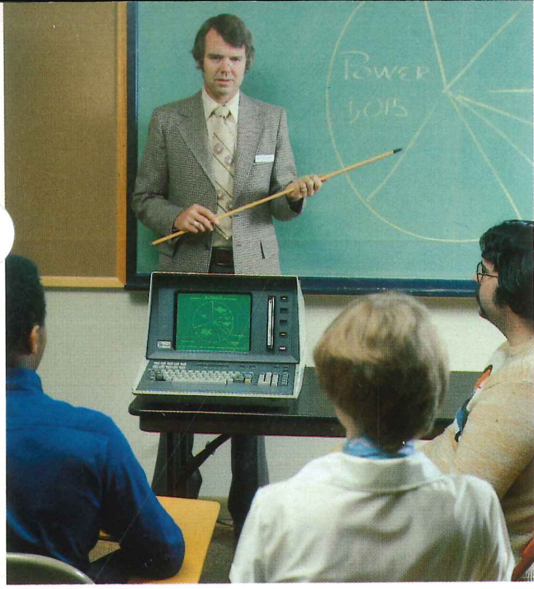

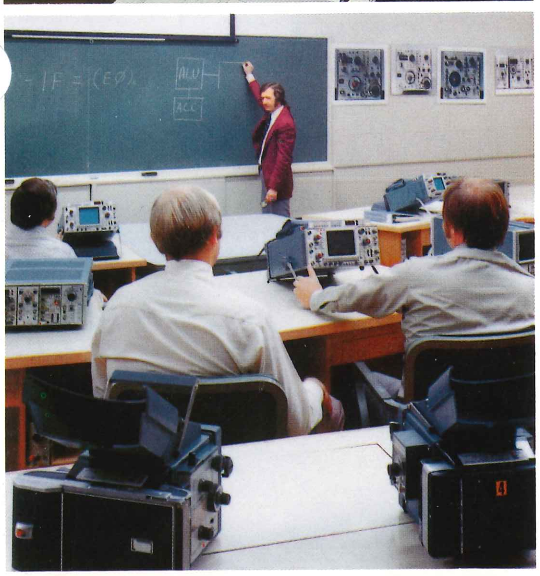

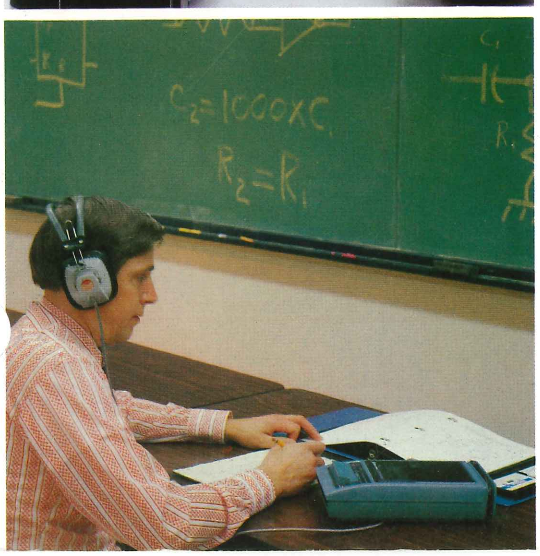

Low Voltage Power Supplies

Oscilloscope Maintenance Concepts

Section VII

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COMMITTED TO EXCELLENCE

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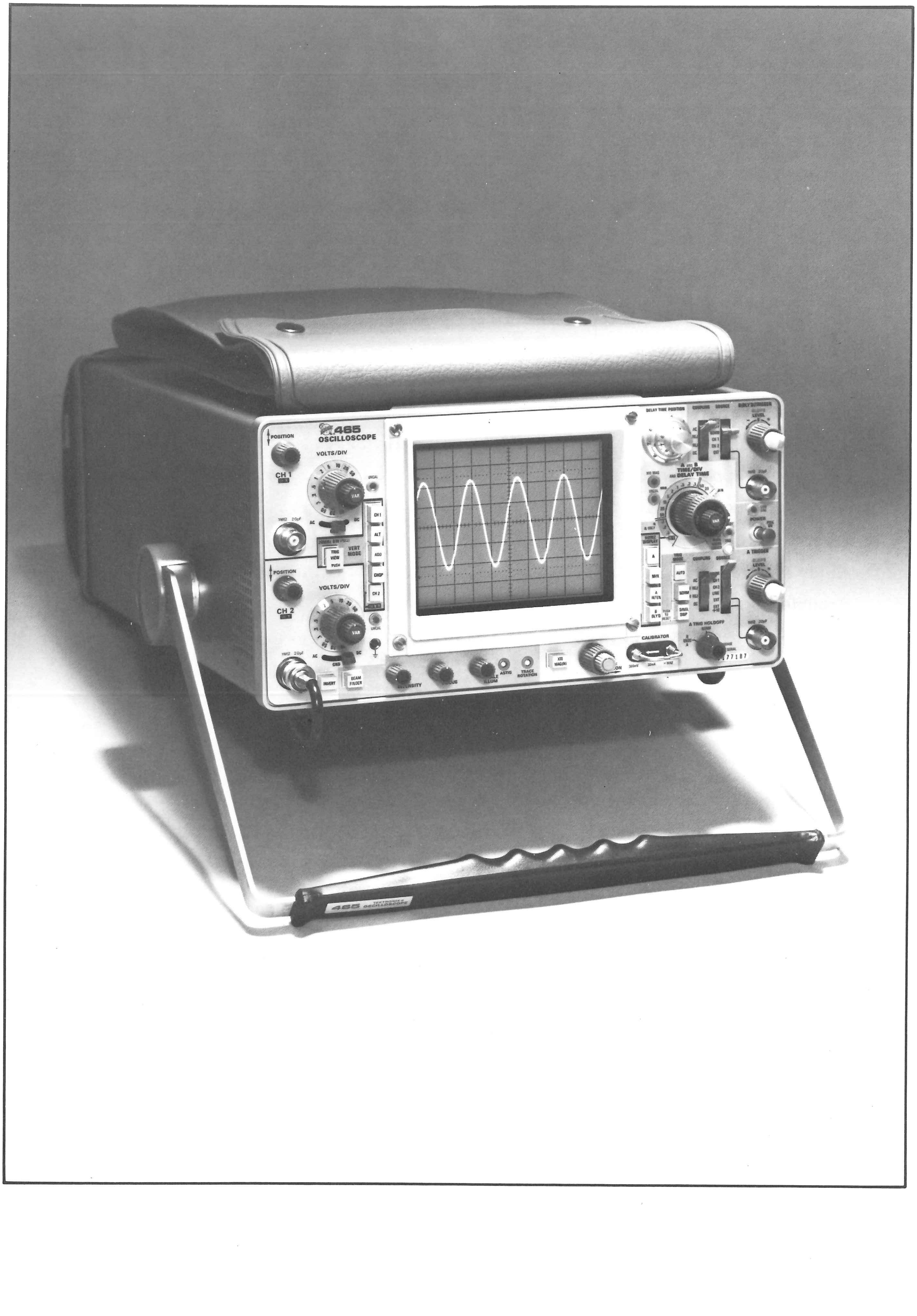

465
OSCILLOSCOPE
POSITION
CH 1
VOLTS/DIV
VERT MODE
POSITION
CH 2
VOLTS/DIV
INVERT
BEAM FINDER
CALIBRATOR
A TRIGGER
POWER
465 OSCILLOSCOPE

OSCILLOSCOPE MAINTENANCE CONCEPTS

SECTION VII
LOW VOLTAGE POWER SUPPLIES

INTRODUCTION

Low Voltage Power Supplies is the seventh booklet in the modular training package, Oscilloscope Maintenance Concepts.

Effective troubleshooting involves the application of general circuit concepts to each specific circuit you encounter. The concepts in this booklet are representative of current design in quality instruments.

The subject matter is presented in a depth and style which recognizes your prior training and experience with circuit concepts and applications. A pre-test, study aid questions, and an end of booklet quiz help you evaluate your understanding of these concepts.

You should retain this booklet for later use as a handy reference to recall concepts or applications.

OBJECTIVES

Oscilloscope Power Supply Concepts Objectives

After completing this material, you will be able to:

A. Draw a block diagram of a conventional series-regulated power supply operating from the ac line. The diagram will include:

1. Power transformer
2. Rectifiers
3. Capacitive filtering
4. Series regulator
5. Load

B. Identify the above blocks on a schematic.

C. Identify the following circuits on a TEKTRONIX 465 low-voltage power supply schematic.

1. Error divider with error sense line
2. Error amplifier
3. Current limiting to prevent excessive current in the series regulator.
4. Voltage reference
5. Fuse
6. EMI filtering in the transformer primary

D. Describe the purpose of each of the blocks in objective (A) above and describe signal and current flow directions in and out each of the blocks in the diagram.

