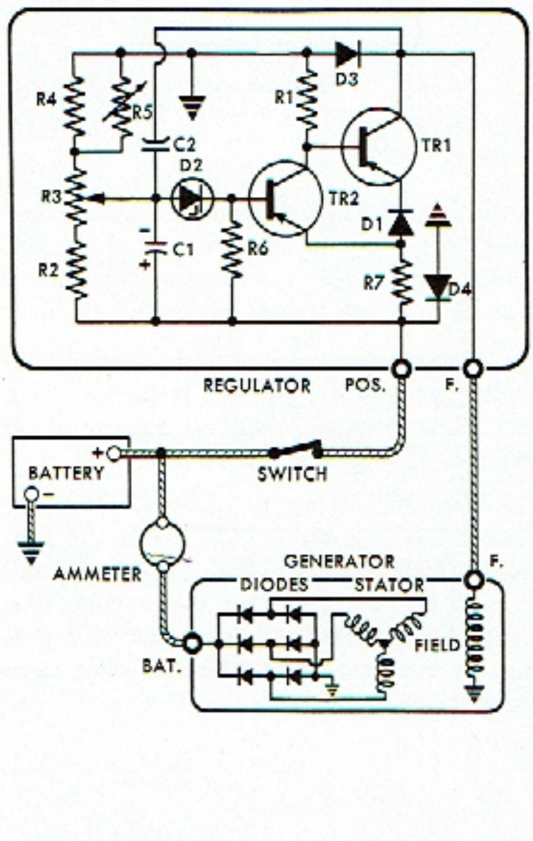
There are many different models of transistor regulators, each designed to meet the requirements of a specific application. Although the external appearance of these regulators may vary considerably, the internal circuitry on each model is basically the same. Since this section describes the basic internal circuit, it applies equally well to all models of transistor regulators.



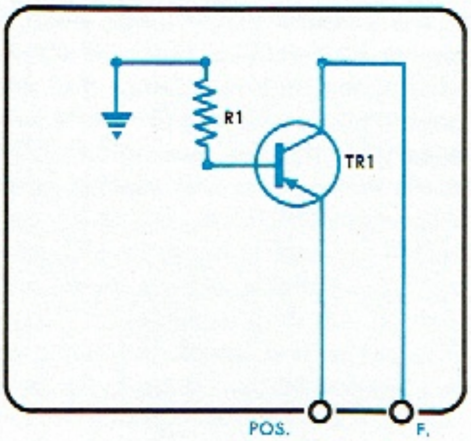
The need for a regulator in the charging circuit is brought about by the fact that the generator voltage increases with increases in generator speed. Since sufficient voltage must be developed at low speeds to charge the battery and operate electrical accessories, this voltage if uncontrolled at high generator speeds would increase to values that would overcharge the battery and damage the accessories. The sole function of the regulator is to prevent high voltage by limiting the generator voltage to a safe, preset value.

The regulator limits the generator voltage to a preset value by controlling the generator field current. In the typical negative grounded circuit shown, the regulator is connected between the battery positive terminal and generator field winding. It operates electronically to alternately "turn off" and "turn on" the voltage across the field winding. In a sense, the transistor regulator is nothing more than a very fast-acting electronic switch. This switching, between open and closed and back again, can occur at a rate as low as 10 times per second, and as high as 7000 times per second.

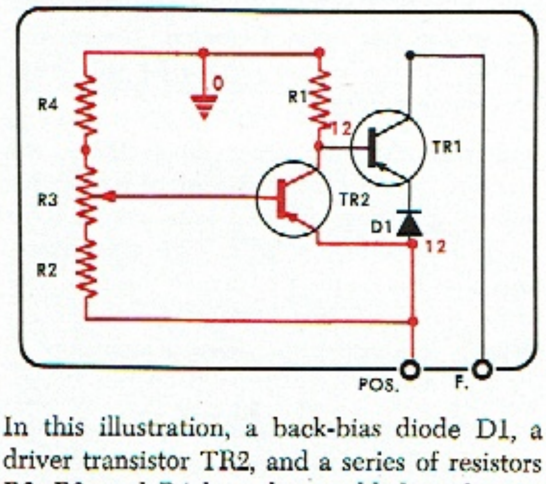
The internal wiring of a typical transistor regulator and Delcotron® generator is illustrated. Although every component shown in the diagram may not be used in every model of regulator, the illustration will serve as a basic



design generally applicable to all regulator models.



