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8

Troubleshooting

8.1   Component Testing

When you have completed study of this chapter, you should be able to:

- Test diodes, SCRs and TRIACs

- Test BJTs, JFETs and MOSFETs

- Use Ohms and Kirchhoff's laws to troubleshoot biased BJTs and FETs

8.1.1   Testing Diodes

As was discussed in Chapter 2, the diode is a semiconductor device, which conducts direct current in one direction only. In other words, the diode exhibits a very low resistance when it is forward-biased and an extremely high resistance, when it is reverse-biased. Similarly in Chapter 7 we learned that an ohmmeter applies a known voltage from an internal source (batteries) to the measured resistor. Theoretically, this voltage can reach 1.5 V or 3 V. The diode requires a voltage of 0.7 V to become forward-biased. Therefore, if the positive test lead of the ohmmeter is connected to the anode and the negative test lead of the ohmmeter is connected to the cathode, the diode becomes forward-biased. In this case, the ohmmeter reads a very low resistance. If the test leads are reversed with respect to the anode and the cathode, the diode becomes reverse-biased. Then, the ohmmeter reads a very high resistance. Thus an ordinary ohmmeter can be used to test a diode.

Most digital multimeters (DMMs) have a **diode test function**. It is marked on the select switch with a small diode symbol. When the DMM is set to diode test mode, it provides a sufficient internal voltage to test the diode in both directions. Figure 8.1 illustrates the testing procedure of a diode. The positive test lead of the DMM (in red color) is connected to the anode, and the negative test lead of the DMM (in black color) is connected to the cathode. If the diode is in good working order, the multimeter should display a value in the range between 0.5 V and 0.9 V (typically 0.7 V). Then the test leads of the DMM are reversed with respect to the anode and

the cathode. As the diode in this case appears as an open circuit to the multimeter, practically all of the internal DMM voltage will appear across the diode. The value on the display depends on the meter's internal voltage source and it is typically in the range between 2.5 V and 3.5 V.
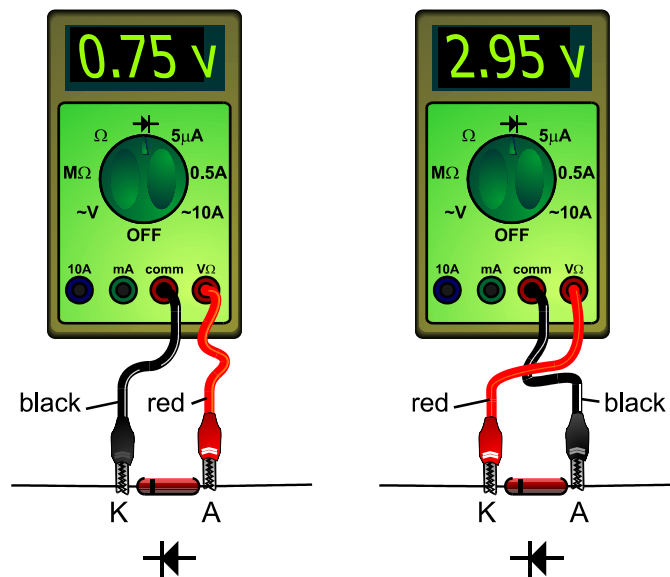

Figure 8.1
Properly Functioning Diode

A defective diode appears either as an open circuit or as a closed circuit in both directions. The first case is more common and it is mainly caused by internal damage of the pn-junction due to overheating. Such a diode exhibits a very high resistance when it is both forward-biased and reverse-biased. On the other hand, the multimeter reads 0 V in both directions if the diode is shorted. Sometimes a failed diode may not exhibit a complete short circuit (0 V) but may appear as a **resistive diode**, in which case the meter reads the same resistance in both directions (for example 1.5 V). This is illustrated in Figure 8.2.
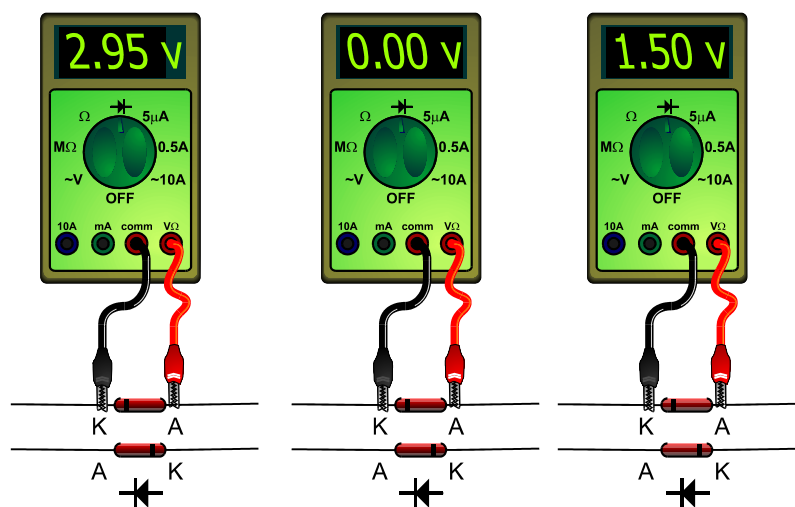

Figure 8.2
Defective Diodes

As was mentioned earlier, if a special diode-test function is not provided in a particular multimeter, the diode still can be checked, by measuring its resistance in both directions. The selector switch is set to OHMs. When the diode is forward-biased, the meter reads from a few hundred to a few thousands ohms. The actual resistance of the diode normally does not exceed 100 Ω, but the internal voltage of many meters is relatively low in the OHMs range and it is not sufficient to forward-bias the pn junction of the diode completely. For this reason, the displayed value is higher. When the diode is reverse-biased, the meter usually displays some type of out-of-range indication, such as "OL", because the resistance of the diode in this case is too high and cannot be measured from the meter.

The actual values of the measured resistances are unimportant. What is important, though, is to make sure that there is a great difference in the readings, when the diode is forward-biased and when it is reverse-biased. In fact, that is all you need to know. This indicates that the diode is working properly.

8.1.2   Testing SCRs

As was discussed in Section 2.4.1 the SCR is a diode, with an additional gate terminal. The SCR can be brought into conduction only if it is forward-biased and if it is triggered from a pulse applied to the gate. Thus, the SCR can be checked in a similar manner to the conventional diode, employing a DMM with a diode-check function or with an ordinary ohmmeter.

The positive (red) test lead of the meter is connected to the anode of the SCR and the negative (black) test lead is applied to the cathode. This is illustrated in Figure 8.3. The instrument should show an infinite high resistance. A jumper can be used to trigger the SCR. Without disconnecting the meter, use the jumper to short-circuit the gate terminal of the SCR with the positive lead of the meter. The SCR should exhibit a great decrease of resistance.
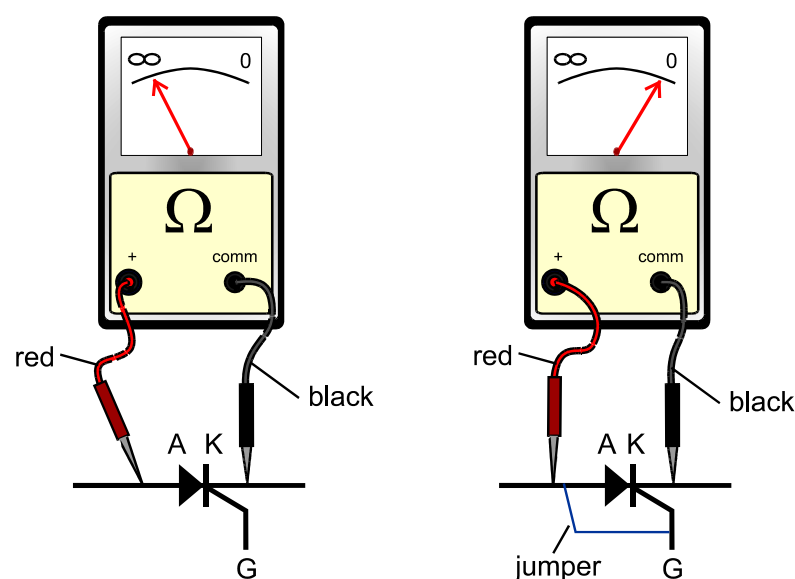

Figure 8.3
Testing the SCR

When the jumper is disconnected, the device may continue to conduct or may turn off. This depends on the properties of both the SCR and the meter. If the holding current of the SCR is small, the ohmmeter could be capable of supplying enough current to keep it turned on. However, if the holding current of the SCR is high, the device will turn off upon disconnection of the jumper.