E. Describe the most prominent symptoms that will occur if given active devices should open or short.

F. Identify components that control the output voltage and components that can affect the output stability and ripple.

G. Describe acceptable methods of measuring supply output voltage and supply ripple, and describe the effects of high and low line voltage on the output.

PREREQUISITES

This course section on oscilloscope power supplies is section six of a complete oscilloscope concepts course. The other sections of this course cover the oscilloscope block diagram, the concepts of vertical amplifiers, triggers, time bases and horizontal amplifier circuits, channel switching, and crt circuits.

In order to make the best use of the material in this course, the user should be able to:

1. Understand the basic concepts of center tapped full-wave rectifier and full-wave bridge rectifier circuits.

2. Describe the effects of capacitive filters and resistive loads on the output voltage waveform of a full-wave rectifier circuit,

3. Predict the behavior of the output of an inverting and a noninverting amplifier when a dc input is applied and when the input dc level changes.

4. Predict the output at the center of a resistive divider with a dc voltage across the divider and describe the effects on the output voltage if one resistor value is changed in the divider.

5. Identify the following transistor amplifier circuit configurations.

   A. Emitter follower
   B. Common emitter

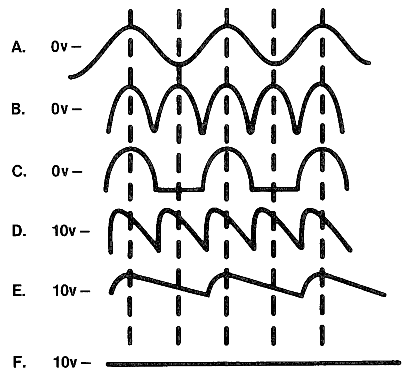
6. Describe the polarities of input vs output for the emitter follower and common-emitter amplifier configurations.

If you've completed the previous material in this course, or passed the quizzes without completing the material, you probably meet all the prerequisites. In case you are not sure you meet the prerequisites, a pretest is included on the following pages. If you can answer only a few questions correctly, it might be a good idea to review the preceding training package sections that are appropriate.

If you meet the prerequisites, study the text material, and answer the study aid questions as they appear. If you have trouble with the study aid questions, re-read the text and/or refer to other material on power supplies. At the end of this part of the oscilloscope circuit concepts course is a short quiz on this section. If you can pass this quiz, you should be ready to do the next part of the course, which is on Crt and High Voltage Circuit Concepts. Upon completion of the last course section, there will be a final quiz on all the material covered in the entire course. If you pass each of the individual course quizzes comfortably, you should be able to pass the final quiz.

PRETEST

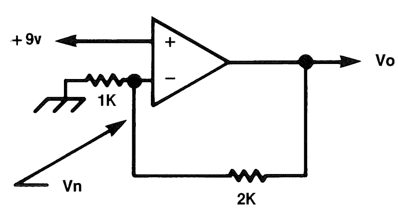
1. Which waveform below best describes the output of a full-wave bridge rectifier with no filter? ________



2. Which waveform above best describes the output of a full-wave center-tapped rectifier with no filter? ________

3. Which waveform above describes the output of a full-wave bridge rectifier with a capacitive filter and a moderate resistive load? ________

4. The amplifier below has an open loop gain of greater than 10^4. It is operating in its linear region.
   What is Vo? ________ volts
   What is Vn? ________ volts



5. Assuming that the amplifier in question 4 can supply several amps to a load at Vo, what will be the voltage at Vo if a 1 kΩ resistor is connected between Vo and ground?

   _______ volts

6. Which of the following describe the purpose(s) of the power transformer in a low voltage power supply? Mark all correct answers.

   A. Provides dc isolation of the output voltage(s) from the ac line.

   B. Provides a voltage or voltages different than the ac line voltage.

   C. Provides multiple output voltages in some cases.

   D. Provides ripple filtering at and slightly above the line frequency.

   E. All the above.

Check your answers against the key.

Block Diagram Concepts

All major circuits in oscilloscopes, except the delay line, need one or more voltage sources. The purpose of power supplies in oscilloscopes is to provide the necessary voltages for the oscilloscope circuits. The supplies we will discuss here are power supplies that are operated from the ac power lines. For stability and accuracy, the power supplies should provide a constant output voltage in spite of normal line voltage variations and normal variations in load current.

The purpose of the power supply is to convert the ac line voltage from alternating current to a constant dc voltage (regulated dc). The power supply should correct the dc output voltage if it deviates from the proper voltage because of line voltage fluctuations or variations in current demanded by the load.

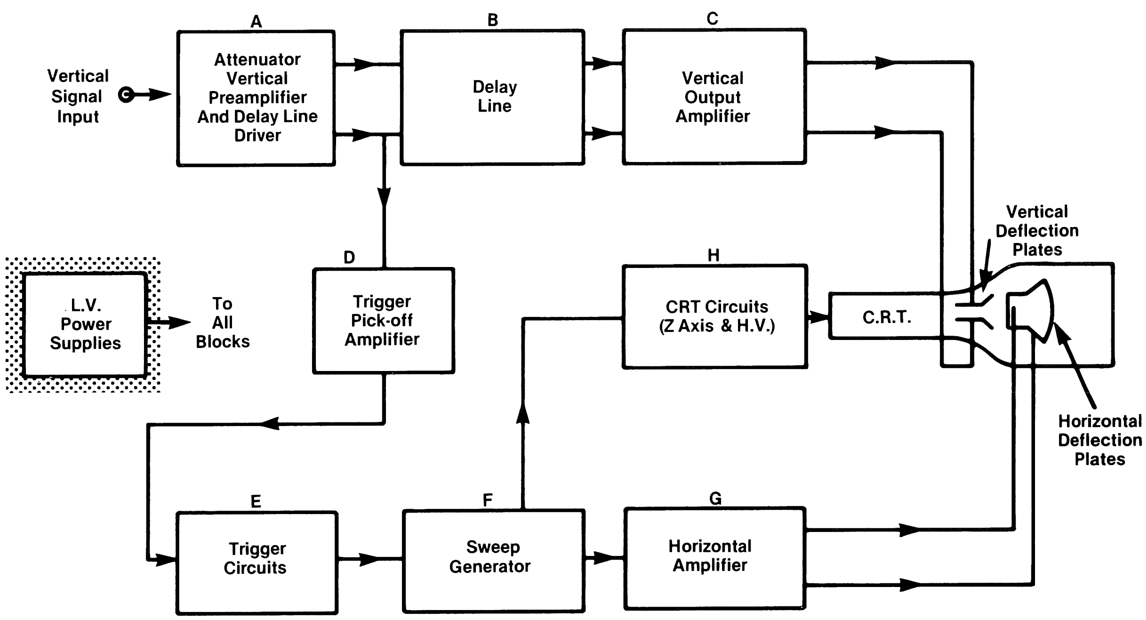


Fig. 7-1. Block diagram of a basic oscilloscope.

The process of obtaining a regulated dc voltage from the ac line usually involves four major steps. The steps, in order of occurrence are:

1. Transformation of the ac line voltage to one or more ac voltage levels that are suitable for the following circuitry.

2. Rectification of the transformer output to convert the ac transformer output to pulsating dc.

3. Filtering to reduce the ripple component of the pulsating dc.

4. Regulation to further reduce the ripple and to correct the output dc voltage level if it should attempt to change because of changes in line voltage or load.

Even though power supply circuits may vary considerably from one oscilloscope to another, almost all of them employ the steps listed above. The low-voltage power supply for the TEKTRONIX 465 Oscilloscope will be used for our discussion of power supply concepts. Figure 7-2 shows a block diagram of an oscilloscope low-voltage power supply. The ac line is connected to the transformer primary through a fuse, an on-off switch, ac line voltage selection switching, and usually some form of thermally operated switch. This circuitry is located in block A of Fig. 7-2.

The ac line current in the transformer primary winding generates four different ac voltages; one voltage across each secondary winding of the transformer (block B of Fig. 7-2). The ac voltages on the secondary windings are rectified by their respective rectifier circuits, blocks C, D, E, and F of Fig. 7-2. The pulsating dc outputs of the rectifiers are then filtered, by capacitors in this case, and then applied to the regulation circuits.

