VOLTAGE REGULATORS

You have covered the main parts of a power supply. The transformer, rectifier, and filter have been covered in detail. You may want to take a few minutes to review this material. In the powe supply lesson, you learned that the filtered output of a rectifier supplies a constant DC voltage. However, the voltage output of a power supply may not always be constant; it may vary with fluctuations in the load that it is supplying, in the power supply itself, or in AC input voltages. Many types of electronic equipment in use today involves circuitry that will not tolerate variances in supply voltage. Amplifiers are an example. They must have constant biasing voltages. Changes in input voltages to an amplifier can result in the amplifier changing classes of operation resulting in distortion of the signal being amplified. To compensate for possible fluctuations, voltage regulator circuits have been developed to keep the output of a power supply at a constant level. The purpose of a regulated power supply is to provide a constant output voltage regardless of changing loads or changing input voltages. See fig. 1.

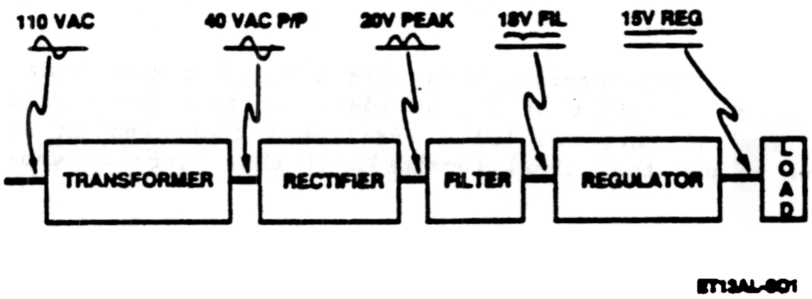


Fig 1.

LOAD

The term load can have two meanings. In previous lessons the load was a resistor, (load resistor) or another circuit that was being driven by a particular circuit. When talking about power supplies, the load is referred to as the current that is being drawn from the power supply. If the resistance or impedance of a circuit being driven is reduced, then more current will pass through it. The load, or current from the power supply has then increased. By the same reasoning, if the resistance of the load, (meaning the current from the power supply), decreases. It should be evident then, that when referring to "LOAD", some thought must be given to what is actually being talked about, the load that is the resistance of the circuit being driven by the power supply or the load that is the current being drawn from the power supply.

NEED FOR REGULATION

It was stated earlier that many circuits require a constant voltage to operate properly. If for some reason the current through a load increases, due to a decrease in load resistance, the output of a non-regulated power supply will decrease. Up to this point, we have not considered the possibility that the voltage available from a source such as a battery or a generator might change as the current drawn from that source changes. In many cases, where very close tolerances are not required, the change is so slight that we can ignore it. In other cases, computers or radars for example, the decrease in the terminal voltage of a source of emf, (electromotive force), as the current through it increases, must be taken into account. An example of this change in terminal voltage is the way automobile headlights dim when the starter motor is drawing current from the battery.

A convenient way of representing this effect is to assume that the practical source of emf consists of (1) an ideal source which develops a constant emf at any current, and (2) a resistance connected in series with this ideal source and the actual terminals of the source as shown in fig. 2.

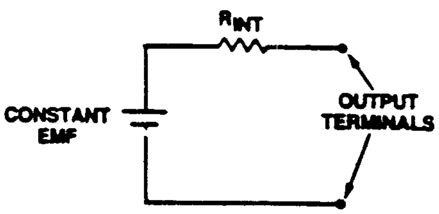


Fig 2

This resistance is known as the INTERNAL RESISTANCE of the source. It's this internal resistance that will cause the terminal voltage to drop as the current, (load), increases. When the load current flows through this internal resistance, the resultant voltage drop subtracts from the voltage delivered to the load. In fig. 3 we see that a 100-volt battery supplies a decreasing voltage to the load as the load is made to consume more current. Here, Rint, (R internal), represents the effective resistance, which actually comprises ohmic, electrochemical, and other effects within the battery.