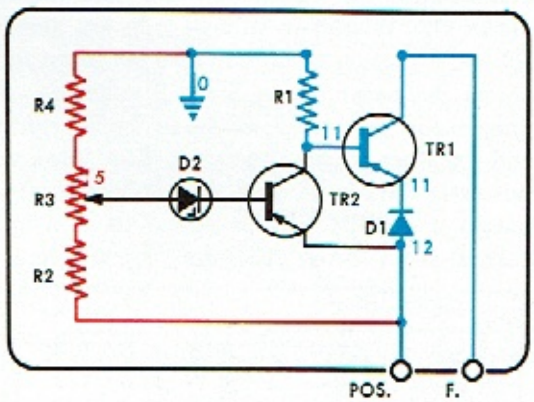
In order to see how a transistor regulator works, we will "build up" the typical regulator circuit step by step, adding components as we go until the entire circuit has been completed. Our "build up" of the basic circuit begins with an output transistor TR1 and a resistor R1. With the switch closed, and the emitter connected to the battery positive terminal, an emitter-base current will flow through resistor R1 to ground. The transistor resistance, therefore, will be very low, and the battery will supply full generator field current through the emitter-collector of the transistor. Under this condition, the transistor acts like a closed switch and the generator voltage will become very high with speed, so some means must be devised to cause the transistor to "turn off."



In this illustration, a back-bias diode D1, a driver transistor TR2, and a series of resistors R2, R3, and R4 have been added to the circuit. Since the base of transistor TR2 is connected to ground through resistors R4 and a portion of R3, this transistor will turn "full on," and emitter-collector current will flow through resistor R1 to ground. The potential on the collector of TR2, neglecting the small drop in the transistor, will be 12 volts.

If current were flowing to the field winding, a voltage drop would appear across diode D1, causing the potential on the emitter of transistor TR1 to be less than 12 volts. This would reverse bias the emitter-base of transistor TR1; therefore, this transistor will not conduct current and the field current is turned off. The transistor TR1 acts almost like an open switch, and the generator field winding is electronically disconnected from the battery. Under this condition of no field current, the generator would produce no voltage. Now some means must be found to turn transistor TR1 back on.

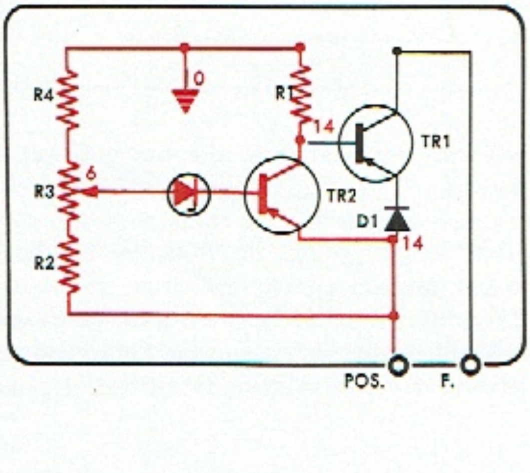
In this illustration, a zener diode D2 has been connected into the circuit. Note that the zener has been connected to prevent or block current flow from the base of driver transistor TR2 to resistor R3. With no emitter-base current in transistor TR2, there will be no emitter-collector current and this transistor will act like an open switch. With the 12 volt



potential removed from the base of output transistor TR1, this transistor will "turn on" and full current will be restored to the generator field winding. In effect, we are back to our original circuit, consisting of resistor R1 and transistor TR1, with the switch closed, and full current flowing to the field winding. With a one volt drop in the diode D1, and neglecting transistor voltage drop, the potentials would be as shown. Now, some means must be found to turn transistor TR1 off, so the generator voltage can be limited during operation. Let's take a closer look at diode D2.