The regulation circuitry is necessary because without regulation the dc output voltage from the filter will vary as the line voltage varies. If the line voltage drops 5 percent, the output voltage from the rectifier/filter circuit will drop 5 percent. Also, even if the line voltage never varied, the capacitor filter cannot hold the output voltage constant. Most loads constantly demand current and the rectifiers only supply current in pulses. The voltage across the capacitor and the load will drop in the absence of the pulse and will rise again when the pulse occurs. The regulation circuit normally reduces these two problems, and in most cases, virtually eliminates them.

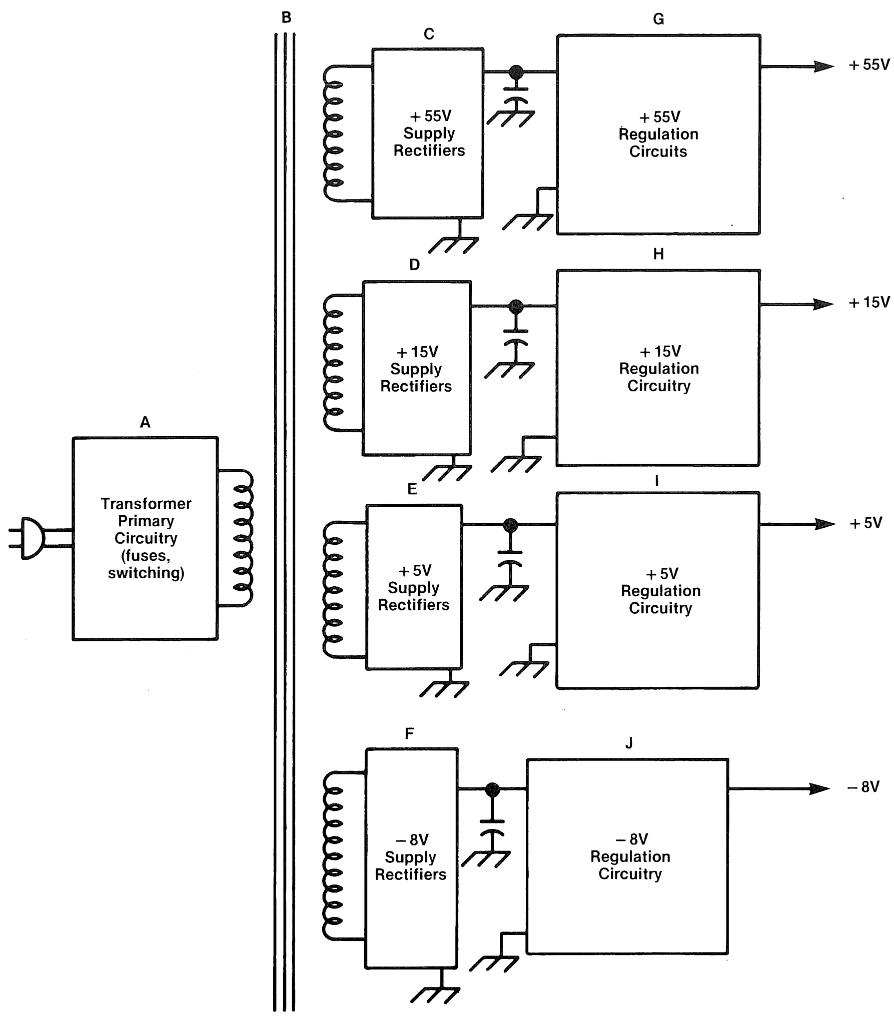


Fig. 7-2. Block diagram of an oscilloscope low voltage power supply.

The regulation circuits are blocks G, H, I, and J of Fig. 7-2. The primary purpose of the regulator block is to adjust an internal impedance, usually the degree of conduction of a regulator transistor, as necessary to hold the output voltage constant. The series regulator is the most commonly used form of regulator circuitry in oscilloscope power supplies. To understand its operation, the series regulator transistor can be thought of as a variable resistor in series with the load. We've shown this schematically in Fig. 7-3.

Under the conditions shown, there will be 15 volts across the load resistance. If the line voltage were to drop, and if the 15 kΩ load resistance doesn't change, the voltage across the load would drop. In many circuits, this might be intolerable.

To compensate for this drop in line voltage, the resistance of the potentiometer can be changed to keep the voltage across the load at a constant 15 volts. In an actual circuit the degree of conduction of a transistor is changed rather than using a potentiometer, but the effect is the same. In Fig. 7-4 we've shown the same equivalent circuit with the potentiometer (series-regulator transistor) adjusted to look like 5 kΩ to compensate for the drop in line voltage. Notice that if the rectifier output dropped *below* the desired load voltage, the regulator could not compensate to maintain the original voltage across the load.

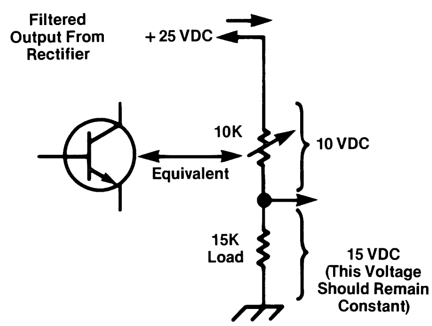


Fig. 7-3. Series regulator equivalent circuit.

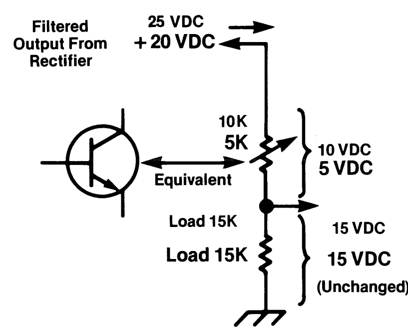


Fig. 7-4. Series regulator equivalent circuit.

If the resistance of the load in Figs. 7-3 and 7-4 had changed (within certain limits), the voltage across the load could be adjusted to the original value, in the same manner as above, by adjusting the series regulator's conduction. In either case, change in line voltage or change in load, the regulator can respond rapidly enough to hold the output voltage constant. In fact, normal ripple from the rectifier/filter circuit is virtually eliminated because the regulation circuit sees this as a voltage change and corrects for it, usually within a matter of microseconds.

Power Supply Study Aid Questions

1. Number the blocks listed below in the sequence they normally appear, starting at the ac line input and following the signal path through the power supply to the load. Assume a conventional power supply as discussed previously.
   - A. ________ Filter capacitor.
   - B. ________ Transformer
   - C. ________ Switching, fuses, and thermal cutout.
   - D. ________ Rectifiers
   - E. ________ Regulation circuitry.

2. Filter capacitors are used to reduce the amount of ripple on the dc output of the rectifiers. If the ripple is reduced by these capacitors, why is regulation circuitry necessary? Mark all correct answers below.
   - A. The pulsating dc output voltage may momentarily drop below the desired load voltage and the regulation circuit will increase the voltage during this interval.
   - B. Regulation circuitry is used to limit output current. Output voltage level is controlled only by the filter capacitors.
   - C. The ripple on the rectifier/filter capacitor output may be greater than can be tolerated by the load. The regulation circuitry will reduce the power-supply ripple to a value considerably less than the capacitor filter would provide without the regulator.
   - D. If the line voltage changed, the rectifier output voltage would change. The capacitor would not hold the output constant if the line voltage changed for longer than a few milliseconds. The regulation circuitry could compensate for line voltage changes within certain limits.
   - E. The regulator circuit holds the *average* level constant, which the capacitor alone cannot do, but the regulator does nothing to correct ripple on the supply output.

Check your answers against the key.