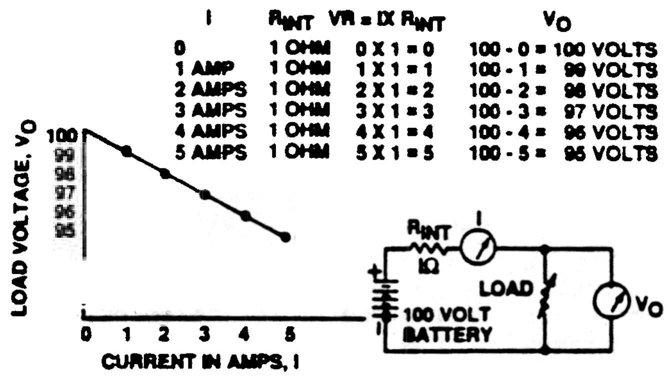


Fig 3.

The regulation characteristics of such a battery are also typical of generators, rectifiers, transformers and other energy convertors for supplying electrical power.

CURRENT REGULATED POWER SUPPLIES

Most loads encountered in electronics derive maximum benefit from operation with a voltage-stabilized source of power. However, this is not universally true. Sometimes it is more important that the current be maintained at a constant level. For example, many stereo turntables are driven by a motor that must be turned at a constant speed. The speed of the turntable is controlled through a gear changing device, and different speeds will put different loads on the motor. The speed of the motor is a direct result of the current passing through it. This arrangement would then require a constant source of current. When a current-regulated power supply is used, the current remains at a fixed value even though there are wide variations in load and considerable fluctuations in the voltage. The voltage delivered by such a supply has such poor voltage regulation that its use is prohibited with voltage-sensitive loads.

ZENER DIODES

A zener diode, (also called an avalanche or breakdown diode), has basically the same characteristics as a conventional diode. One exception being, that it is capable of recovering from the avalanche condition while the ordinary diode frequently is destroyed. When an ordinary diode avalanches, the heat created is concentrated in a small area of its junction, usually as a result of a small flaw or a low resistance path, thus the current is concentrated and melting occurs, destroying the diode. The zener diode, which is designed to avalanche safely, spreads the conduction, and thus the heat, over the entire surface of the junction. Therefore, the zener diode can recover from avalanche. If a conventional diode spreads the avalanche current over the full junction, it too can be operated in this area without burnout provided it does not exceed the diode voltage rating. Different doping levels will cause the diode to breakdown at different voltage levels.

Special applications are possible for a zener diode because it can operate continuously in the breakdown area. Its characteristic curve, (fig 4), is similar to the conventional diode. When forward biased, the zener diode can pass very high current after the barrier potential is overcome. When reverse biased by a small value of voltage, a small current will flow due to minority carriers. As the reverse bias increases, there is a slight but insignificant increase in the flow of minority carriers. When the reverse bias reaches the value marked Vb in fig. 4A, breakdown occurs and a heavy reverse current flows. Notice that when breakdown occurs, very large changes in current result from very small changes in voltage. Fig. 4B is a graph that displays the relationship between the reverse biased resistance of a zener diode and the current flow through it. Notice that as the resistance decreases, current increases resulting in a constant voltage drop across the diode. Once the zener goes into avalanche, changes in the reverse bias account for changes in the resistance. The greater the reverse bias, the greater the avalanche, and the greater the decrease in resistance of the diode. It is this characteristic of zener diodes that make them very useful in regulating circuits. Since the zener diode operates in the breakdown region, for it to be used as a regulating device, it must be **REVERSE BIASED**.

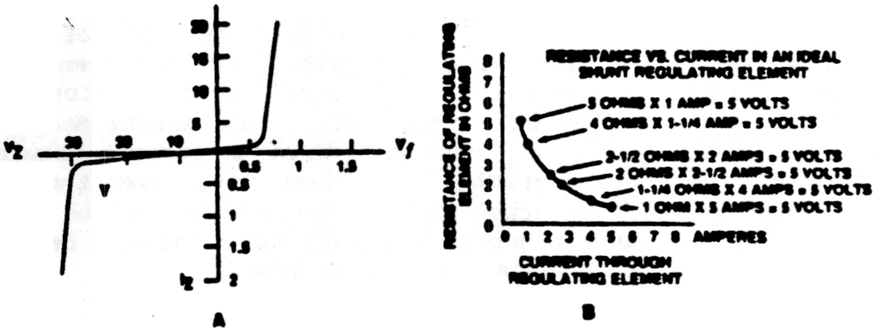


Fig 4.

ZENER CHARACTERISTICS

On the zener diode characteristic curve, (reverse only), in fig. 5, the following important points are indicated:

Vz, the breakdown or zener voltage.
Vzmax, the maximum voltage that can appear across the diode. Iz, the minimum current required to establish the breakdown knee. Izmax, the maximum reverse current, determined by the diode power rating.