Zener diode D2 is a special kind of diode that will allow current to flow from transistor TR2 to resistor R3 when the voltage across the diode reaches a certain value. For purposes of discussion, we will assume that this voltage, called the "breakdown voltage," is eight (8) volts. Below this voltage the diode refuses to pass current, but when the voltage reaches eight (8) volts the diode suddenly "breaks down" and readily conducts current. Below eight volts the zener diode acts like an open switch, and at eight volts or above it acts like a closed switch.

Note, that with the battery connected to the regulator, current will always flow through resistors R2, R3, and R4 to ground. If the battery voltage divides in the ratio of about seven (7) to five (5), the voltage potential at the zener diode connection to resistor R3 will be 5 volts, as shown. This means that the voltage drop across resistors R2 and the other portion of R3 is 7 volts. **This same 7 volts is impressed across the zener diode,** because these two resistors are in parallel with the emitter-base of transistor TR2 and zener diode D2. Whatever voltage appears across R2 and a portion of R3 will also be impressed across the zener diode. Since 8 volts are required for the zener diode to break down and conduct current, current flow through transistor TR2 is blocked. As previously mentioned, transistor TR1 is turned on and full current flows to the generator field winding.

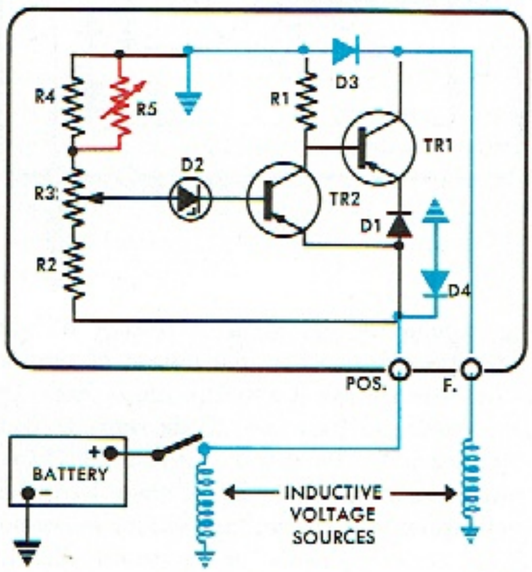


As the generator voltage starts to increase, the voltage across resistors R2, R3, and R4 also increases. With the generator producing 14 volts, the potential at the zener diode connection to R3 would be about six (6) volts, and the remaining voltage drop that would be impressed across the zener diode would be eight (8) volts. The zener diode will immediately break down and conduct current. With transistor TR2 full on, a 14 volt potential appears at the base of transistor TR1, and its emitter has a potential of 13 volts, caused by the one (1) volt drop in diode D1. With the emitter-base reverse biased, the output transistor TR1 turns off the voltage to the generator field. The generator voltage decreases until the voltage across the zener diode barely goes below 8 volts. The zener diode then blocks current, transistor TR2 stops conducting, and transistor TR1 turns the field voltage back on. This cycle then repeats many times per second to limit the voltage to 14 volts.

The arrow at resistor R3 indicates that this is an adjustable connection; resistor R3 is called a potentiometer. By adjusting the potentiometer the regulator can be made to limit the generator voltage to different values. For example, if the connection is moved toward resistor R2, a higher current through resistor R2 and resistor R3 is needed to provide the 8 volts required across the zener diode for breakdown. To provide this additional current, the system voltage must rise above 14 volts. Accordingly, the regulator will operate to limit the system voltage to some value above 14 volts, and the regulator voltage setting has been increased. Conversely, moving the connection toward R4 will lower the voltage setting.