Some high-power SCRs may have an internal resistor connected between the cathode and the gate. This resistor prevents the SCR from triggering due to small interference surges. A maintenance technician, who is not aware of the existence of this resistor, may mistakenly diagnose such SCR as being leaky between the cathode and the gate. The resistor's value can be measured with an ohmmeter during the test.

8.1.3 Testing TRIACs

Since the TRIAC actually consists of two SCRs connected in parallel and in opposite directions, the procedure for testing a TRIAC is essentially the same as testing an SCR. The positive test lead of the meter is connected to MT2 and the negative test lead is applied to MT1. When the gate is open, the ohmmeter should indicate an infinite resistance. Then, similarly to the SCR testing procedure, a jumper is used to touch the gate terminal to MT2 (a positive triggering pulse is applied to the gate). The TRIAC should exhibit a great decrease in resistance. This indicates that one of the SCRs in the pair functions properly.

Then the test leads of the ohmmeter are reversed with respect to the anode and the cathode. Again, if the gate is open, the ohmmeter should exhibit an out-of-range resistance. Using the jumper, the gate terminal is briefly touched to MT2 (a negative triggering pulse is applied to the gate). The resistance of the TRIAC greatly decreases, which indicates the proper functioning of the second SCR in the pair. This procedure is illustrated in Figure 8.4.
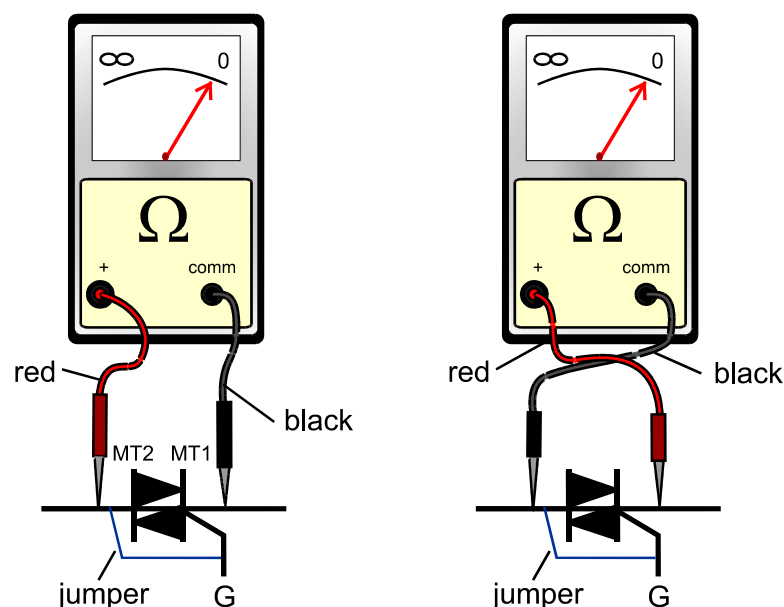

Figure 8.4
Testing the TRIAC

8.1.4 Testing BJTs

As you know from Chapter 2, bipolar junction transistors (BJTs) are devices, consisting of three layers of semiconductive material and can be either pnp or npn type. Therefore, each transistor can be represented as a combination of two diodes, connected together as shown in Figure 8.5. The equivalent base of pnp type transistors appears as connected to the cathodes of both diodes. If transistors are npn type, the equivalent base appears as connected to the anodes of both diodes. The two remaining terminals of the diodes represent the emitter and the collector. Both pn-junctions of the transistor are tested separately as two independent diodes. If both of them show no defects, the transistor is working properly.
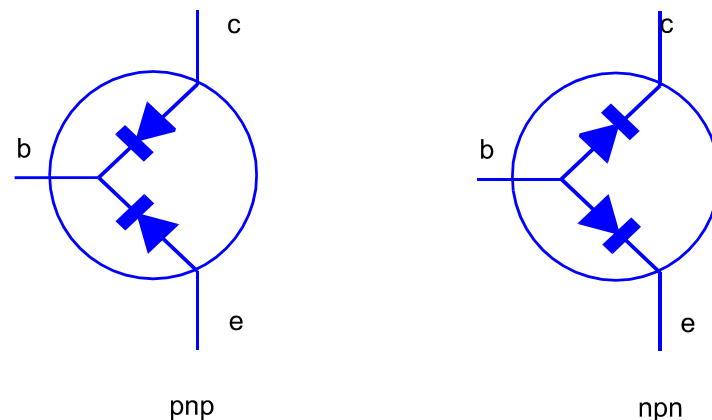

Figure 8.5
A Transistor, Represented as Two Diodes

The diode-test function of a digital multimeter can be also used to test transistors. Let us assume that a pnp type transistor has to be tested. The negative test lead (black) of the multimeter is applied to the base of the transistor. The positive test lead (red) is applied first to the emitter and then to the collector. In this arrangement, both junctions will be forward-biased when tested. The DMM should read low resistance in both cases. Then the red test lead is applied to the base of the transistor instead of the black one. The procedure is repeated. Both pn-junctions are now reverse-biased, when tested. The multimeter reads high resistance in both cases. The procedure for testing npn transistors is identical. The difference is that the DMM will now read a *high* resistance, when the black lead is applied to the base and a *low* resistance, when the red lead is connected to it.

If a multimeter without a diode-test mode is used, the transistor can be tested with the OHMs function. The test operations are similar to the OHMs function diode checking, described in the previous section. It is important to emphasize again, that the reading of a few hundred to a few thousand ohms for forward the bias condition does not necessarily indicate a faulty transistor. It is rather a sign that the internal power supply of the meter is not sufficient to forward bias completely the pn-junction. The out-of-range indication for reverse-biasing the same transistor clearly shows that the device is functioning properly. The important consideration here is the *difference* between the two readings and not their actual value.

The transistor is faulty if both pn-junctions exhibit *approximately the same* resistance in both directions. In a similar way to diodes, the pn-junctions of the defective transistors exhibit either a very high resistance in both directions (an internal open-circuit), or a zero resistance in both directions (an internal short-circuit). Sometimes the faulty pn-junction exhibits a small resistance, which is equal in both directions. For example, the meter readings in both directions are 1.2 V instead of the correct 0.7 V and the 2.9 V readings respectively. In this case, the transistor is defective and should be discarded.

Most digital multimeters are capable of measuring the current gain of the transistor β_{DC}. The three transistor terminals are placed in special slots, marked E, B and C respectively. Then a known value of I_B is applied to the transistor and the respective I_C is measured. As you know, the ratio I_C / I_B is equal to β_{DC}. Though this is a convenient and quick method to check the transistor, one should be aware that some DMMs measure the value of β_{DC} with a low accuracy. The specifications of the DMM have to be checked, before relying on the measured value of the current gain. Some testers have the useful feature of an **in-circuit β_{DC} check**. Here there is no need to disconnect the suspected transistor from the rest of the circuit and it can be tested directly on the PCB.