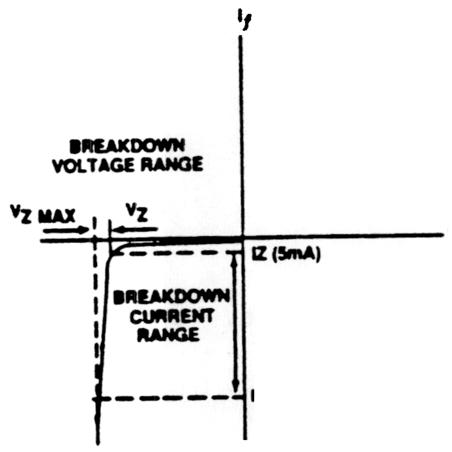


Fig 5.

ZENER IDENTIFICATION

The zener diode symbol is different from that of the standard diode. See fig. 6. The zener diode normally operates continuously in the breakdown state, (reverse condition). Its electron flow is in the direction shown in fig. 6, with the arrow. "a" is the most commonly used symbol.

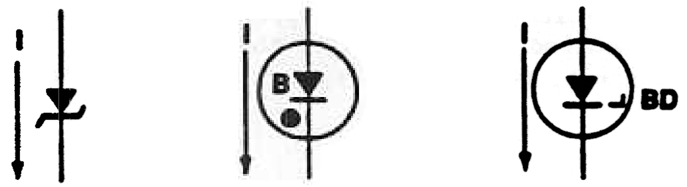


Fig 6

TYPES OF REGULATORS

SHUNT REGULATORS

Voltage regulators can be divided into two groups, Shunt and Series. Series is a term with which you are familiar, shunt is a term meaning parallel. Fig. 7A is a very simple shunt regulator. 7B shows three loads have been added and can be switched in and out.

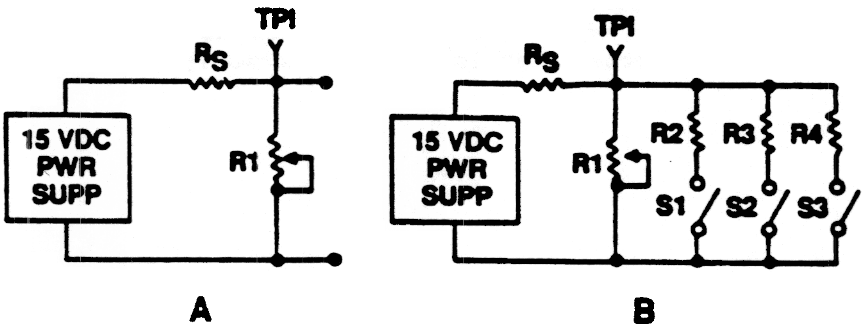


Fig 7.

Resistor Rs is in series with R1 and the loads and is necessary for circuit operation. R1 is in parallel with, and will regulate the voltage across the loads. Assume that S1 is closed and R1 has been adjusted so that TP1 reads 10 VDC. Rs is dropping 5V. The regulated output (10V) will always be less than the unregulated (15V) output. If S2 is closed R3 will be added to the circuit. R3 is now in parallel with R2 and R1. Total resistance will drop. Total current must then rise. Since total current flows through Rs and this current has increased, Rs, being a fixed resistance now drops more voltage, (E=I X R). Assume Rs is now dropping 7V, due to the increase in current through it. TP1 has decreased to 8V. Since TP1 must be regulated to 10V something must be done to bring it back to 10V. Increasing R1 by moving the wiper arm down will increase the total resistance and decrease total current. This decrease in total current means Rs will drop less voltage. R1 can be adjusted so that TP1 again reads 10V. If either load is removed, (S1 or S2), the regulated voltage at TP1 will again change. If S1 is opened the total resistance of the circuit is increased and total current decreases. A decrease in current through Rs means it will not drop less voltage leaving more to be felt at TP1. Assume TP1 increases to 12V. Again, R1 must be adjusted to correct the voltage now felt at TP1. Decreasing the resistance of R1, (moving the wiper arm up), will result in an increase in total current. More voltage is now dropped by Rs and TP1 again returns to 10V. Notice, R1 is in parallel, (shunt), with the load. The regulating device is R1, this is where the Shunt Regulator gets its name. We can see that when a load is added to the circuit, the tendency is to pull the power output voltage down. Since very few power supplies have constant loads, the need for voltage regulators should now be obvious.

