Analog Signature Analysis Training Manual

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ANALOG SIGNATURE ANALYSIS TRAINING MANUAL

GUIDE TO THE MANUAL

SECTION	CONTENT
1 – ANALOG SIGNATURE ANALYSIS	Introduces the concepts of analog signature analysis and the Polar Instruments T-Series and PFL Fault Locators.
2 – USING THE FAULT LOCATOR	Discusses setting up and operation of the Fault Locator, and the display signatures of open and short circuits.
3 – TESTING RESISTORS	Examines the signatures of resistors on the demonstration board. Discusses single channel and comparison techniques to locate wrong value resistors.
4 – TESTING CAPACITORS	Introduces the capacitor and capacitive reactance and shows how the capacitor produces its characteristic signature. Examines the effect of different voltage and frequency ranges on capacitor signatures. Discusses the significance of leakage current in capacitors and how leakage is displayed by the Fault Locator.
5 – TESTING INDUCTORS	Introduces the concepts of electromagnetic induction and the inductor. Examines inductive signatures at different frequencies.
6 – TESTING DIODES	Examines the semiconductor diode. Discusses forward and reverse bias and uses the Fault Locator to measure zener diode breakdown voltage. Uses comparison techniques to check diodes and discusses some special purpose diodes.
7 – TESTING TRANSISTORS	Discusses the *bipolar junction transistor* and describes its action and how to test and identify unknown devices. Introduces the concepts of three terminal testing using the Fault Locator's Pulse Generator and verifying the switching action of the transistor. Describes how the pulser may be used to test

	field effect transistors.
8 – TESTING SPECIAL DEVICES	Examine the signatures of opto-couplers and four-layer devices, including SCRs and triacs.
9 – TESTING INTEGRATED CIRCUITS	Examine the signatures of some typical analog and digital integrated circuits (ICs).
	Shows that even very complex devices can be effectively tested using comparison techniques.
10 – REPAIRING CIRCUIT BOARDS	Summarises some of the techniques learned and suggests ways to apply analog signature analysis to locate faults likely to be encountered in field repair.
	Suggests a methodical approach to troubleshooting and lists common circuit faults.
11 – ANSWERS TO EXERCISES	

CONTENTS

SECTION 1 – ANALOG SIGNATURE ANALYSIS

Introduction

In this lesson we introduce the concepts of analog signature analysis and the Polar Instruments T-Series and PFL Fault Locators.

We show that signatures are a graphical representation of Ohms' law and briefly discuss how signatures are produced and displayed by the Fault Locator.

Objectives

At the end of this lesson you should:

- Understand what a signature is.
- Understand that a signature displays the impedance of a component.
- Recognise the signature of a pure resistance.
- Understand how the Fault Locator represents impedance on screen.
- Recognise the Fault Locator 4-quadrant display.
- Recognise the signatures of open and short circuits.

About this manual

The purpose of this manual is to introduce the fundamental concepts of Analog Signature Analysis and guide the new user through trouble-shooting faulty circuit modules using Analog Signature Analysis and a Polar Instruments Fault Locator.

This manual is designed to be used in conjunction with the Polar Instruments T-Series Demonstration Board and a Polar Instruments Fault Locator.

Note: The principles described in this manual are applicable to all of Polar Instruments' T-Series and PFL products. For some of the fault finding techniques described in portions of this manual, however, you will need access to a Fault Locator incorporating a Scanner or Pulser.

The manual is arranged as a self-study course designed to reinforce the concepts of Signature Analysis with exercise questions and practical examples.

By working carefully through the manual the student will become familiar with the operation of the Fault Locator and quickly recognise the display patterns of both good and defective components.

The student will find the Polar Instruments Fault Locators powerful and easy to operate working tools which will save many hours of troubleshooting time.

1-1 Why use a Signature Analyser?

In the course of fault finding, technicians may have to use a variety of techniques to locate a problem with a circuit. Many faults, for example, can be found by visual inspection — missing components, reversed ICs, mis-wired cables, etc.