8.1.5 Troubleshooting Biased BJTs

Sometimes the transistor itself may not be faulty, but due to faults in the external circuitry, it may not operate properly. For example, a cold junction on the transistor base terminal effectively isolates the base from the rest of the circuit. Therefore, the bias voltage on the transistor is 0 V, which will drive it into cutoff. When checking such transistor from the component side of the PCB, it will appear to be functioning correctly. And yet, the signal is not present at the output.

To better understand how to troubleshoot a biased BJT, let us consider a simple amplifier stage as shown in Figure 8.6. It is built on the transistor 2N3946. According to the data sheets, β_{DC} for this transistor is in the range of 50 to 150. Therefore, we can assume that β_{DC} for the specified transistor is 100. The bias voltages are chosen V_{BB} = 3 V and V_{CC} = 9 V. Performing some simple calculations, we can determine that:

$$V_{BE} = 0.7 \text{ V}$$

$$I_B = \frac{3V - 0.7V}{56k\Omega} = \frac{2.3V}{56k\Omega} = 41.4\mu A$$

$$I_C = \beta_{DC}\, I_B = 100 \ (41.1 \ \mu A) = \ 4.1 \text{ mA}$$

$$V_C = 9 \text{ V} - I_C\, R_C = 9 \text{ V} - (4.1 \text{ mA}) (1k\Omega) = 4.9 \text{ V}$$

The voltages and the component values are specified in the Figure 8.6. All measured voltages are with respect to the ground. If the circuit operates correctly, the following voltages should be measured: +0.7 V in point A; +4.9 V in point B and 0 V in point C.
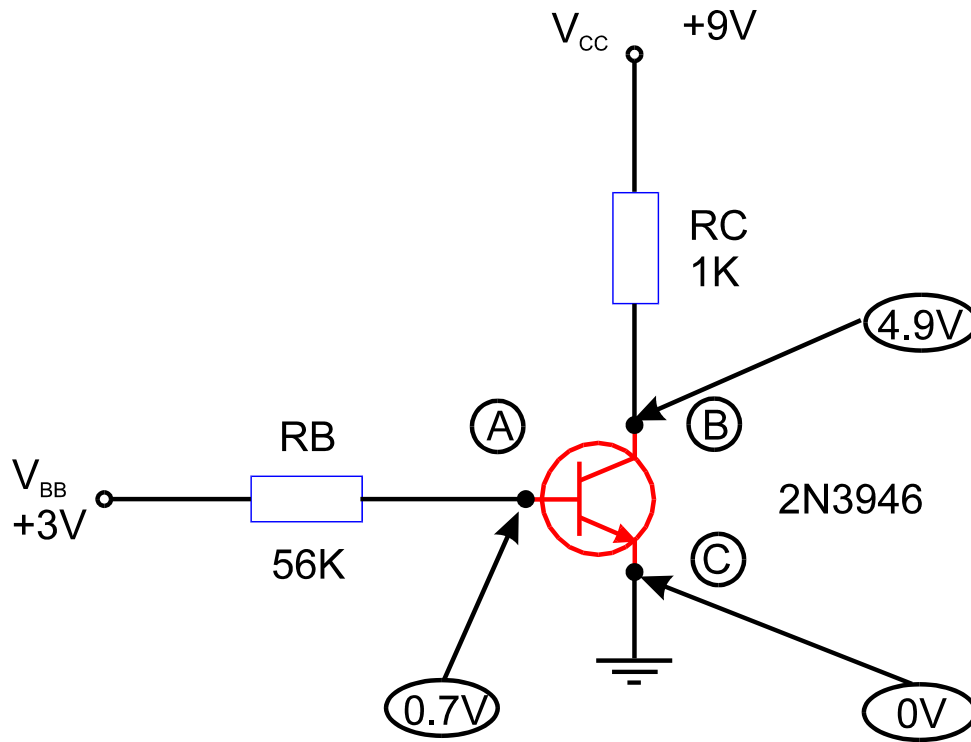

Figure 8.6
Troubleshooting a Single Amplifier Stage

First, the transistor has to be checked. If the transistor is not defective, the PCB has to be inspected visually for mechanical defects, burned components and badly soldered joints. Finally, the voltages on the transistor terminals have to be measured.

Three typical abnormal conditions may occur, due to faults in the external circuitry. They are illustrated in Figure 8.7. Measuring the voltages on the transistor terminals can help to more effectively detect these faults. If the voltage at point B is only several μV instead of the normal +0.7 mV, this is an indication that the base of the transistor is open (Figure 8.7a). The soldered joints at the base of the transistor and at R_B have to be checked. The value of the R_B has to be measured. Any external circuitry, leading to the base of the transistor has to be inspected for bad soldered joints and for components that are out of tolerance.
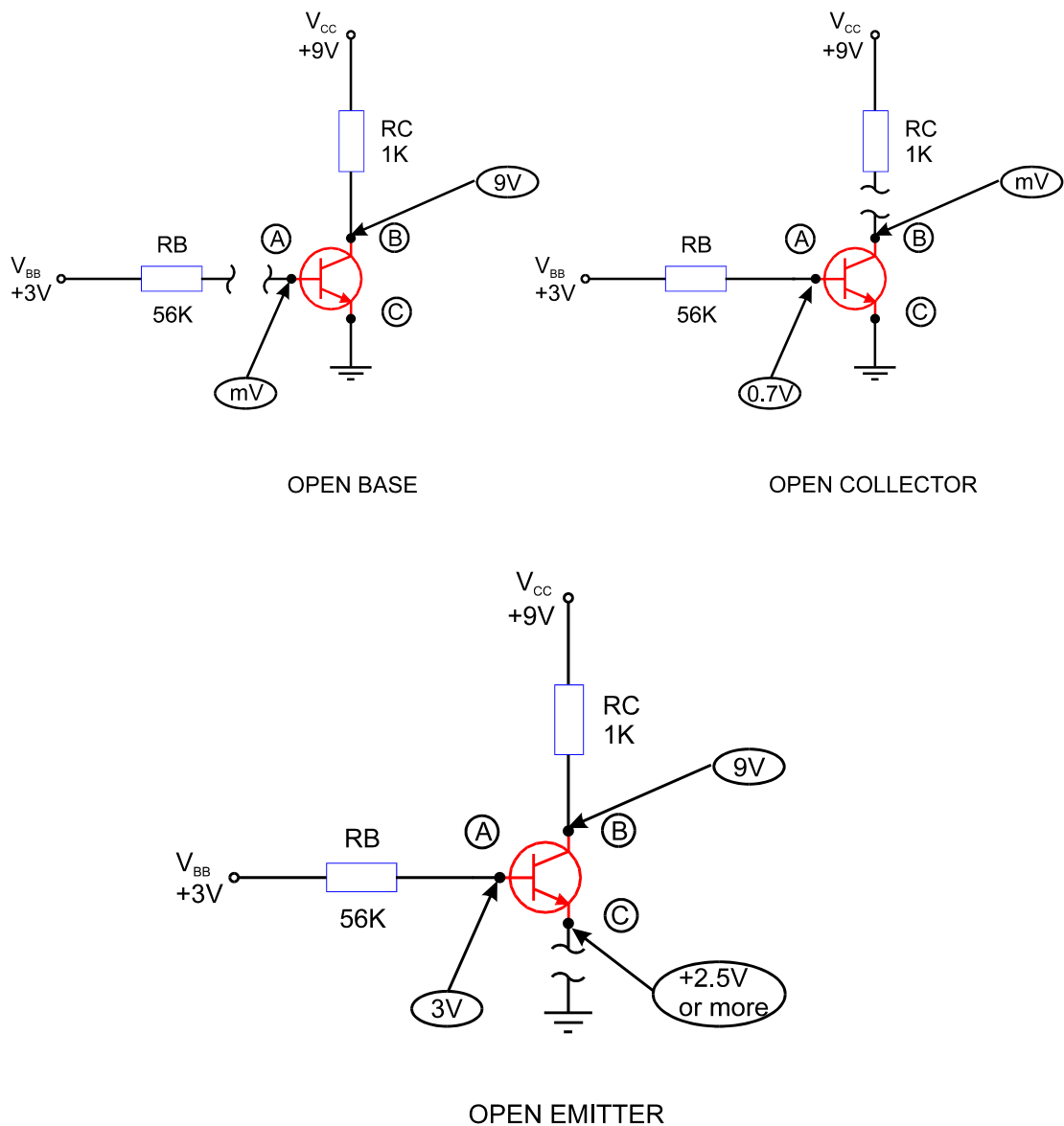
Figure 8.7
Typical Abnormal Conditions in a Biased BJT