SERIES REGULATORS

Figure 8A is a basic Series Voltage Regulator.

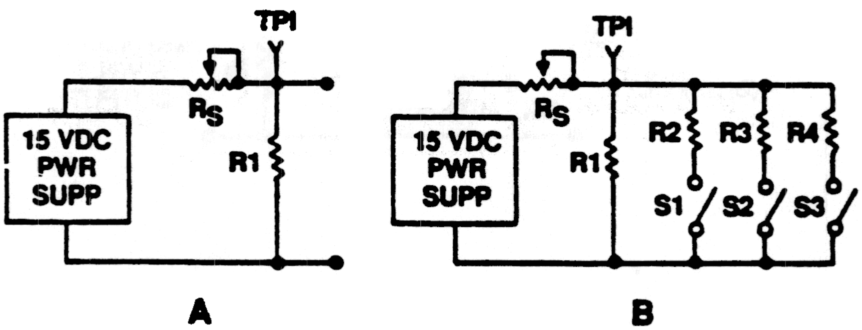


Fig 8

In this case, total current will flow through Rs. Rs is variable and will be the device used to regulate the output. Because total load current flows through the regulating device, the regulator is then a series regulator.

Assume S1 is closed, and the voltage at TP1 is 10V. Rs is dropping 5V. If S2 is closed, total resistance of the circuit will decrease allowing total current to increase. An increase in current through Rs results in its dropping more voltage. If RS now drops 7V, 8V will be felt at TP1. To return TP1 to 10V the wiper arm must be moved to the left. This reduces the size of the resistor and it will now drop less voltage leaving more to be felt at TP1. If one of the load resistors is opened, circuit resistance will increase. Circuit current must then decrease. A decrease in current through Rs will result in it dropping less voltage. If Rs drops less voltage, TP1 will then be higher. To pull TP1 back down to its original level, Rs must drop more voltage. This can be accomplished by increasing the resistance of Rs by moving the wiper arm to the right. We have looked at what varying the output causes. Varying the input (line) voltage results in the same problems and solutions. In both circuits just discussed a voltmeter would have to be placed between TP1 and ground to monitor the output of the regulator. Someone would have to constantly monitor the meter and when the output voltage increased or decreased, adjust the variable resistor. A much simpler solution would be to develop a regulator that would monitor the output and adjust itself.

SEMICONDUCTOR VOLTAGE REGULATOR

Fig. 9 is a very simple voltage regulator that uses a zener diode as a regulating device.

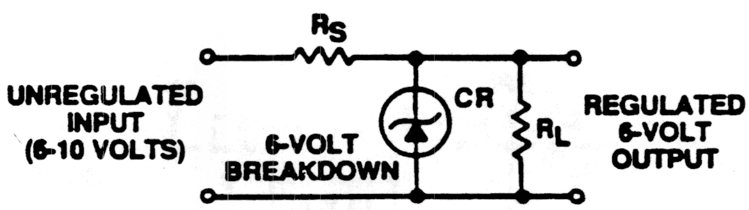


Fig 9.

In the example shown, the breakdown voltage of 6V is the voltage reference. As long as the input does not exceed 6V, the diode will not conduct. If the input voltage exceeds the 6V breakdown voltage, the diode will go into avalanche. Extra current that is the result of the input voltage increasing will be shunted around the load through the diode. Rs will feel an increase in the voltage dropped. It is a characteristic of zener diodes to allow varying currents to pass through them while holding the voltage drop across them constant. This makes them ideally suited for simple regulators. Shunt regulator circuits are not as efficient as series regulators for the majority of uses but have the advantage of simplicity. Shunt regulators offer built in protection against shorted loads because the regulator is in parallel with the load. Any shorts are felt across the regulator, and extreme current surges caused by shorted components will not pass through the regulator. A short across the output terminals merely removes the operating voltages.

TRANSISTOR SERIES REGULATORS

The series regulators you will work with in the practical exercise are actually "error-sensing" circuits. The main objectives of series regulation is to control the output voltage in response to an error signal. Rather than use a variable resistor in series with the load to control the output, a transistor is inserted. By varying the bias on the transistor, its conduction level can be controlled. In this sense, it will act as a variable resistance. The more forward bias applied, the harder it conducts and the lower the resistance, collector to emitter. A decrease in bias will decrease the conduction level thereby increasing the resistance.