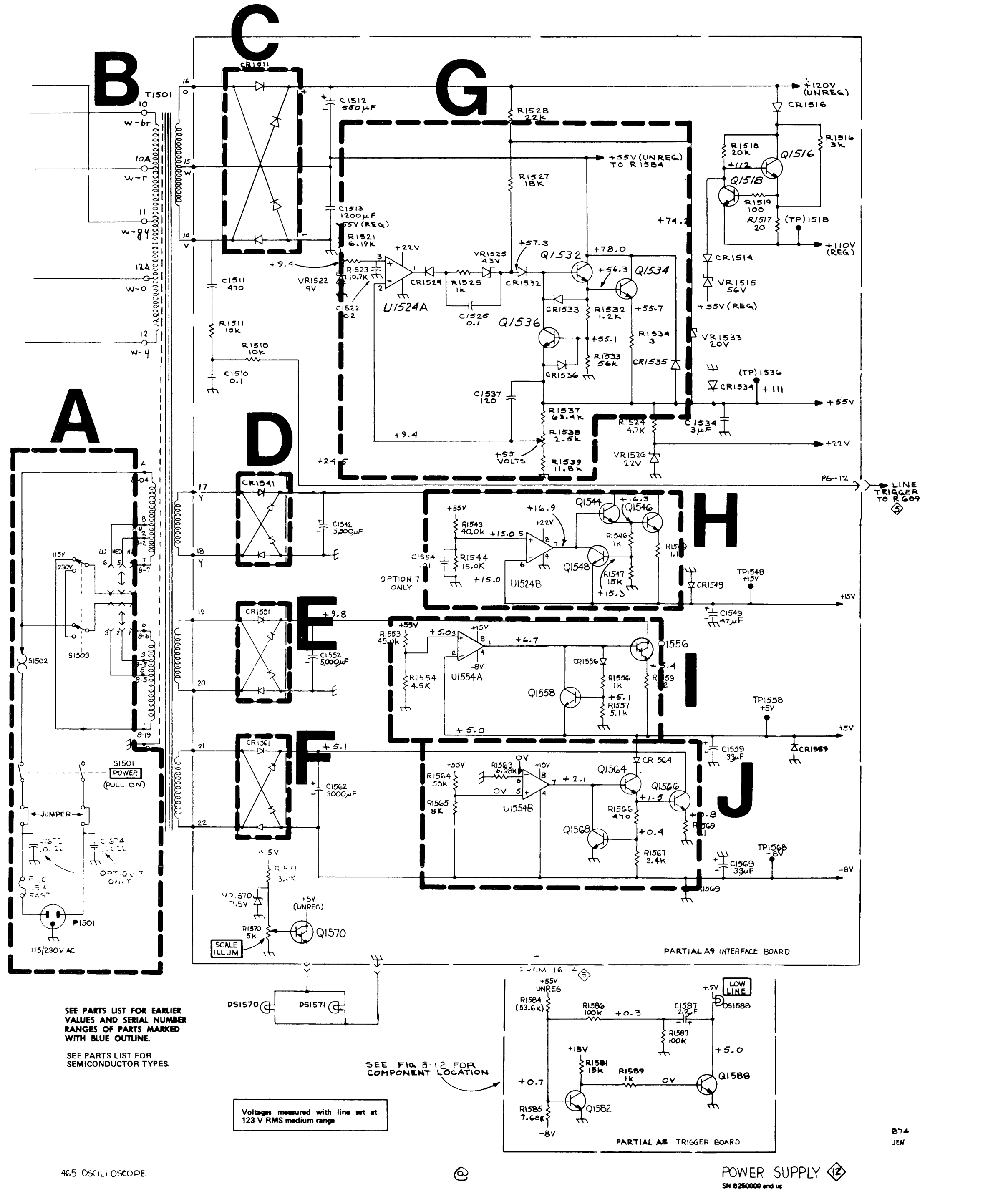


Fig. 7-5. Typical power supply schematic.

Power Supply Circuit Concepts

In the previous section we saw how the output voltage of a regulated power supply could be regulated by increasing or decreasing an impedance in series with the load. In our power supply circuits, the series impedance is a series regulator transistor. Let's look at the +15 volt supply circuit in Fig. 7-5. The +15 volt supply consists of the circuitry in blocks A, B, D, and H on Fig. 7-5. To relate this circuitry to the supply block diagram, refer to the same blocks in Fig. 7-2 at the beginning of the preceding text. Blocks A, B, and D and capacitor C1542 form a conventional full-wave bridge-rectifier power supply with C1542 used as a filter capacitor.

The voltage at the output of block D consists of a dc voltage a few volts greater than the +15 volt level the supply should provide at the output. The output voltage from block D can vary considerably if the line voltage varies. This voltage at the output of block D will also have an undesirable amount of ripple. The output from block D goes through some regulation circuitry and appears as a precisely controlled +15 volt level with only a few millivolts of ripple at the output of block H (test point TP 1548).

Block H, the regulation circuitry, and how it removes the effects of line voltage variations and ripple from the output is our next subject.

In the previous section we showed how the voltage across a load could be controlled by controlling the degree of conduction of a transistor in series with the load. Q1546 in block H is this series-regulator transistor. The conduction of Q1546 is controlled by an operational amplifier consisting of U1524B and Q1544. We will ignore Q1548 as it serves another purpose that we'll discuss later. If the +15 V supply voltage output should begin to increase slightly, the voltage on pin 6 of U1524B will rise.

U1524B is a high-gain amplifier and the very slight change in voltage at pin 6 will cause a much larger change in voltage at the output of U1524B (pin 7). The change in voltage at the output of U1524B will be in a *negative* direction, (indicated by the minus sign at pin 6 of U1524B). The negative-going voltage at the IC output drives the emitter follower, Q1544. The negative-going output from the IC reduces conduction of Q1544 which reduces conduction of Q1546. This reduces the voltage across the load, correcting the output voltage across the load, and thereby correcting for the output voltage's original attempt to increase.

Q1544 is placed between the IC and the series regulator transistor to provide a relatively high impedance load for the IC U1524B, and also to provide relatively large amounts of emitter current to drive the series regulator transistor's base. The base current required to drive the base of the series regulator transistor, Q1546 in this case, is usually greater than can be supplied by the high-gain IC amplifiers so another transistor stage, Q1544, is usually included.

If the output voltage had attempted to drop because of current demands by the load or because of line voltage change, the same things would happen except all transitions would be in the opposite direction. Figure 7-6 shows a very simplified version of the correction path.

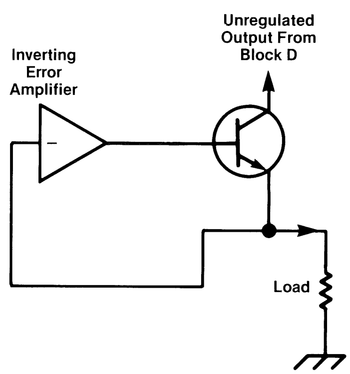


Fig. 7-6. Simplified error correction circuit of block H, Fig. 7-5.

Up to this point we've discussed how the error correction occurs, but we haven't identified how the regulation circuit knows what the correct output voltage should be. After all, how can the circuit correct the output voltage if it doesn't know what the correct output voltage is? Our regulation circuit obviously needs a reference voltage of some sort.

U1524B has a precisely controlled +15 V level applied to pin 5, the non-inverting input of the amplifier IC. This is the reference voltage for the +15 V regulator circuit. We'll see where the +15 V reference comes from in a moment. U1524B is a high-gain differential amplifier. If the voltage at *either* input to the amplifier moves significantly away from the voltage on the other input, the output will change. With the voltage on pin 5 held at a constant +15 volts, pin 6 of the amplifier must remain at +15 volts also, or the amplifier's output will try to change. The change will be in a direction that will move the +15 volt output voltage and the voltage on pin 6 of the IC amplifier back to +15 volts. The amplifier always tries to hold zero difference between the inputs. In other words, the amplifier nulls the voltage between pins 5 and 6.

To summarize the whole thing, the regulator output voltage will try to be whatever is necessary to maintain a zero difference between the two inputs. Because pin 5 is at a fixed voltage, the amplifier and feedback circuit will try to null pin 6 to the same voltage (+15 V in this case).

Study Aid Questions

3. The voltage across the filter capacitor at the output of block D in Figs. 7-2 and 7-5 has certain characteristics that are essentially the same in all power supplies of this type. Mark all the characteristics listed below that describe the voltage across the filter capacitor at the output of block D (Rectifier output).
   A. Precisely regulated dc voltage with only a few millivolts of ripple. Voltage output of block D does not vary appreciably with changes in line voltage.
   B. Only a few millivolts of ripple on a dc voltage when providing 1 amp of current to a load, but dc voltage may vary with line voltage changes.
   C. Ac signal varying plus and minus from zero volts. Ac voltage varies with line voltage.
   D. Peak-to-peak ripple varies with line voltage but average dc level is constant.
   E. Dc level varies with changes in line voltages.

4. In block H of Fig. 7-5, Q1546 is the series-regulator transistor. Which of the following conditions would cause a significant increase in Q1546's collector current? Mark all correct answers.
   A. Decrease in load resistance.
   B. Increase in load resistance.
   C. Increase in ac line voltage, load resistance constant.
   D. Decrease in load capacitance, load resistance constant.
   E. Decrease in ac line voltage, load resistance constant.