If the meter reads from a few μV to a few mV on the collector terminal (point B), this is an indication that the collector is not connected to the rest of the circuitry (Figure 8.7b). At the same time, the voltage on the base terminal should be around 0.7 V, as the base-emitter pn-junction is forward biased. The soldered joints on the collector and the collector resistor to the PCB have to be inspected. The value of R_C has to be measured. Any components, connected to the collector resistor have to be checked.

Finally if there is an open ground connection the symptoms are as follows: +3 V at the base terminal and +9 V at the collector terminal, as there is no collector and no emitter currents (Figure 8.7c). The voltage measured at the emitter is +2.5 V or more. This occurs because the internal resistance of the measuring voltmeter provides a forward current path. It flows from V_{BB}, through R_B, the base-emitter junction and through the measuring voltmeter to the ground. Thus, the voltmeter registers the voltage drop across the pn-junction. The soldered joint on the emitter has to be

checked. All external circuitry connected to the emitter also has to be checked and tested.

8.1.6   Testing FETs

Field effect transistors are more difficult to test than bipolar junction transistors. Before testing a FET, it must be known if the transistor is a JFET or a MOSFET type. Hereafter it has to be clarified if it is a p-channel or an n-channel device. JFETs can be tested with an ordinary ohmmeter.

Figure 8.8 depicts an equivalent circuit of a JFET. It appears to the ohmmeter as two diodes connected in series between the drain and the source. The polarity of the diodes is inverted. The gate terminal is taken from the midpoint between them. In the case of an n-channel type, the gate is connected to the anodes of both diodes. If the transistor is a p-channel type, the gate is connected to the cathodes of both diodes. The insulation layer of SiO_2 appears to the ohmmeter as a resistor connected between the drain and the source in parallel to both diodes.
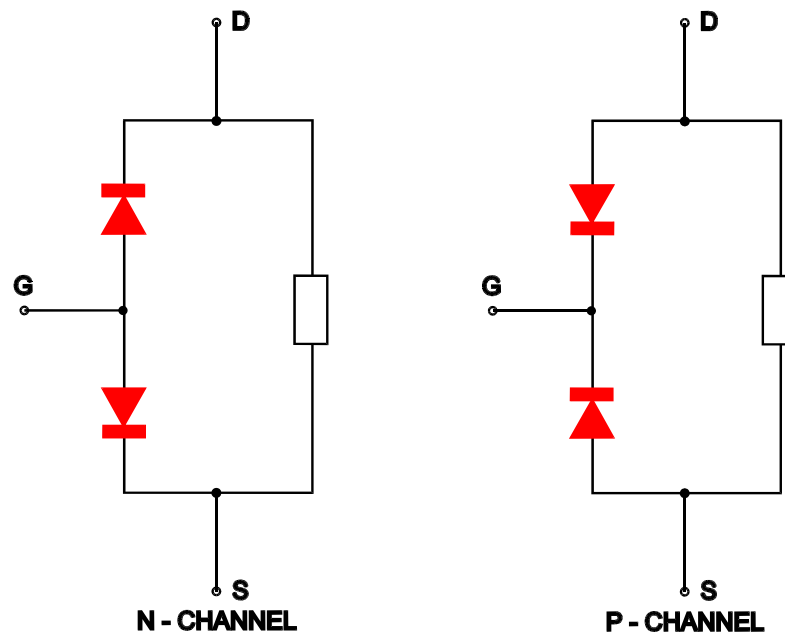

Figure 8.8
A JFET, represented with Two Diodes and a Resistor

Therefore, the JFET transistors can be checked using an ohmmeter, by testing the pn-junctions between the gate and the drain from one side and the gate and the source from the other. If the JFET is in good working order, both pn-junctions should behave as ordinary diodes, exhibiting a high resistance in one direction and a low resistance in the other. Then the resistance between the drain and the source is measured. The meter should indicate some amount of resistance, which depends on the JFET properties.

In the best case scenario, testing MOSFETs with an ohmmeter is a very difficult task. As you know, the gate junction and the channel are separated with a very thin layer of metal oxide insulation. This property of the MOSFET ensures extremely high input impedance of the device, but makes it vulnerable to permanent damage even

when minimal static voltages are built up at the transistor terminals. In fact, a MOSFET can be easily damaged even when it is slightly touched with a finger. For this reason, MOSFETs come in packages that provide an electrical connection between all terminals and prevent the static voltages from building up.

MOSFETs can be tested very carefully with a low voltage ohmmeter, set to the highest possible range. D-MOSFETs that are in a good working order, exhibit some continuity between the source and the drain. However, there should be no resistance between the gate to drain and the gate to source terminals. E-MOSFETs that are working properly show no continuity between any of the terminals.

8.1.7   Troubleshooting Biased JFETs

It is not a recommended practice to unsolder a FET transistor in order to test it. After the visual inspection for damaged components or bad soldered joints, the voltages on the drain and the source have to be measured with respect to the ground.

A typical faulty symptom is the drain voltage, which is nearly equal to the power supply voltage (Figure 8.9a). This condition occurs when the drain current is zero and therefore there is no voltage drop across R_D. The following faults may be the cause for it:

- Dry joint at R_S (R_S appears as an open circuit),

- R_S is faulty or it is out of tolerance,

- Dry joint at R_D (R_D appears as an open circuit),

- R_D is faulty or it is out of tolerance,

- Dry joint at the source terminal,

- Dry joint at the drain terminal,

- Internal JFET open-circuit between the source and the gate terminals.
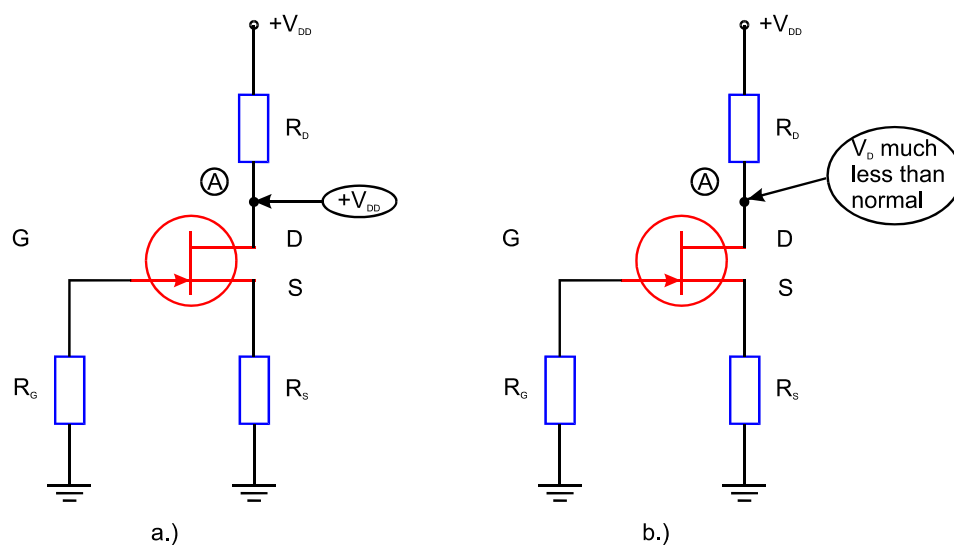

Figure 8.9
Typical Abnormal Conditions in a Biased JFET

Another typical faulty symptom is a drain voltage that is much less than the normal value (Figure 8.9b). This condition occurs when the drain current is at a far higher level than normal, in which case there is a great voltage drop across R_D. Several faults may cause this to happen:

- Dry joint at R_G (R_G appears as an open circuit),
- R_G is faulty or it is out of tolerance,
- Dry joint at the gate terminal,
- Internal JFET open circuit at the gate terminal.