Other faults may be found by resistance meters (e.g. wrong value resistors, open circuit inductors). A resistance meter, however, is unlikely to pinpoint a diode with a soft "knee" characteristic, or a "leaky" input line on a microprocessor.

An oscilloscope can prove a powerful troubleshooting tool but requires the circuit to be powered up and a good working knowledge of the circuit on the technician's part.

Analog Signature Analysis with a Polar Instruments Fault Locator is *always* performed on circuits with no power applied, and the Fault Locator can locate faults even when the trouble-shooter has little knowledge of the circuit operation. Faults such as leaky capacitors, wrong value zener diodes and many microprocessor data bus problems will be quickly found with the Fault Locator.

1-2 Locating faults with Analog Signature Analysis

What is a signature?

Every electrical component displays a characteristic pattern of electrical behaviour which, given appropriate instruments and conditions, can be observed and measured. Behaviour patterns are distinct for different components and can quickly identify the type (and soundness) of a component. For this reason these behaviour patterns are often referred to as *signatures*.

This property of a component to reveal its identity and whether it is functioning correctly through its distinctive signature can be very useful to a technician who is required to analyse circuit behaviour and identify faulty components in a circuit which is malfunctioning, particularly when no documentation is available.

Even when documentation is available, modern electrical circuits often contain many complex integrated circuits (ICs). It is often impossible to anticipate from circuit theory which of dozens of ICs is faulty.

Using signature analysis techniques, technicians may be able to avoid costly and time-consuming fault-finding activities (such as changing many ICs on a hit and miss basis to locate the faulty component).

1-3 Impedance signatures

We know from Ohm's Law that if a potential difference, or voltage, is applied across a conductor, the resultant current will be predictable and will depend on the voltage applied across the conductor and the electrical characteristics of the conductor.

For example, in the case of a pure resistance (R), if we know the applied voltage (V) and can measure the current (I) that flows through that resistance we can easily calculate the value of the resistance.

From Ohm's Law, $R = V/I$

If we draw a graph of current flow in the resistance against a range of applied voltages we find that the relationship between current and voltage is a simple straight line for all values of applied voltage.

Let's arrange the graph so that the voltage applied to the component forms the horizontal (X) axis of the graph and the current flow through the component is plotted in the vertical (Y) direction. The slope of the line (i.e. Voltage/Current) then represents the resistance (R) of the component.

The diagram below (Figure 1-1) represents the graph of resistance of a 1000 Ohm resistor.

It can be seen that at all points on the graph, V/I is equal to 1000.

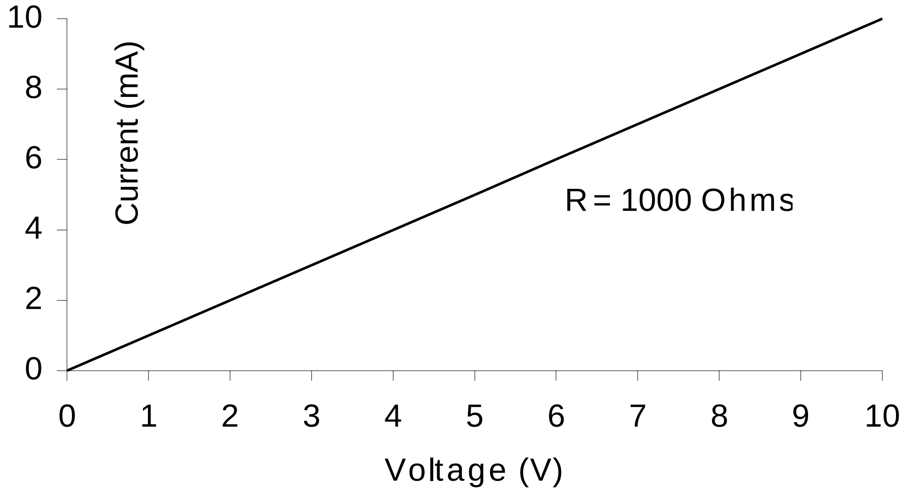


Figure 1-1 Voltage – Current graph for 1000 Ohm resistor

Drawing the graph for a lower value of resistance would have produced a straight line with a steeper slope, since a greater current would flow for the same applied voltage. A higher value of resistance would have produced a line with a shallower slope (since a smaller current would flow).