It is seen that the zener diode D2 is the "trigger" that "senses" a portion of the system voltage, and turns off and turns on the generator field voltage so as to limit the voltage. Now that the method by which the regulator limits the generator voltage has been explained, let's add some more components to the regulator that will make it operate better.

When the output transistor TR1 turns off, the generator field current can not immediately decrease to a zero value because the inductance of the field winding causes the current to continue flowing. Before the current can decrease to zero, the system voltage decreases and the regulator turns the field current back on. However, the decreasing field current will induce a high voltage in the field winding, and this high voltage will damage transistor TR1 unless some protection is provided. To prevent damage, field discharge diode D3 is added to the circuit. This diode conducts generator field current flow caused by the induced voltage in the field winding, thereby diverting the current flow from and avoiding damage to transistor TR1. The inductive current flow caused by the induced voltage can be traced through the field winding to ground,



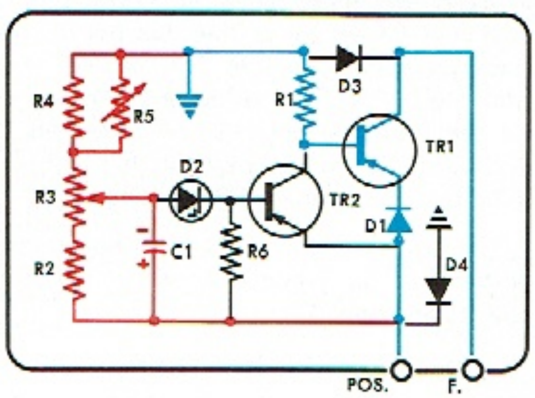
through ground into the regulator, and then through diode D3 back to the field winding. Note that the diode blocks current flow from the battery and generator output terminal to ground.

To provide protection against other induced voltages, called transient voltages, that may appear in the external electrical system, transient suppression diode D4 is added to the circuit. High transient voltages originating at inductive sources, such as solenoids, that would cause damaging currents are effectively shorted out by this diode. The inductive current flows from the source, through ground, and then through diode D4 back to the source. The diodes D3 and D4 effectively short-out and prevent high induced voltages from appearing in the electrical system.

On some applications, it is desirable that the regulator voltage setting automatically change with changes in temperature in order to provide the most suitable charging voltage across the battery. Since for any battery terminal voltage the battery charge rate increases with increases in battery temperature, it is desirable for the regulator to lower its setting as the temperature increases. This change in voltage setting tends to protect the battery from overcharge when hot and from undercharge when cold. To accomplish this operating characteristic a thermistor R5 is connected in the resistor network.

A thermistor is a special resistor that **decreases** its resistance with increases in temperature. As the operating temperature increases, the effective total resistance of thermistor R5 and resistors R2, R3, and R4 becomes less. Since the current through R2 and a portion of R3 needed to provide the 8 volt drop for triggering the zener diode can now be obtained with less voltage, the net result is a lowered voltage setting at which the regulator operates. The thermistor, therefore, will cause the regulator to operate at a lower setting during hot weather and at a higher setting during cold weather.

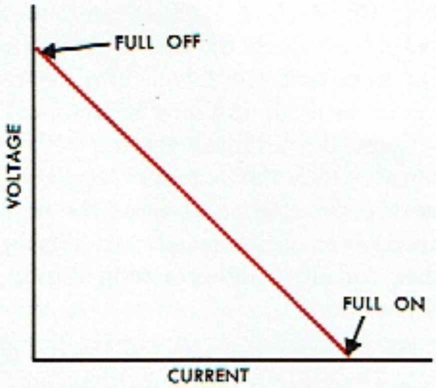
In order to make the regulator more stable, a resistor R6 and a capacitor C1 are added to the circuit. Consider first the resistor R6.



Since the resistance of transistors decreases with increases in temperature, it is possible at higher temperatures for a small leakage current to flow through the emitter-collector of transistor TR2 even though the zener diode completely blocks emitter-base current. This leakage current would cause more heating in transistor TR2, leading to more leakage current and eventually to regulator damage. To prevent this, resistor R6 is connected across the emitter-base of the transistor.