Some faults are very difficult to troubleshoot. One such example is an internally opened gate in a zero-biased D-MOSFET. After the fault occurs, the gate to source voltage remains the same (0 V). For this reason, the drain current does not change its value and the bias appears to be normal. In general, troubleshooting FETs is a much more difficult task and requires more skills and experience than troubleshooting BJTs.

8.1.8   Troubleshooting Op-amps

Op-amps are complex and sophisticated devices. Many internal failures can occur. However, the operational amplifier as such cannot be tested. Should there be an internal problem, it is not possible to troubleshoot it and to fix it. Therefore, if the op-amp fails, the only option is to replace it.

Usually there are only a few external components in the op-amp circuits. A typical circuit consists of an input resistor, a feedback resistor, and a potentiometer, used for off-set voltage compensation. If the circuit malfunctions, the external components have to be checked first. There could be dry joints, or the components may be burnt, or out of tolerance. If this does not fix the problem, the contacts on the op-amp itself have to be checked. It is possible that some of them are faulty. Finally, if everything else appears in a good working order, but the circuit is still not operating properly, it has to be assumed that the operational amplifier itself is faulty. In this case, the op-amp is simply replaced as you would replace a resistor, transistor or any other component.

Some typical faults in op-amp circuits are given below:

- **Power supply voltage.** This is the first thing you should check (as is the case with troubleshooting any other circuit). A proper supply voltage and a ground must be present. It should be remembered that the level of the power supply is quite critical for most ICs.

- **Open feedback resistor.** This fault results in a severely clipped output voltage, as the op-amp operates at its maximum voltage gain (i.e. the circuit appears as an open-loop amplifier).

- **Shorted feedback resistor.** In this case, the output signal has the same amplitude as the input signal.

- **Open input resistor.** In the case of an inverting amplifier, there is no signal at the output, as there is no signal at the input. In the case of a non-inverting

amplifier, the gain is equal to 1, and the output voltage follows exactly the input voltage. In other words, the amplifier will act as a voltage-follower.

- **Incorrectly adjusted potentiometer.** This fault results in clipping only the positive, or only the negative peak of the output voltage.

8.1.9   Summary

Most digital multimeters (DMM) provide special functions for testing diodes and BJTs. However, if such functions are not available, most electronic components. can be tested with an ordinary ohmmeter. If a diode is in a good working order, the ohmmeter readings should change from high to low (and the vice versa) every time the test leads are reversed with respect to the anode and the cathode. The SCR is tested in a similar way. The difference is that in addition a jumper is used between the gate and the anode to trigger the SCR. When the SCR is triggered, its resistance drops significantly from high to low. TRIACs are tested as SCRs, but in both directions (i.e. the test leads of the meter are reversed and the procedure is repeated). BJTs are treated as two diodes, connected in series. Each equivalent diode is tested independently. FETs are more difficult to test. Special care must be taken not to damage the device due to static charge build up. JFET transistors can be represented as two diodes connected in series, with an additional resistor connected in parallel across them. Both equivalent diodes are tested independently. The value of the resistor is also measured. To find out faults in biased transistor circuits, initially, the approximate voltages on each transistor terminal are calculated. Then the voltages are measured. Any deviations from the calculated values are analyzed logically, which essentially leads to finding and fixing the problem. Op-amps cannot be tested, as the other devices. All external components and the soldered joints have to be checked and if the circuit still does not operate properly, the op-amp has to be replaced.

8.2   Troubleshooting Techniques

When you have completed study of this section, you should be able to:

- Determine the relationship between the symptom and cause of a problem

- Troubleshoot common circuits, using accepted techniques

- Conduct a fault analysis

8.2.1   The Symptom and the Cause

The **troubleshooting** of electronic circuits involves three steps, which should be done in a specific order. The first step is to identify the defect in the circuit. The second step includes fault analysis and determination of the possible causes. The third step is fixing the problem.

First, it is important to identify the problem. In other words, we have to recognize the symptoms in the defective circuit. A **defective circuit** can be defined as one, where the output parameters are incorrect, although the input parameters are correct. For example, the input signal of the amplifier, depicted in Figure 8.10a is correct, but there is no signal at the output. In this case, the symptom is lack of voltage at the output.
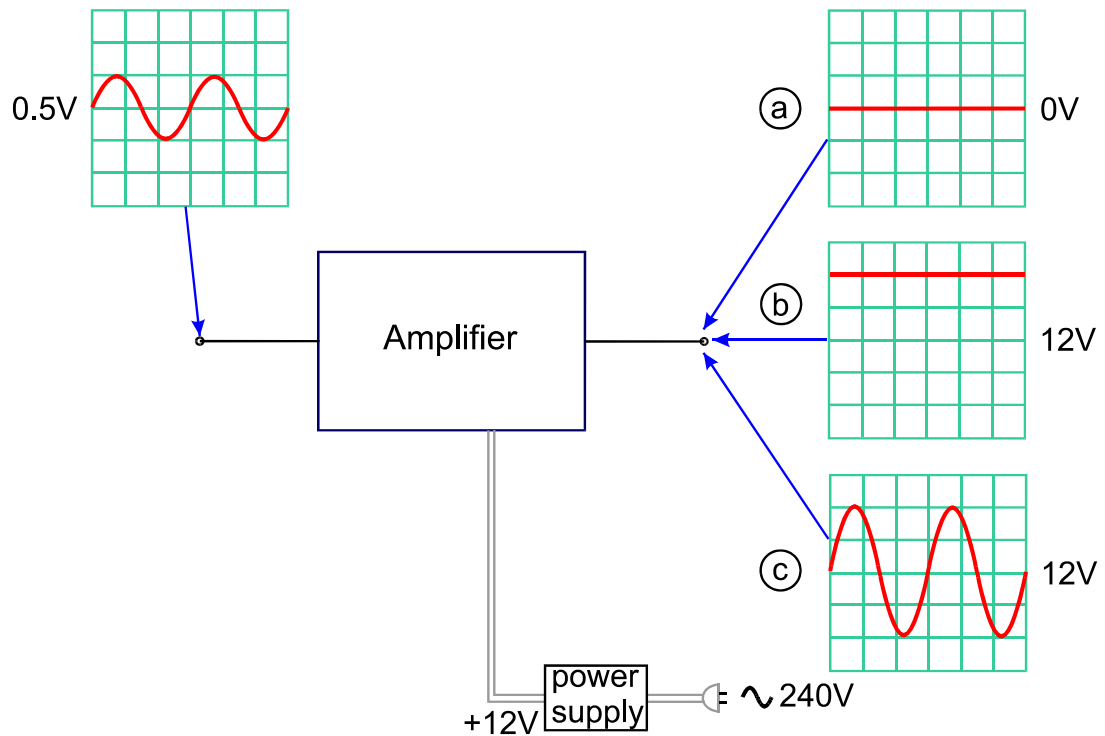

Figure 8.10
Identifying the Symptoms in a Defective Circuit

This particular symptom does not provide much information about the possible causes of the defect. The failure of various components in the circuit will result in the same symptom   (zero voltage at the output). In other cases, a particular symptom points directly to a certain area where the fault is most likely to have occurred. For example, a dc voltage at the output with the level equal to the supply voltage indicates that there is a transistor in a cutoff condition in the circuit (Figure 8.10b). Starting from the stage that is closer to the output and going backwards, all transistors have to be checked for an internally open pn-junction. The soldered joints and the values of the emitter resistors also have to be checked.