ZENER REFERENCED REGULATOR

Refer to fig. 10

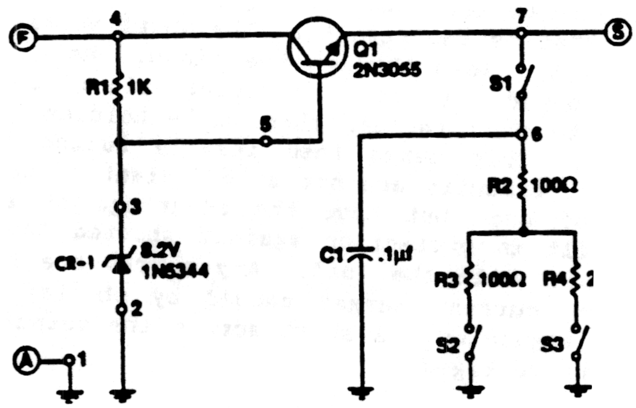


Fig 10.

CR1 and R1 form a voltage divider network used to supply the base of Q1 with the proper bias. Q1 will be the regulating device, (variable resistance). R2 with R3 and R4 will function as the load for the circuit. Keep in mind these are simulating other electronic circuits. S2 and S3 allow different loads to be applied to the regulator. S1 permits the circuit to be opened so an ammeter can be connected to monitor the output current.

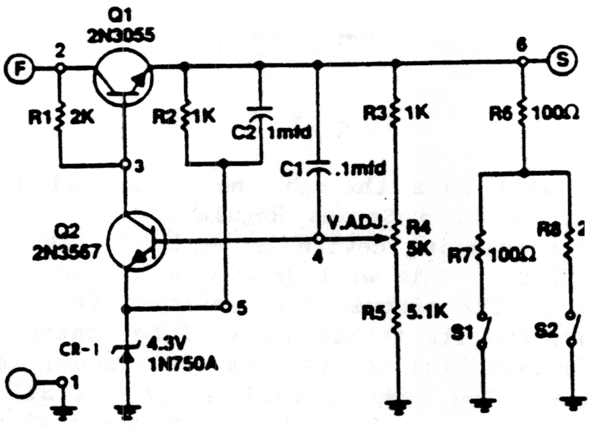
Notice that the collector of Q1 is connected directly to the power supply. The regulated output voltage will be taken from the emitter. The circuit is basically a common collector configuration.

CR1 will hold the base of Q1 constant regardless of what other changes take place in the circuit. With S2 and S3 closed, R3 and R4 are in parallel and have a combined resistance of 66 ohms. This 66 ohms is in series with R2 so the total resistance of the load is 166 ohms. If S2 is opened the total resistance of the load becomes 300 ohms. Due to the increase in resistance, the voltage at TP7 will attempt to increase. Assume the voltage at TP7, (regulated output) was 7V before increasing the load resistance. If the 7V starts to increase, it will become more positive or less negative. The emitter of the transistor is N (negative) material. This increase in the positive potential will be felt as a decrease in forward bias. Remember the base will not change.

The base is held constant by CR1. As the bias decreases, the transistor will conduct less. The resistance of Q1 has increased due to less forward bias. The voltage drop across Q1 will now increase, leaving less voltage to be felt at TP7. This returns TP7 to its original level. If you measure TP7 with a voltmeter you will see very small changes when the loads are changed. Regulator circuits are not 100% efficient so there will be some small changes in the output. Keep in mind, though, the load was doubled and the voltage dropped across this large increase in resistance would have increased greatly had it not been regulated.

Troubleshooting this circuit is no different than those you have already experienced. An oscilloscope will not be necessary since no signals are involved. DC readings should be taken around the circuit and analyzed to determine the malfunction. As in other circuits, it will be necessary to take all the normal DC readings so that you will have something for comparison.

VOLTAGE REGULATOR (PC 26)



VOLTAGE REGULATOR PC 26

Fig 11.

Fig. 11 is another series voltage regulator. It is somewhat more complicated than the one just discussed but is more accurate. A block diagram of the circuit will be discussed then the operation of the actual circuit will be covered.

See fig. 12. The regulator is made up of four basic blocks. They are the regulating device, sampler or sensing device, comparator, and the reference. The unregulated DC supply and the load are not part of the regulator.