5. In block H of Fig. 7-5, U1524B is the error amplifier for the +15 volt power supply regulator. If this circuit is operating properly what will be the voltage *difference* between pins 5 and 6 of U1524B?
   A. $\approx$ 0 volts
   B. $\approx$ 10 volts
   C. $\approx$ 15 volts
   D. $\approx$ 55 volts
   E. $\approx$ 15 volts plus two Junction drops.

6. In normal operation, what will be the voltage at pin 7 of U1524B? Mark only one answer.
   A. 0 volts
   B. +1.7 volts
   C. +15 volts
   D. +55 volts
   E. +15 volts plus two Junction drops plus Voltage across R1549.

Check your answer against the key.

Reference Supply Tracking Concepts

We've discussed the basic concepts of the +15 V power supply and these same concepts apply to all the other supplies shown in Fig. 7-5. In the −8 V supply there are some circuitry differences but the concepts are the same. In the +15 volt supply, the negative side of the bridge rectifier (block D, Fig. 7-5) was tied to ground and the positive side was tied to the load through the series regulator. In the −8 volt supply the negative side of the bridge rectifier (block F, Fig. 7-5) is removed from ground and tied to the load. The positive side of the bridge rectifier is tied to ground through the series regulator and a small resistor. Even with these differences, we still control the current in the circuit, and consequently the load voltage, with the series-regulator transistor, Q1566. The error amplifier U1554B still tries to maintain zero difference between its two inputs and to do so in the circuitry of block J, it must provide enough current to develop −8 volt across the load.

Notice that both the +5 volt supply and the −8 volt supply, as well as some of the other supplies, depend on the +55 volt supply to set the reference voltage for their respective regulator circuits. This is common practice in power supplies that must supply more than one output voltage. This method provides tracking of supplies if the reference supply should drift slightly because of temperature changes, etc. It also allows the designer to precisely control the ratios between the reference supply voltage and the other supply voltages with a few precision resistors. This reduces the number of calibration adjustments and reduces the number of opportunities for instrument failure because of improper adjustments. This method does make all the supplies dependent on the reference supply and if the reference supply fails, none of the other regulated supplies will operate.

The rectifier circuit for the +55 volt supply is block C of Fig. 7-5. This rectifier circuit and the associated transformer winding provide two unregulated output voltages for two separate regulator circuits. The regulator circuit consisting of Q1518 and Q1516 are discussed in the cassette audio tape circuit description that accompanies this course. The unregulated voltage for the +55 volt supply comes from the center tap of the transformer winding. The rectifier circuit for the +55 volt supply behaves as a center-tapped full-wave rectifier using the bottom two diodes of block C. The major differences between this supply and the other supplies we've discussed are the regulator circuit reference supply (Zener diode) and the potentiometer in the feedback path of the regulator circuit, both in block G of Fig. 7-5. In the regulator circuit we use a 9 volt Zener diode to set a reference voltage on the positive (noninverting) input of the error amplifier.

If the voltage divider consisting of R1537, R1538 (+55 volt adjustment), and R1539 attenuate by the proper factor, the regulator circuit output will be +55 volts when the error amplifier properly nulls the voltage between the two inputs of U1524A. The capacitor on pin 3 of the error amplifier filters Zener diode noise.

Another Zener diode is used between the IC amplifier and the discrete transistor circuitry. This diode serves to translate the output of the IC amplifier, which is at approximately 12 volts, up to approximately 58 volts which is a level suitable to drive the series regulator circuits, Q1532 and Q1534.

The +55 volt supply has a regulated output that is referenced to the 9 volt Zener diode at the noninverting input of the IC error amplifier. Because the +55 volt supply is regulated, its output is used as a reference for the other regulated supplies in Fig. 7-5. This avoids the need for separate Zener diode supplies for each regulated circuit.

Study Aid Questions

7. In the power supply represented by Fig. 7-5 at the beginning of this section, each of the regulator circuits use a reference voltage to compare with a sample of the regulator output. If the voltage across VR1522 (block G) changed, because of a circuit fault, to +3 volts, some other things might change in the power supplies. Listed below are the normal power supply outputs (left column) and some possible effects that might occur under these conditions. Match the items in the left column with the appropriate items in the right column. Select *all* correct answers.

A. _____ +55 volt supply	(1) output voltage would change toward zero.
B. _____ +15 volt supply	(2) output would go further away from zero.
C. _____ +5 volt supply	(3) output would go less negative (or more positive).
D. _____ −8 volt supply	(4) output would go less positive (or more negative).
	(5) output would not be affected.
	(6) output would go south for the winter.

8. Which of the following circuit characteristics are used directly in power supply regulators such as were covered in the preceding material?
   A. High-gain amplifiers with negative feedback will adjust their outputs to whatever level is necessary to maintain a zero volt or near zero volt difference between their two inputs.
   B. As in A except high-gain amplifiers adjust for maximum difference between inputs.
   C. Voltage dividers set the proper ratio between the desired output voltage and the available reference voltage.
   D. Common-base amplifiers are often used to drive the error amplifiers because their low bandwidth tends to reduce noise in the supply output.
   E. All the above.
   F. None of the above.

Check your answers against the key.

Current Limiter Concepts

Most power supplies supply current to a resistive load and are designed to operate with loads having no less than some minimum amount of resistance. If the load drops below that resistance level because of a short circuit, component failure, or some other reason, the power supply will try to supply whatever current is necessary to maintain the output voltage. The power supply must be able to sense excessive current and limit its current output when this happens. Without current limiting, the power transformer, the rectifier diodes, and the series regulator transistor may be subjected to currents above the amounts originally intended by the designer. Without some form of fusing and/or other protection, the results can be disastrous to these circuit components and possible other components.

In each of the regulator circuits in Fig. 7-5, blocks G, H, I, and J, there is a transistor connected between a point in the error amplifier and the supply output (between amplifier and ground in the −8 volt supply). These transistors are used to limit the current delivered by the supply in case of a short circuit or excessive load. Invariably these protection circuits break the feedback loop and allow the output voltage to drop in order to limit the current output. We will use the +15 volt supply regulator, block H, to describe the current limiting circuit behavior. Q1548 is the current limiting transistor.

If a short occurs or if the current demands on the +15 volt supply increase, the series regulator transistor, Q1546, will be turned on harder by the error amplifier in an attempt to maintain the +15 volt output. If excessive current is present in R1549, the 0.1 ohm resistor, the emitter of Q1546 will have to be pulled significantly (0.5 V or so) above the +15 volt supply output level. To pull the emitter up, the base of Q1546 must be driven to a more positive voltage. A more positive voltage on the base of Q1546 also places a more positive voltage on the base of Q1548.

When Q1548 begins to conduct, it limits the voltage at the output of U1524B to the point where Q1548 is barely conducting. If the load increases or becomes a short circuit to ground, Q1548 will still allow only enough current through Q1546 to develop sufficient voltage across R1549 to hold Q1548 on. The +15 volt supply output voltage will drop when the current limit occurs. This drop in supply voltage will pull down on the emitter of Q1548. Pulling down on the emitter of Q1548 also limits the output current even though the output voltage may have dropped to zero.

The current limiters in the other supplies all operate the same way. If the voltage across a small current sensing resistor indicates excessive current, the protection transistor limits the conduction of the series regulator.

Study Aid Questions

9. In the power supply circuit in Fig. 7-5 at the beginning of this section, several components are included to protect the circuitry from damage because of excessive current being drawn from the supply. Which of the components listed below are primarily for protection of the power supply circuitry? Mark all correct answers.

   A. F1501 (block A)
   B. Q1536 (block G)
   C. R1534 (block G)
   D. R1549 (block H)
   E. Q1548 (block H)
   F. R1569 (block J)
   G. Q1568 (block J)
   H. All of the above
   I. None of the above.

10. Which of the following statements describe the normal behavior of the protection circuitry of the +5 volt supply shown in block I of Fig. 6-5 when a short circuit is connected between the supply output and ground? Mark all correct answers.

    A. Q1558 is cut off.
    B. R1559 will have enough voltage across it to cause Q1556 to saturate at high ac line voltages.
    C. Q1558's emitter will drop below its base voltage sufficiently to help turn on Q1558.
    D. When the short first occurs, U1554A's output tries to go positive to try to maintain the +5 volt output level but U1554A's output goes positive enough to turn on Q1558 which will limit the current in Q1556.

Check your answers against the key.