If the amplifier is not defective, the amplified signal appears at the output. The amplitude of the output signal is approximately equal to the value of the rectified power supply. The waveform has to be an exact amplified replica of the input signal, without any kind of distortion. This is illustrated in Figure 8.10c.

8.2.2 Troubleshooting Techniques

Once the symptom is identified, the reasons that cause it have to be determined. The choice of which of several methods to use depends on the circuit complexity; on symptoms and on the personal preferences of the technician. The most common troubleshooting techniques are listed below:

- **Power check**. This is the first thing you should do. It is amazing how many times a simple issue such as a blown fuse, or a flat battery is the cause of the circuit malfunction. So initially, ensure that the power cord is plugged in and that the fuses are not blown. If the circuit is powered from batteries, make sure that their voltage level is acceptable. If a power supply rectifier is present, check the level of the voltage at the output and make sure that the circuit is powered with the correct polarity.

- **Visual inspection**. This inspection is part of the so called sensory checks. Sensory checks rely on your senses to detect a possible fault. The visual inspection of the PCB is the simplest troubleshooting technique (which is very effective in half of the cases). The soldered joints have to be inspected thoroughly. If any doubt exists about the quality of a certain joint, it has to be re-soldered. The PCB has to be inspected visually for any burnt components. Sometimes, components that overheat leave a brownish mark on the board. They can be used as "starting points" in the troubleshooting process and the reasons why they overheat have to be determined. It is bad practice simply to replace such components, without trying to find out what actually caused the component to overheat. In many cases the reason is a faulty (or out of range) component in the vicinity of the failed component. It also has to be replaced.

- **Using a sense of touch**. This is another sensory check. Overheated components can be detected by simply touching them. However, this check has to be performed with extreme caution. The circuit has to be turned off, and some time allowed for the biggest capacitors to discharge. Always touch the components with your *right* hand only! This is important because in the case of electric shock it is less likely that the current will pass through your heart. If possible, wear insulated shoes. In addition, care should be taken not to burn your fingers. Using the sense of touch is a very useful troubleshooting technique in circuits, where everything seems to work properly for a while, and then the circuit fails, due to overheating of a certain component. Identifying such components helps to detect the possible cause of the fault. Special freezing sprays are available, which allow instant freezing of components. If the circuit begins to operate properly immediately after the heated component is sprayed, this is an indication that this component is causing the circuit failure. Before replacing the component, further investigation is needed to determine what caused the overheating in the first place.

- **Smell check**. When certain components fail due to overheating it is possible in most cases to detect a smell of smoke. This is usually the case, if the technician happens to be there at the time the accident occurred. If not, it is usually possible to detect the failed component by visual inspection afterwards.

- **Component replacement**. This troubleshooting method relies mostly on the operator's skills and experience. Certain symptoms are an obvious indication of

a particular component failure. This statement is especially true for an experienced electronic technician. For example, some TV service technicians can unmistakably identify the failed component in a TV set (even before opening it), by just briefly examining the symptoms. Component replacement is a good troubleshooting technique for an experienced electronics technician, as it saves a lot of time and money. Moreover, this technique guarantees the success of the repair, because if enough components are replaced, eventually the faulty one will be replaced too. However, it is recommended that the amateur technician initially applies some logical thinking to the troubleshooting process.

- **Signal tracing**. This troubleshooting technique is not the most common one, but it is the most desirable as it requires intelligent and logical thinking from the troubleshooter. This method is based on the measuring of the signal at various test points along the circuit. A test point in the circuit is the point, where the value of the voltage is known to the operator. This troubleshooting technique relies on finding a point, where the signal becomes incorrect. Thus, the operator knows that the problem exists in that portion of the circuit, between the point where the signal becomes incorrect, and the point where the signal appeared correct for the last time. In other words, the operator constantly narrows the searched portion of the circuit, until he finds what causes the fault. There are two basic approaches in conducting the signal tracing. In the first approach, the signal check starts from the input, checking consecutively the test points towards the output. The checks are carried out, until a point, with an incorrect signal is found. The second approach is to start from the output and to work backwards towards the input in the same manner until a correct signal appears.

8.2.3   Fault Analysis

Fault analysis requires a good knowledge of the theory and a good analytical thinking. It is not something, which can be studied from books, but it can be acquired through constant troubleshooting and experimenting. The basic question in fault analysis is: "What would the symptoms in the circuit be, if the component X is faulty?" For each specific application, there are no ready answers to this question. If they were, many books devoted to industrial electronics would be meaningless, anyway. However, there are certain rules, which can be adhered to, during the troubleshooting process. One of the tasks of this manual is to teach you some of these basic rules.

As an example, let us examine a bridge rectifier, to illustrate the process of the fault analysis. The block circuit of a bridge rectifier that is working properly is shown in Figure 8.11. It consists of a transformer, a rectifier and a filter. The voltages, taken with an oscilloscope at each test point are depicted in the figure.
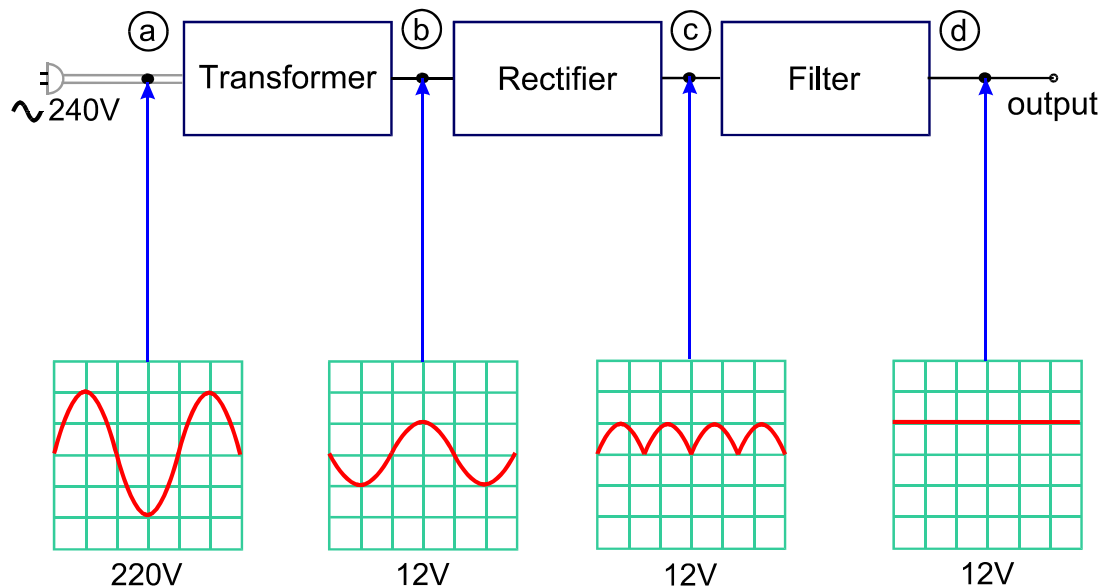
Figure 8.11
A Block Diagram of a Rectifier in Good Working Order