The graph showed current flowing in one direction (positive) as voltage is increased from 0 to 10V.

If we reverse the polarity of the applied voltage we see that current will now flow in the opposite direction (negative).

We can extend the graph to show voltage across the component applied in both directions – see Figure 1-2.

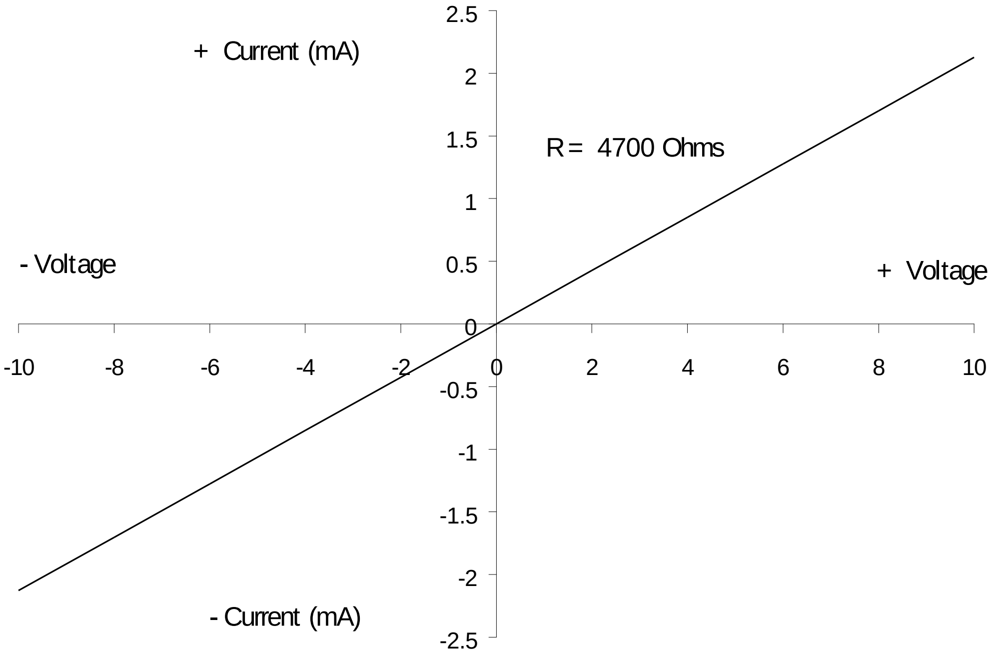


Figure 1-2 Voltage – Current graph for positive and negative voltages

This graph shape represents the resistor's *signature*.

Straight line signatures are characteristic of all pure resistances.

1-4 The T-Series and PFL Fault Locator

The Polar Instruments T-Series and PFL Fault Locators allow the technician to display graphs of component impedance.

Using the Fault Locator we apply an alternating voltage to a component or circuit and display the resulting current on a CRT screen.

In the Fault Locator, the voltage applied across the component is displayed horizontally, the current through the component is displayed vertically, so the resulting V/I graph represents the resistance, or impedance, of the component.

The Fault Locator generates voltages of both polarities, i.e. applies both positive and negative voltages to a component, causing current to flow in both directions. The result is a four quadrant graph (see Figure 1-3).