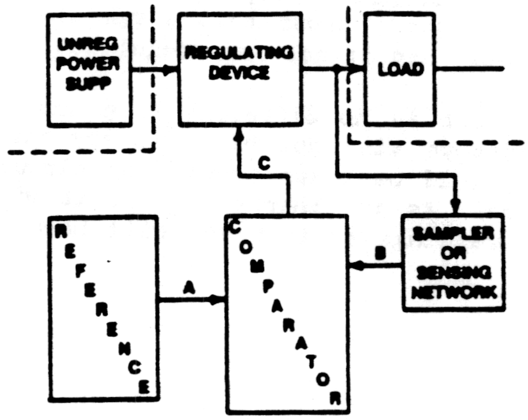


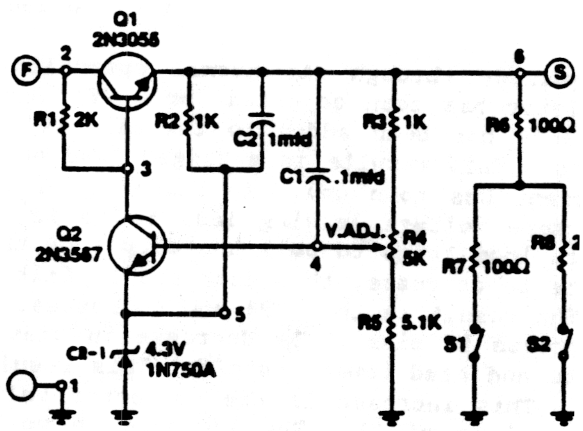
Fig 12

All the current that will pass through the load will pass through the regulating device thus it is a Series Regulator. As mentioned earlier, the resistance of the regulating device is varied to increase or decrease the voltage drop across it. This will determine the output voltage delivered to the load. As in the circuit just covered, (PC25), the regulating device is a transistor, and its resistance will be controlled by the biasing voltages. More forward bias equals less resistance; less forward bias equals more resistance. The sampler will apply a small portion of the output voltage to the comparator, (signal B). This signal will be directly related to the output voltage. If the output starts to rise, the output of the sampler will rise. If the output starts to drop, the output of the sampler will drop. In many cases, the sampler is adjustable so its output can be varied to control the operation of the circuit. On PC card 26, the sampler will consist of R3, R4, and R5.

It is the job of the reference to provide a constant output which will also be applied to the comparator. The reference output, (signal A), will not change no matter what the rest of the voltages in the circuit do.

The comparator will receive two signals, (A & B). It will compare these two signals. It is the comparators job to create an ERROR SIGNAL, (signal C). The error signal will be applied to the regulating device as an increase or decrease in bias and used to control its resistance. Don't be confused by the term signal.

In this case, all signals are DC voltages and not AC signals like you are accustomed to seeing. The error signal is the result of comparing the reference voltage (A) and the sample (B) of the output. In the circuit we will discuss, the comparator is a transistor connected in the common emitter configuration. An increase on the base results in a decrease on the collector. If the output of the regulating device remains constant, the error signal will remain constant. If, for some reason, the output attempts to increase or decrease, the sample voltage will change in the same direction. The comparator will compare this voltage to the reference and change the error signal. If the output increases, the sample increases. The comparator output, (error voltage), will then decrease. This decrease will be applied to the regulating device resulting in its resistance increasing thereby dropping the output back to normal. The comparator, (Q2), also serves as a voltage amplifier. Any change in the output DC voltage will be felt across the sensing network and a portion of the voltage is felt by Q2's base. If Q2 has a gain of 10 the change on Q2's collector will be ten times larger than the voltage change on its base. This means a fairly small change in the regulated output will result in a large error signal being generated. If the gain of Q2 is increased the same change in regulated output will result in a larger error signal. This serves to increase the sensitivity of the circuit. Refer to the schematic of PC26, fig. 13.