The circuit diagram of the same bridge rectifier is depicted in Figure 8.12. A signal trace is conducted commencing from the output and working towards the input. An analysis of all possible faults in this circuit are given below:
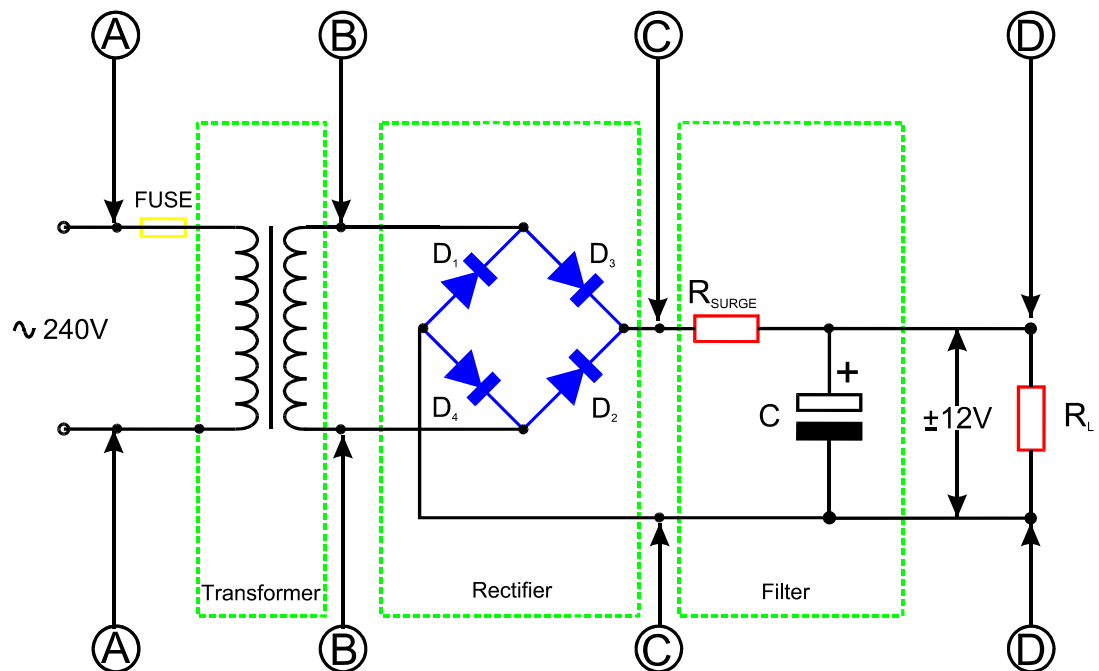

Figure 8.12
A Circuit Diagram of the Bridge Rectifier

- **Faulty capacitors C.** There are three possible problems. The capacitor could be shorted, opened or leaky. If the capacitor is shorted, it effectively brings both terminals of the load resistor together and therefore the output voltage is zero. This is illustrated in Figure 8.13a. If the capacitor is open (Figure 8.13b), it does

not filter the output voltage supplied from the rectifier. The waveform of the voltage at the output remains the same as the waveform of the voltage after the rectifier. Therefore, the waveforms at points C and D are identical. The only difference is that the amplitude of the voltage at the point D is smaller due to the voltage drop across the resistor Rsurge. Finally, if the capacitor is leaky the output voltage will appear with increased ripples on the output (Figure 8.13c). A leaky capacitor appears as if there is a leakage resistor, connected to it in parallel. The leakage resistor decreases the time for a discharge, thus the voltage ripples increase at the output.
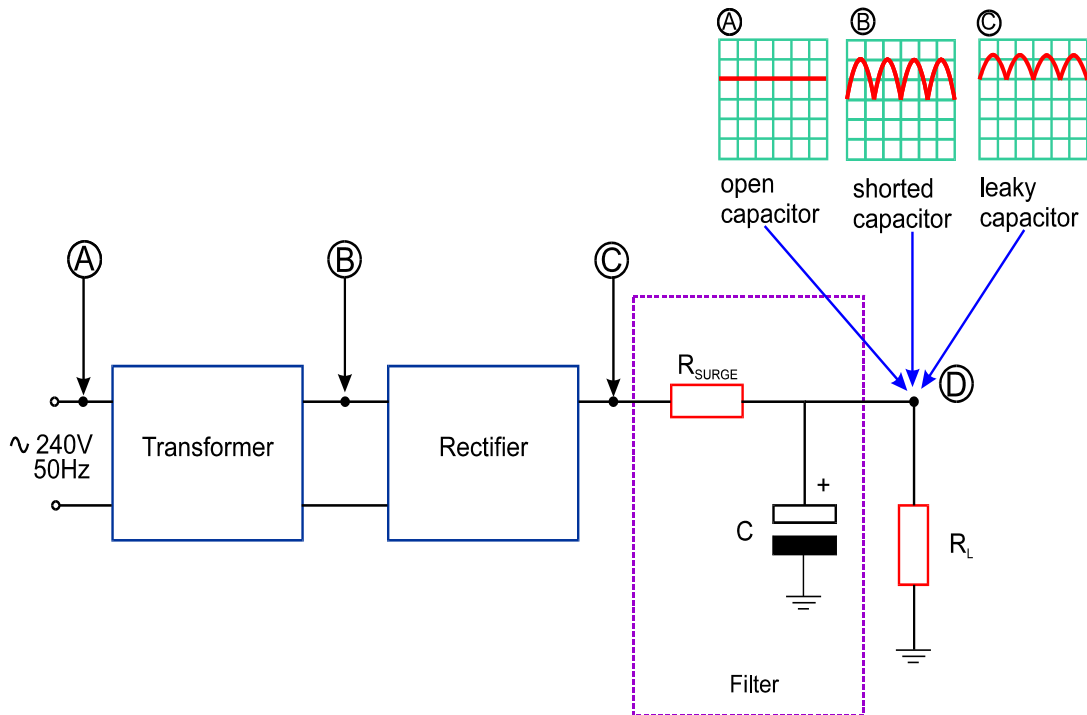

Figure 8.13
Symptoms of a Faulty Capacitor

- **Faulty resistor Rsurge**. There is only one possible faulty condition, namely a blown resistor Rsurge (Rsurge appears as an open circuit). This occurs, when an excessive current flows through it. An excessive current flows through Rsurge if the output terminals are short-circuited or if the capacitor is shorted. In both cases when Rsurge blows, it brakes the circuit and prevents the diodes (which are more expensive than the resistor) from burning too. The output voltage in this case is zero. Before replacing Rsurge make sure that the capacitor or the output terminals of the circuit are not shorted and that the conductive paths of the PCB are not shorted out.

- **Shorted diode**. A shorted diode appears as a jumper between the points of the connection, as it conducts the current in both directions. Figure 8.14 illustrates the current that flows in the circuit, when the diode D_4 is shorted out. During the positive half-period, the current flows through D_3 and D_4 as normal. The shortened diode exhibits zero resistance in both directions and it appears for the circuit as if it is simply forward-biased. Thus, the positive half-period appears as normal at the point C. However, during the negative half-period the picture changes. The current now flows through D_1 and D_4 instead of through the rest of the circuit, because these two diodes, connected in series provide a path of less resistance. Effectively the secondary winding is short-circuited and an