TROUBLESHOOTING

Fault Isolation Concepts

Found chiseled into the wall of a cave outside the City of Shaniko:

> I have invented the short circuit. Someday someone will invent the power supply and the short circuit will thereafter see extensive use.
>
> (Anamalous)

Possible problems that may occur in power supplies can be categorized into several groups, but the caveman's invention mentioned above (the short circuit) is, no doubt, the biggest contributor to power supply problems. Usually, when power supply problems occur, the problem is not in the supply itself. The problem is usually a short circuit (or a near short) in an external circuit between a power supply and ground, or a short between two power supplies. The latter case is usually the most disastrous.

The first step in troubleshooting is to isolate the problem to one supply, Fig. 7-6 illustrates a practical approach to troubleshooting. Often power-supply short circuits can be isolated to one power supply by measuring the resistance between the supplies and ground after insuring that the power is off and capacitors are discharged. The short can be isolated further by disconnecting half the circuitry from the supply and measuring the resistance to ground in each of the two isolated halves. Needless to say, make sure the supply is off and that the filter capacitors are discharged first. Repeat the procedure in the bad half until the short is localized.

If the short is not apparent when the circuit is off, the ohmmeter method doesn't work well. If a second power supply of the same type is available and in operating condition, make sure the power is off and that all the filter capacitors are discharged. Then compare the resistance(s) of the good supply and the bad one. Even this method may not be useable in some cases. If the ohmmeter method is not useable, and the supply has current limiting, the loads can often be removed one at a time while monitoring the regulator output. Turn the power off each time

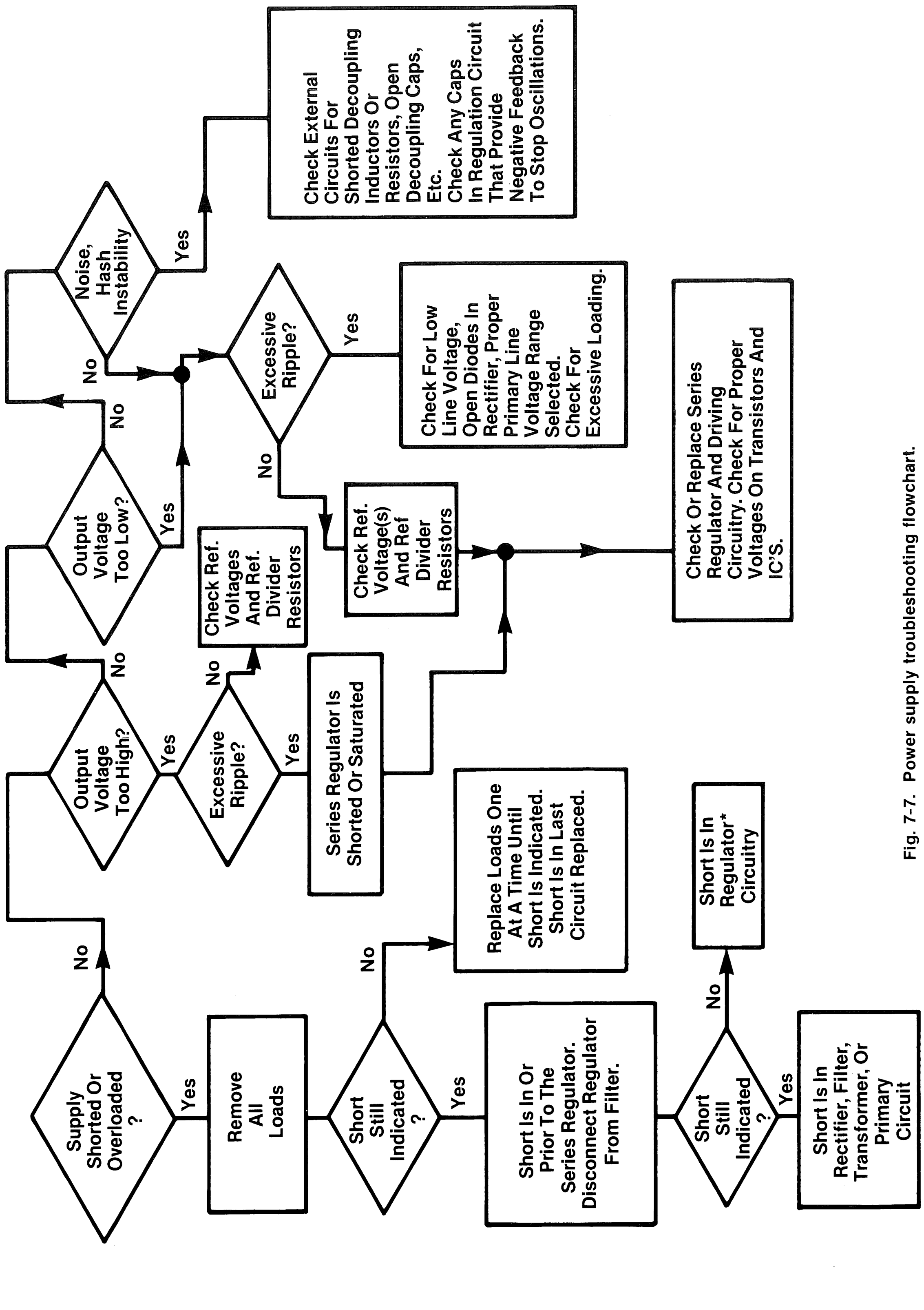


Fig. 7-7. Power supply troubleshooting flowchart.

before you remove the load. If the output goes to the proper voltage, the short is in the last circuit removed. Reconnecting the other circuits that were removed (but not the one with the short circuit) should not appreciably affect the power supply output voltage if those circuits are normal.

If the supply does not have current limiting but does have fuse protection, the procedure is a little different. You may need a few spare fuses if the problem can't be isolated with an ohmmeter. **DON'T USE THE WRONG FUSE!!!** In this situation **ALL** circuits should be disconnected from the supply that is shorted, or from all supplies if you don't know which supply is shorted. Sometimes this can be done by simply removing connectors. In other cases, unsoldering may be necessary. Do it the quick and easy way where possible.

CAUTION

With no load, power supply filter capacitors may take a long time to discharge. Discharge them through a suitable resistance if it's safe. Don't damage the capacitor by shorting the cap with a low resistance. See the instrument manual.

Once all the loads are removed and the fuse has been replaced, apply power and check that all supplies work. If not, the problem is in the supply itself and that will be covered later.

TURN THE POWER OFF and check that it's off and that filter caps are discharged. Replace one load (or half of the loads if you have a large amount of fuses but not much time). Apply power and see that the supplies still work. If the fuse blows or the supply shows other signs of being overloaded, such as smoking, low output voltage, etc., you've found the bad circuit. If not, turn the power off, check that the filter capacitors are discharged, and when they are discharged, reconnect another load, apply power, and check the output. Repeat the procedure until the faulty circuit is connected. Of course the circuit with the short will blow the fuse (if it did originally).

Once you've located the faulty circuit, remove power supply leads in the circuit with the short to "divide and conquer". Common causes of short circuits are shorted capacitors, shorted active devices in high power circuits, foreign material, physical damage, and cavemen.

If all the loads are removed from the power supply and the short still blows fuses, or the current limit circuit doesn't allow the output voltage to come up to the normal voltage, of course the problem must be in the supply itself.

First, we'll discuss the situation where current limiting, or some other fault, keeps one supply from coming up but the fuse remains intact. In this case, check the voltage output of the rectifier block for that supply (blocks C, D, E, and F in Fig. 7-5). The dc voltage should be slightly higher than the supply's normal regulated output. If you check with an oscilloscope, also note the ripple frequency, amplitude, and waveshape. If the ripple frequency is the same as the line frequency, half-wave rectification is occurring. If the rectifier is a full-wave circuit, the ripple frequency should be twice the line frequency. If not twice the line frequency, a diode is probably open.

If the peak-to-peak ripple amplitude is higher than normal, but of the proper frequency, the problem is usually due to an excessive load somewhere in the regulator circuit or a bad (leaky or open) filter capacitor at the output of the rectifier. If the rectifier output dc level is normal and the ripple is lower than normal but the regulated supply output is still at zero volts or very low, there may be a fault in the current limit circuit that is causing the series regulator to turn off or the series regulator may be open.