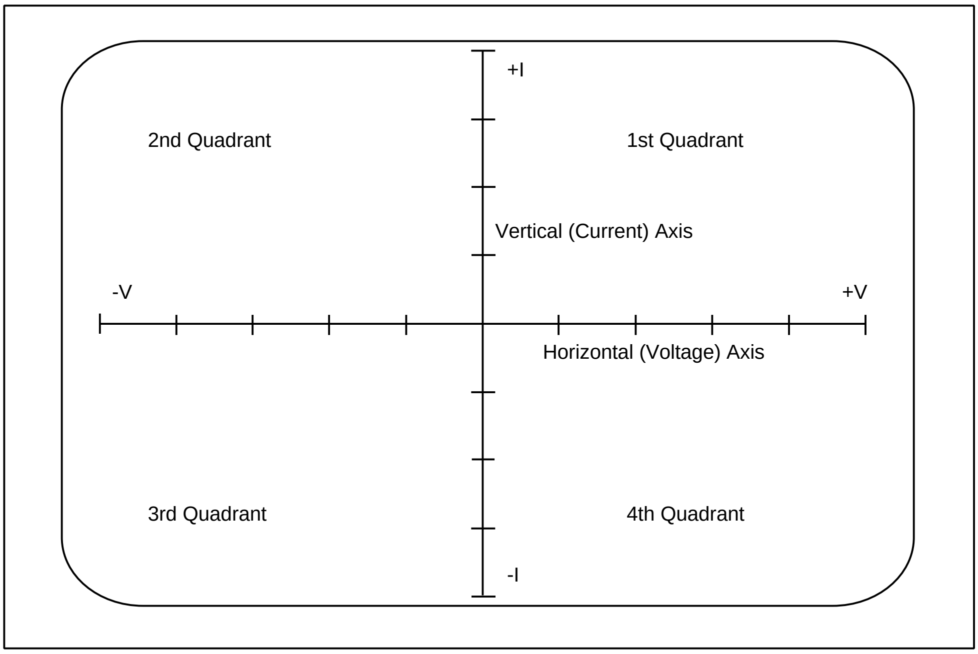


Figure 1-3 The Fault Locator CRT Display

1-5 Four-quadrant signatures

We have seen that impedance signatures are graphs of current against voltage, plotted on a scale which has its origin at the centre of the CRT display screen.

As the voltage applied to the component is driven positive and negative, positive voltages and currents are displayed in the upper right quadrant on the CRT, negative voltages and currents are displayed in the lower left quadrant.

The Fault Locator incorporates several voltage ranges to accommodate different device impedances. The operator selects a range (i.e. a voltage/impedance combination) usually defined by peak voltage (open circuit) and peak current (short circuit).

When fault finding on an electrical circuit, the technician is frequently looking for components that have failed completely. Often, a brief glance at the signature of a suspect device will be sufficient to show whether it is good or defective.

1-6 The Fault Locator equivalent circuit

We saw earlier that the Fault Locator generates an alternating voltage which is applied across the component or circuit to be tested.

As an aid to understanding how a signature is produced by the Fault Locator, we can represent the Fault Locator by a voltage source, V_S, in series with an internal (or source) impedance, Z_S, and the component under test by a simple impedance, Z_L (Figure 1-4).

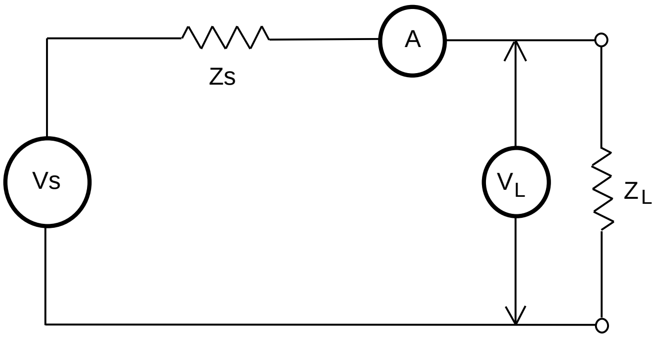


Figure 1-4 Fault Locator equivalent circuit

The Fault Locator contains circuits which measure and display the voltage across, and the current through, the component to be tested. The voltage, V_L, across the impedance, Z_L, will depend on the value of the component under test and controls the horizontal deflection of the display.