excessive current flows through it. Thus, the diode D_4 can be damaged fairly quickly, due to overheating. The increase in the current in the secondary winding increases the current in the primary winding. If the circuit is properly fused, the fuse on the primary winding should blow. If this is not the case the diode D_1 overheats (and even possibly burns) and the voltage at the test point C has the form shown in Figure 8.14. With some thought you can analyze what happens in the circuit when some other diode shorts out, or when two or more diodes short out simultaneously.
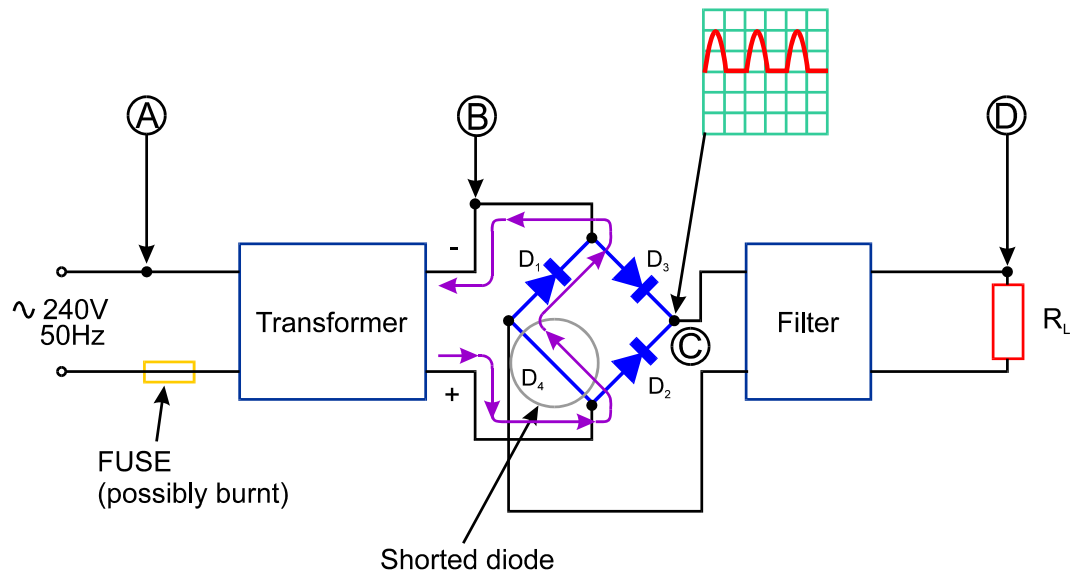

Figure 8.14
Symptoms of a Shortened Diode

- **Open diode**. Let us assume that the same diode (D_4) is open. No current flows through an open diode in both directions. During the negative half-period, this diode appears to the circuit to be reverse-biased, and therefore it has no impact on the output voltage. However, during the positive half-period, the path for the current is broken and no voltage appears at the output. In other words, the circuit works as a half-wave rectifier. This can be detected by the larger ripples in the output voltage. In addition, the frequency of the ripples is 50 Hz, instead of 100 Hz. This is illustrated in Figure 8.15. Similarly, the circuit can be analyzed for other open diodes.
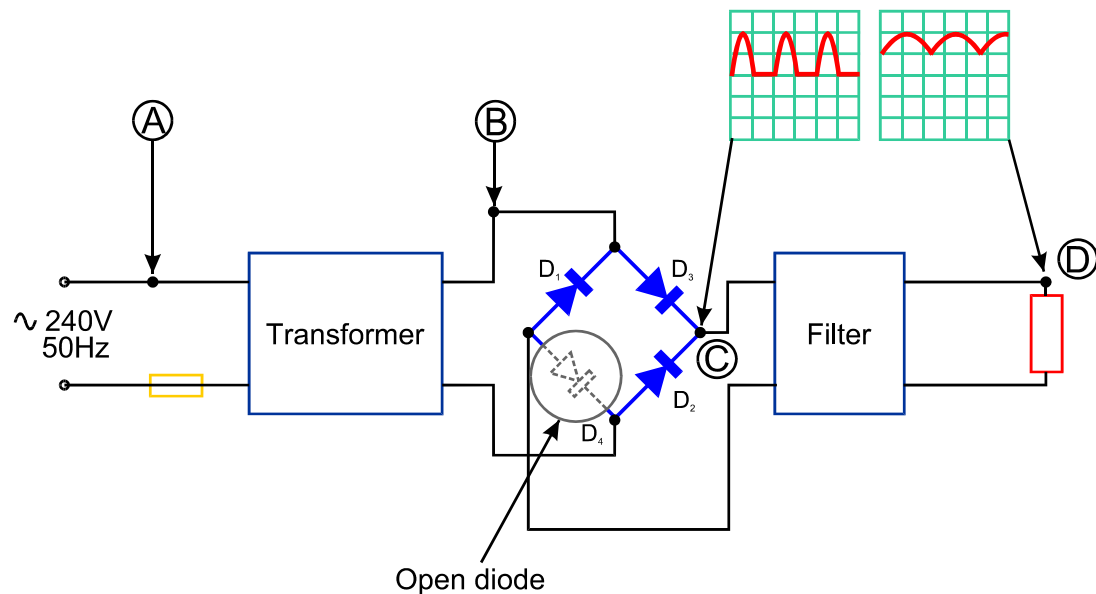
Figure 8.15
Symptoms of an Open Diode

- **Faulty transformer**. This is not a very common fault, though if the rest of the circuit appears in a good working order, the transformer has to be checked. Several faults are possible: the primary or the secondary windings can be open or partially shorted. If one of the windings is open, no voltage is applied to the rest of the circuit. This obviously results in 0 V at the output. If the primary winding is partially shorted, the turns ratio of the transformer is effectively increased. The voltage on the secondary winding is also increased; thus, the level of the voltage at the output of the circuit is higher. A partially shorted secondary winding decreases the turn ratio of the transformer. The voltage supplied to the rectifier is lower; thus, the level of the circuit output voltage is also lower.

- **Blown fuse**. As was mentioned earlier, this occurs when one of the diodes is shorted. Thus, before replacing the fuse, the diodes have to be checked. A partially shorted primary or secondary winding of the transformer can also increase the current to a level, where the fuse blows. Thus, the transformer also has to be tested before replacing the fuse.

- **Power supply**. It sounds trivial, but if the power cord is not plugged in, or the power supply knob is not turned on, the circuit obviously will not function. If you have checked the whole circuit from the output just to find out that this is the case, we recommend that next time you start from the input!

8.2.4 Summary

Troubleshooting of electronic circuits involves three steps, which should be performed in a specific order. The first step is to identify the defect in the circuit. A defective circuit can be defined as one, where the input parameters are correct, but which has incorrect output parameters. The second step includes fault analysis and

determination of the possible causes. Various techniques can be applied here. The most common are: the power supply check, sensory checks (visual, using the sense of touch, smell etc.), component replacement and signal tracing. Component replacement is a very effective troubleshooting technique and works well for experienced electronic technicians. Signal tracing involves measuring the voltage at test points, until a voltage with an incorrect value is found. This is the most desirable technique, as it requires a good knowledge of the theory, and some logical thinking. The third step of the troubleshooting process is fixing the problem. This can be done by component replacement, re-soldering a dry joint and so on.

8.3   Quiz

1. A diode, tested with a DMM, exhibits 1.1 V in one direction and an out-of-range indication ("OL") in the other. Is the diode faulty?
2. A diode, tested with a DMM, exhibits the same value of 1.1 V in both directions. Is the diode faulty?
3. Does it make any difference if the jumper is connected to MT1 or MT2 during the test of a TRIAC?
4. Can you describe how to identify the type of an unknown transistor (pnp or npn) and its terminals (E, B, C), using just an ordinary ohmmeter?
5. The power supply of a one-stage BJT amplifier is 12V. What voltage would you expect to measure at the collector?
6. A single-stage, small-signal amplifier is built using a JFET. The voltage measured at the drain is 0V. What could be the cause of the fault?
7. A single-stage, small-signal amplifier is built using a BJT. Assume that the input signal is a sinusoid with a peak value of 0.5 V and the power supply is 12 V. There is a dry joint on the emitter. What is the form of the output voltage?
8. What are the three steps in the troubleshooting process?
9. What does a defective circuit mean?
10. What is the first thing to be checked in a defective circuit?
11. Which are the most common troubleshooting techniques?
12. What does fault analysis mean?