If this appears to be the case, check the current limit circuit and series regulator circuits with an oscilloscope or voltmeter to see if the transistors are conducting, cutoff, etc. Do *not* remove the current limit transistor to see if the supply comes up. If there is a short in the circuit, and this transistor is removed, other components such as rectifiers, fuses, and series regulator transistors may be damaged. The best alternatives are to turn the power off and replace the transistor with a known good one or check for proper operation of the original transistor with voltage measurements.

If the power supply is blowing fuses even with the loads disconnected, the problem can be isolated (at the expense of a few fuses) by disconnecting the regulator circuits from the rectifier circuits. If fuses still blow, the problem is between the output of the rectifiers and the fuse. Shorted rectifier diodes are not uncommon. Shorted transformer windings or shorts in wiring are also possibilities, though not as probable. If the fuse doesn't blow when the regulators are removed, reconnect the regulators one at a time starting with the reference supply, the one with the Zener diode connected to one side of the error amplifier, and apply power. If the fuse doesn't blow, connect another regulator circuit. When the fuse blows, the problem is in the last circuit connected.

Another power supply problem is a regulator output voltage that is too high or too low. This can be caused by improper adjustments, wrong resistor values, or wrong reference voltage values in the error amplifier. Output voltage too high with excessive ripple is usually caused by shorted or saturated series regulator transistors. Output voltage too low with excessive ripple is usually caused by low line voltage, an open rectifier diode, or faulty transformer.

These are the major categories of problems that occur in power supplies. Troubleshooting power supplies, as in any electronic circuitry, should always involve a lot of care to avoid shock and burn hazards. Many power supplies, in addition to supplying lethal voltages, can supply sufficient current to heat up metal objects such as rings, wristwatches, metal necklaces, etc., which can and often do result in severe burns. So be sure to remove any conductive items you may be wearing before you start. Don't work alone around dangerous voltages and use a lot of caution.

This completes the troubleshooting block of this course section. Work the following study aid questions and listen to the audio tape circuit description of the TEKTRONIX 465 Oscilloscope power supply. An Index follows the study aid questions to help you locate the power supply section of the audio cassette circuit description.

When you've successfully completed the study aid questions and listened to the tape, you are ready to take the quiz for this course section.

Power Supply Study Aid Questions

11. When troubleshooting power supplies, there is always a possibility of electric shock and/or burns. There are precautions that can be taken to avoid both. Listed below are several items. Mark the ones that are good safety practices.

    A. Remove all conductive items such as rings, wristwatches, necklaces, belt buckles, etc., that could possibly come in contact with energized circuitry.

    B. Be sure that power is removed and that all capacitors are discharged before unsoldering wires or removing connectors, components, shields, etc.

    C. Keep one hand in your pocket or behind your back while probing or working around "live" circuits that are exposed.

    D. Don't work alone around shock hazards.

    E. All the above.

12. Short circuits in power supply loads are the most common form of power supply problem. In an oscilloscope that has a shorted power supply, which of the following procedures would probably be used first in trying to isolate the short? Assume that the line fuse blows when power is applied.

    A. Remove power and disconnect the vertical and horizontal amplifiers from the power supplies because these circuits require large amounts of power and are therefore most susceptible to short circuits. Apply power and check for short circuit by measuring supply output voltages.

    B. Remove power and disconnect all circuits *except* the vertical and horizontal amplifiers. Check for presence of shorts by applying power and checking whether or not the supply voltage is normal.

    C. Leave the power applied and work on another instrument until something burns bad enough to cause smoke and/or cause components to appear burned.

    D. Apply power and remove protection transistors, one at a time, to see which supply is shorted.

    E. Remove power and check that all filter caps are discharged. Then measure the resistance between each power supply output and ground to determine which supply is shorted.

13. An oscilloscope power supply has a full-wave bridge rectifier. The supply output ripple becomes excessive unless the line voltage is slightly higher than normal. The dc output voltage is normal when the line voltage is high. The ripple frequency is the same as the line frequency. Which one of the faults listed below is the most probable cause of the problem?

    A. Wrong reference voltage in the regulator circuit.
    B. Series regulator transistor has low Beta.
    C. Shorted turns on the power transformer primary.
    D. Current demands by the load are slightly greater than normal.
    E. Open diode in the rectifier.

Check your answers against the key.

CASSETTE TAPE
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QUIZ

Power Supply Quiz

1. Draw a block diagram of a conventional series regulated power supply operating from the ac line. The diagram should include the following blocks:

   A. Power transformer.

   B. Rectifier.

   C. Capacitive filtering.

   D. Series regulator.

   E. Load.

   The supply should supply only a +55 volt output.

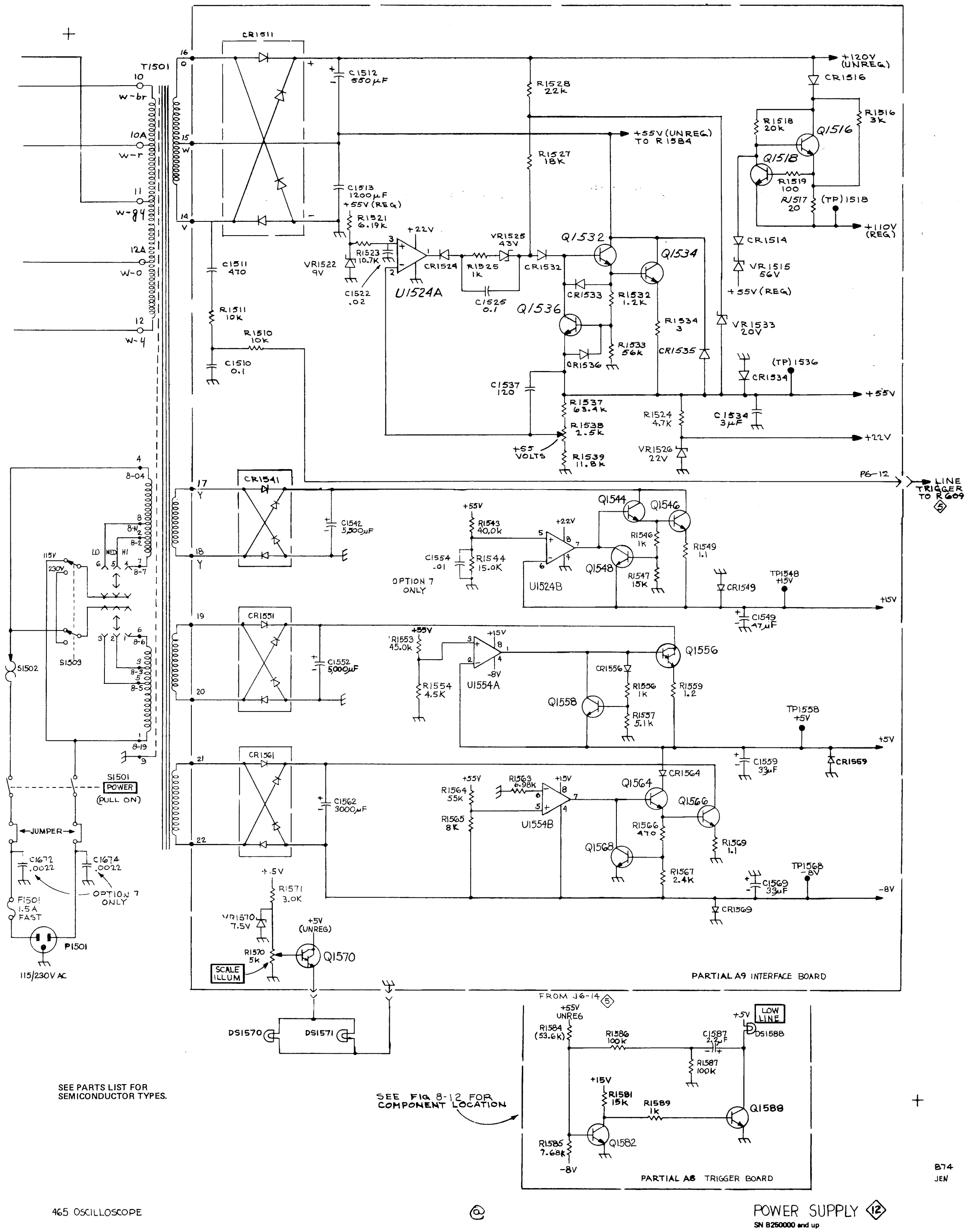


Fig. 7-8. Schematic for questions 2 through 5.

2. Figure 7-8 is a schematic of an oscilloscope power supply. Circle and label the components associated with the following blocks of the +55 volt power supply. Identify each block with the letter preceding that block.

   a. Power transformer.
   b. Rectifiers.
   c. Capacitive filtering.
   d. Regulator circuit.