Current through the component under test will cause a voltage to be developed across the Fault Locator internal impedance, Z_S. This voltage controls the amount of vertical deflection on the display.

A high value impedance in the component under test (that is, high compared with the value of Z_S) will result in low circuit current (and therefore a low voltage across Z_S) with most of the Fault Locator source voltage, V_S, appearing across Z_L, producing a signature with a shallow slope.

A low value impedance will result in high circuit current and most of the source voltage developed across Z_S; the result is a steeply sloping signature.

Before we begin to use the Fault Locator, try the following exercise.

Exercise 1-1

The diagram (Figure 1-5) shows the signatures of two resistors, measured on the same voltage range, superimposed.

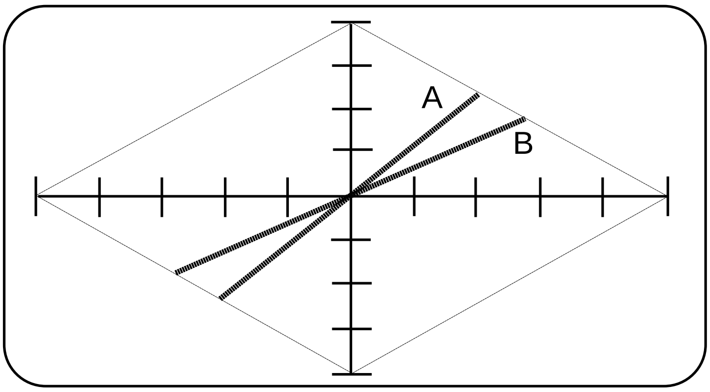


Figure 1-5 Fault Locator CRT display showing two impedance signatures

1. In the diagram above which of the two signatures represents the higher resistance?

2. Explain why you chose this signature.

We will see that, in practice, all signatures are contained within the marked diamond shaped area formed by joining the ends of the marked axes.
3. What slope would you expect to see for:

a. An open circuit?

b. A short circuit?

We can summarise by saying that impedance signatures are graphs of current against voltage, plotted on a scale which has its origin at the centre of the display screen (see Figure 1-6). Positive voltages and currents are displayed in the upper right quadrant on the display. Negative voltages and currents are displayed in the lower left quadrant.

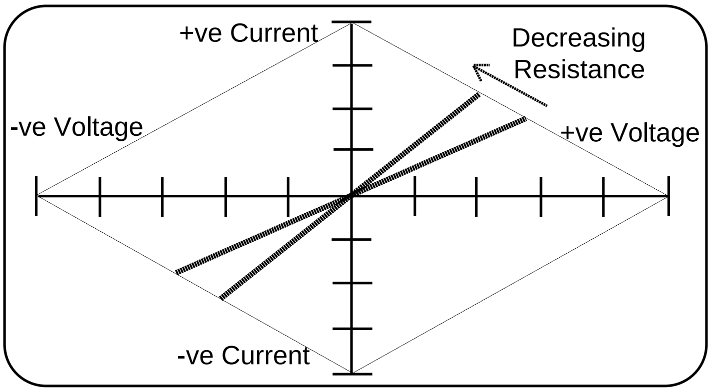


Figure 1-6 Display X and Y Axis

SECTION 2 – USING THE FAULT LOCATOR

Instrument operation

In this lesson we briefly discuss setting up a typical ASA Fault Locator, front panel controls and operation, and display signatures of open and short circuits.

Objectives

At the end of this lesson you should be able to:

? Switch on the Fault Locator.
? Recognise the areas of the front panel.
? Connect test leads to the Fault Locator.
? Display the signatures of open and short circuits

2-1 Signature types

Now that we have some idea of a typical signature we will use the Fault Locator to examine other types of electrical device. Many devices do not exhibit simple straight line characteristics as the applied voltage changes, but display curves or steps as the current changes irregularly, or non-linearly, even though the voltage across the component changes smoothly. We will be examining these component signatures in more detail in later sections.