VOLTAGE REGULATOR PC 26

Fig 13

We will now discuss the actual circuit operation. R6, R7, and R8 will be the load for the power supply. Although they are mounted on the card, they are not part of the regulator circuit. R3, R4, and R5 form the sampler or sensing network. Any increase or decrease in the output voltage will be felt as increases or decreases in the voltage drops across R3, R4, and R5. The voltage felt at TP4 will be something less than the output voltage and will vary as the output varies. R3, R4, and R5 are a voltage divider network that sets the bias for Q2. R4 is variable so the bias for Q2 can be varied. By varying R4 the output can be adjusted. CR1 and R2 form the reference network. It is the function of this voltage divider to keep the emitter voltage of Q2 at a constant level. This voltage will be the reference voltage. As the bias on Q2 changes, its conduction level will change either increasing or decreasing. A Zener diode will allow the current through it to vary without changing the voltage drop across it. Q2 is the comparator. It is set up in the common emitter configuration. Recall that in this configuration the base and collector will be 180 degrees out of phase. R1 serves two purposes. It is Q2's load resistor and is used for biasing Q1. An increase in bias results in a decrease of collector voltage. A decrease in bias results in the collector voltage increasing. As mentioned, Q2 is the comparator. It will compare the emitter voltage to the base voltage. Since its emitter will remain constant due to CR1, and the bias will change if the output changes, any change in collector voltage must then be the result of the output voltage changing. We can say that any change in the collector voltage is due to an error in the output. This voltage is then referred to as the error voltage. The regulating device will be Q1. Q1's collector is connected directly to the output of the rectifier/filter. The error voltage from Q2 is applied to the base of Q1. Q1 is in the common collector configuration. One characteristic of the common collector configuration is that the base and emitter are always in phase. If the base voltage increases the emitter voltage will increase. A decrease in base voltage results in a decrease in emitter voltage. An increase in base voltage (bias) results in the resistance of the transistor decreasing therefore dropping less voltage. Decreasing the bias will cause the resistance of Q1 to increase.

Lets follow the regulator through its normal operation. Assume S1 was closed and the regulator has been adjusted for a 7V output at TP6. If S2 is closed, another load has been added to the circuit. Total resistance of the load decreases. This results in a bigger load on the power supply, (the demand for current has gone up). An increase in current through Q1 means it will drop more voltage leaving less to be felt at TP6. We see that adding the extra load tries to pull the output of the regulator down. As TP6 voltage starts to decrease, this decrease is felt in the sensing or sampling network. The result is that TP4 now decreases. This decrease is felt by Q2 as a decrease in bias. The decrease in bias causes Q2 to decrease its conduction and head toward cutoff. This results in the collector voltage rising. This increase in the collector voltage of Q2 is directly coupled to the base of Q1. The increase in voltage felt by Q1's base is an increase in bias which results in the resistance of Q1 decreasing. If the resistance of Q1 decreases it then drops less voltage, leaving more voltage to be felt at TP6. This action returns the output back up to its normal reading.

Keep in mind, these changes happen instantly. As loads are added or removed, or as the input voltage increases or decreases, the regulator will sense these changes and instantly correct them. It should be remembered that although we say the regulator keeps the output constant, there may be very small changes in the output voltage, but these changes are considered acceptable. The better the regulation the greater the cost of the regulator and the more complex its circuitry must be.

TROUBLESHOOTING:

Both regulator cards, PC25 and PC26 will be troubleshot using only the DMM. Since the input and output of a voltage regulator are DC voltages there is no reason to use an oscilloscope.

Since the DMM is the only piece of test equipment you will use, it is very important that you make normal readings of all test points on the individual cards. Without these normal readings you will have nothing to use as a reference when taking readings on a malfunctioning card.

When troubleshooting a malfunctioning voltage regulator card:

1. Compare the malfunction readings to the normal readings.

2. When comparing the readings certain components will obviously be good Eliminate these at this time.

   EXAMPLE: Refer to PC26

   a. If the output increases, TP4 should increase. If it did, eliminate R3 and R4.

   b. If the forward bias on Q2 increases, TP3 should decrease

   c. Anytime two test points read the same voltage there is either no current flow or the test points are joined by a short.

   d. When several test points in the circuit read OV, don't overlook the possibilities of shorts to ground.

3. From the voltage readings, determine the different possibilities, there may be several.

4. Use resistance checks, when needed, to confirm your selection of a malfunctioning component.

5. Eliminate the sensing network by observing the relationship between TP6 and TP4. With the output adjusted for 10V (TP6), TP4 should measure approximately one-half the voltage of TP6. Regardless of whether the voltage at TP6 increases or decreases, the 2 to 1 ratio should exist. It may not always be exactly 2 to 1, but if the output increases, TP4 should increase. If the output decreases, TP4 should decrease. If the output increases and TP4 decreases or the output decreases and TP4 increases, the problem is most likely in the sensing network.