3. Label each of the following components or circuits on Fig. 7-8 that are associated with the +5 volt supply with the appropriate letter from the list below.

   e. Reference divider.
   f. Error amplifier.
   g. Current limiting circuit excluding error amplifier and series regulator.
   h. +5 volt supply reference voltage.
   i. Line fuse.

4. Listed below are several possible faults that might occur in a power supply and several symptoms that might appear as results of the faults. For each of the abnormal symptoms listed, write in the letter(s) of the fault(s) that would cause that symptom. Assume that the supply is the +55 volt supply shown in Fig. 7-8.

   SYMPTOMS:

   (1) Line fuse blows. ________
   (2) Output voltage too high, ripple normal. ________
   (3) Output voltage too high, ripple too high. ________
   (4) Output voltage $\approx$ 0 volts. Line fuse OK. ________
   (5) Ripple frequency = Line frequency. ________
   (6) Ripple frequency twice line frequency. ________

FAULT:

A. Shorted series regulator transistor.
B. Open series regulator transistor.
C. Shorted filter capacitor.
D. Zener diode voltage too high (reference voltage slightly positive).
E. Full-wave rectifier has one open diode.
F. Full-wave rectifier has one shorted diode.
G. No fault, This is a normal symptom.

5. Mark the items below that will have a pronounced (±5% or worse) effect on the output voltage of the −8 Volt supply shown in Fig. 7-8. Assume only one fault is present at any given time.

A. VR1522 Zener diode in +55 volt supply slowly drifts ±1 volt above and below its normal 9 volt level.
B. VR1525 Zener diode in +55 volt supply slowly drifts ±1 volt above and below its normal 43 volt level.
C. Q1568 in the −8 volt supply opens.
D. Open loop gain of U1554B in the −8 volt supply is 10% higher than normal.
E. R1564 in the −8 volt supply is 70 k instead of 55 k.
F. All the faults above would affect the −8 volt output by more than ±5%.

Check your answers against the key.

ANSWER KEYS

Pretest

1. B.
2. B.
3. D.
4. Vo = 27 volts
   Vn = 9 volts
5. Vo = 27 volts
6. A., B., C.

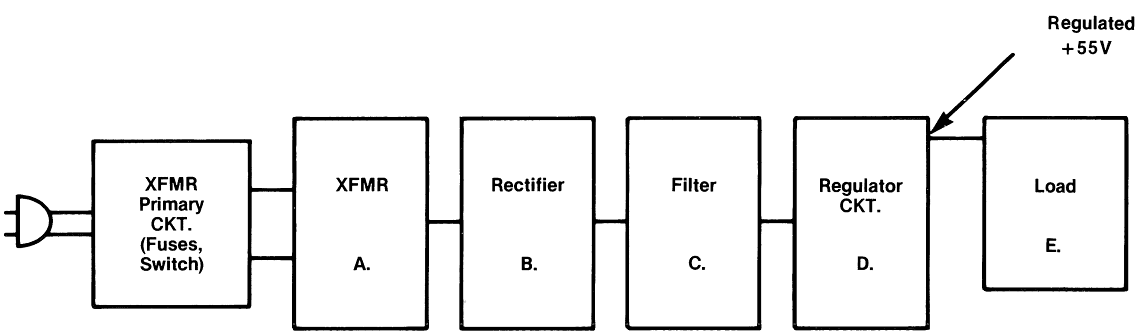
Study Aid Question Answers

1. A. 4
   B. 2
   C. 1
   D. 3
   E. 5
2. C, D
3. E.
4. A. (line voltage changes will affect collector *voltage* but not collector *current* if load resistance doesn't change.)
5. A.
6. E.

7. A. (1), (4)
   B. (1), (4)
   C. (1), (4)
   D. (1), (3)
8. A., C.
9. A, B, C, D, E, F, G, H.
10. C, D.
11. A, B, C, D, E.
12. E.
13. E.

Quiz Answers

1.



2. See Fig. 7-10
3. See Fig. 7-10

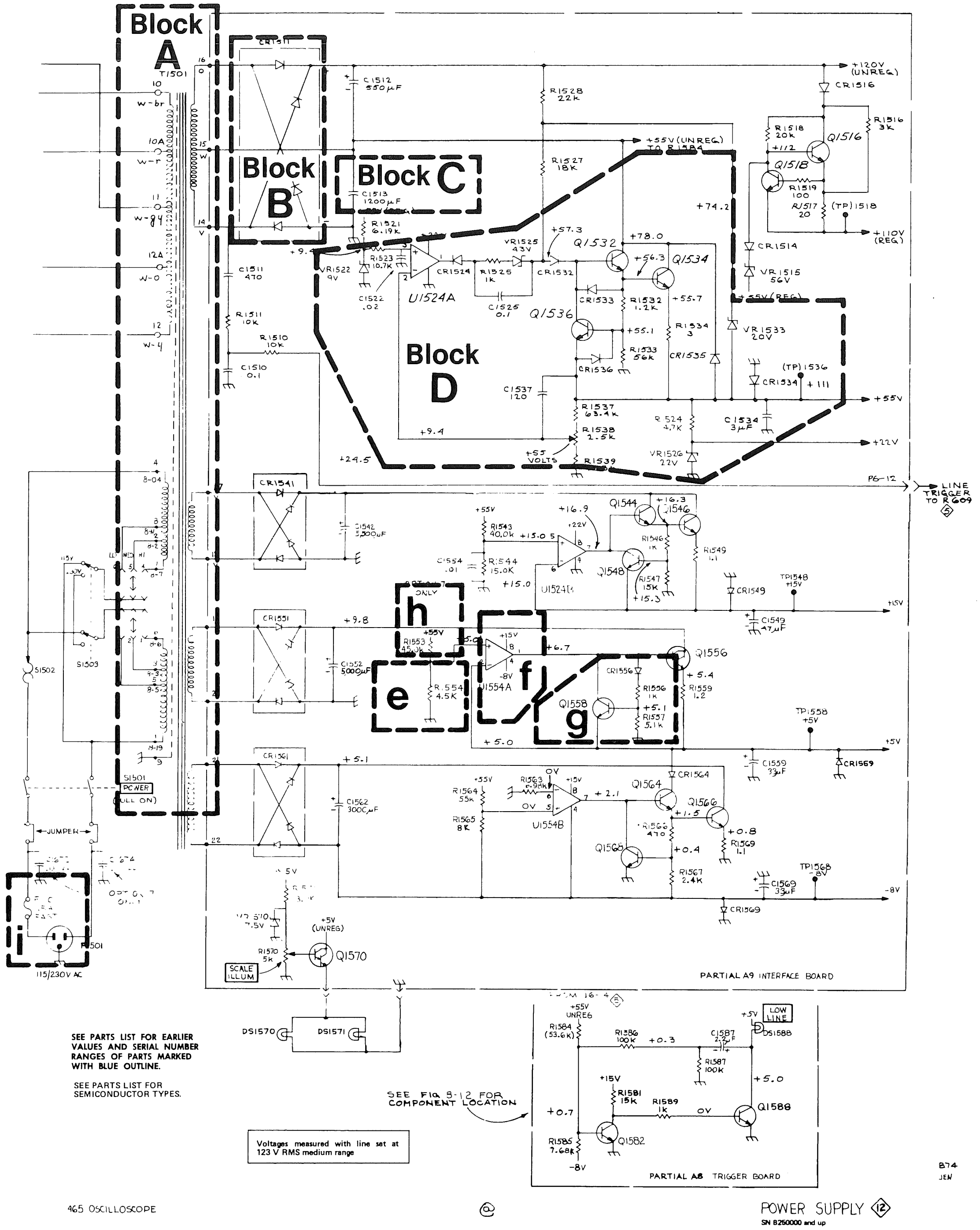


Fig. 7-10. Answer for questions 2 and 3.

4. (1) C, F. (A shorted series regulator may blow the line fuse if the increased output voltage cause something in the load to short, so if you answered A, C, F, you're still right.)
   (2) D
   (3) A, D (Fault "D" would have to be rather severe to cause a noticeable increase in ripple.)
   (4) B
   (5) E
   (6) G
5. A,E.

Summary

Well, how did you do? If you are confused about any of the concepts presented, we recommend you review the course material for those areas. We also suggest you retain this booklet and your notes so you can refresh your memory whenever you wish.

This concludes Section VII and we recommend you take a break before starting Section VIII.

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