The filter capacitor C1 is connected across resistors R2 and R3 to smooth out the system voltage variations that appear across these resistors.

Without the capacitor, as the output transistor TR1 switches between "off" and "on," the generator voltage varies from a peak to a minimum because of the action of the diodes. The filter capacitor C1, when added to the circuit, smooths out these voltage variations, resulting in more stable voltage control.

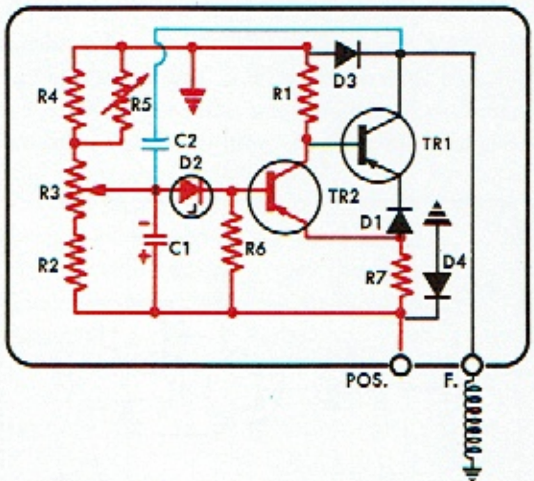


On some models of regulators it is desirable to assist the zener diode in reducing to a minimum the length of time needed for the transistors to switch from "on" to "off" and from "off" to "on." By reducing this time factor the heat developed in the transistors is decreased. To explain why this is true, consider the accompanying illustration.

The heat developed in a transistor is proportional to the product of voltage (V), current (I), and time (t):

$$(V \times I \times t = \text{heat energy}).$$

When the transistor is turned "full on," the current is high but the voltage is very low, so the heat developed in the transistor is very low. When the transistor is "full off," the voltage is high but the current is very low, so again the heat developed is very low. However, as the transistor switches between on and off and back again, the product of voltage and current becomes very appreciable. In order to minimize the heat developed during the time between on and off, the time duration must be reduced to the shortest possible interval. To accomplish this objective, resistor R7 and capacitor C2 are included in the circuit.



To explain the operation of resistor R7 and capacitor C2, consider the instant of time at which the voltage across the zener diode D2 is 8 volts, and the zener diode starts to conduct current. The driver transistor TR2 and output transistor TR1 can be made to switch more quickly if the voltage across the zener diode could suddenly be increased slightly, say to 8.2 volts. This would cause the zener diode to conduct instantly, and the two transistors to switch instantly.

When the output transistor TR1 turns off, the current through resistor R7 decreases, and the very small voltage drop across resistor R7 decreases. This causes the potential at the emitter of transistor TR2 to increase, say by .1 volt. Now the voltage across the zener diode is 8.1 volts.

Also, when the output transistor TR1 turns off (acts like an open switch), the voltage potential at its collector starts to decrease, because the collector is no longer connected to the generator output terminal. This lowered voltage is reflected through capacitor C2 to the potentiometer side of zener diode D2. Assume this lowered voltage to be .1 volt. Now the voltage across the zener diode is 8.2 volts, and it acts almost instantly to cause the transistors to switch.

As the system voltage decreases, the voltage across the zener diode drops below 8 volts, the zener diode suddenly "shuts off," and the two transistors revert back to the full generator field voltage condition. With transistor TR1 turned on, the higher voltage at its collector is reflected through capacitor C2 to cause the zener diode to operate almost instantly.

summary

This concludes our study of the principles on which the transistor regulator operates. It is to be emphasized that some models of regulators do not use all of the components covered in our discussion. Specific circuits, along with trouble-shooting procedures, are covered in complete detail in the applicable Delco-Remy Service Bulletin for every model of transistor regulator.

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