Signatures for different types of components have distinctly different shapes which can be easily distinguished. The Fault Locator tests components (and circuits) by applying a safe, low power alternating drive voltage across the components and monitoring the resultant current flow to display impedance signatures.

All testing is done with power disconnected from the circuit.

The voltage source is current-limited so there is no risk to the user and components under test cannot be damaged.

Selecting drive voltage and frequency

The signatures of many components are frequency dependent, so the Fault Locator provides a selection of voltages and frequencies to allow users to test a wide range of different devices.

Dual Channel operation

Two channels, A and B, enable the operator to apply voltages simultaneously across a known good component and the suspect component or circuit and compare both signatures directly.

By using comparison techniques, faults in complex circuits can be diagnosed without detailed knowledge of the circuit functions; this facility will be found particularly useful when documentation is not available. The comparison technique will be found appropriate for most testing.

Advanced Fault Locator functions

Fault Locators incorporating an integral Scanner can facilitate testing of integrated circuits. The Scanner is able to rapidly scan and display the signature of each pin of an integrated circuit or multi-pin component.

Fault Locators which include a Pulse Generator enable three-terminal devices such as transistors, SCRs and Triacs to be tested.

We will be using pulse techniques during later sessions.

2-2 Connecting the test cables

Single channel applications

For single channel applications connect the red probe to the Channel A (or Channel B) socket, and the black probe to the COM socket.

Dual channel applications

For applications requiring both channels (e.g. comparison testing — covered later in the course) connect the red probe to Channel A, the black probe to Channel B and a test lead to the COM socket.

2-4 Displaying signatures

The Fault Locator is already displaying a signature — an open circuit!

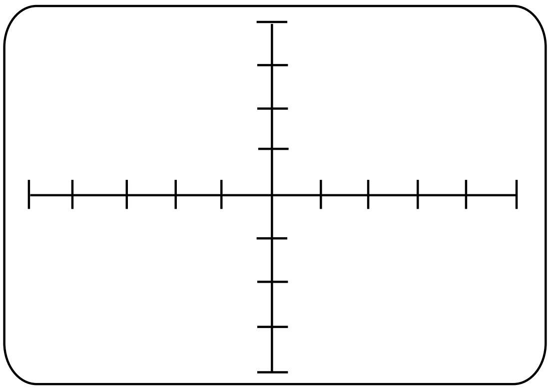
We are applying a voltage across the test leads and no current is flowing. This accords with our earlier discussion of Ohm's law.

Exercise 2-1

Draw the signature in the box below.

1. What will happen to the signature if we touch the points of the two test leads together?

Try and draw the signature before touching the lead tips.



Open/short circuit
Channel A
Voltage = LOW
Frequency = LOW

2. What does this signature imply?

Whilst displaying the new signature, position the signature so that it aligns with the vertical graticule line.

SECTION 3 – TESTING RESISTORS

Resistor Testing Techniques

In this lesson we examine the signatures of resistors on the demonstration board. We observe the effects of using all four voltage ranges on the signature and make simple measurements. We use single channel and comparison techniques to locate wrong value resistors.

Objectives

At the end of this lesson you should be able to:

? Display the signatures of resistors.
? Observe the effect of changing voltage ranges.
? Make approximate resistance measurements.
? Use comparison testing to locate wrong value resistors.

3-1 Resistor testing techniques

We have seen that the signature produced by a pure resistance is an inclined straight line whose slope (gradient) is dependent on the value of resistance.

The Demonstration Board contains two banks of resistors ranging from low to high values, one in the CHANNEL A (GOOD) section and the other in the CHANNEL B (FAULTY) section.

Note: The devices in the CHANNEL B (FAULTY) section are not all defective. They may be of the wrong value or type, or incorrectly fitted.

Exercise 3-1

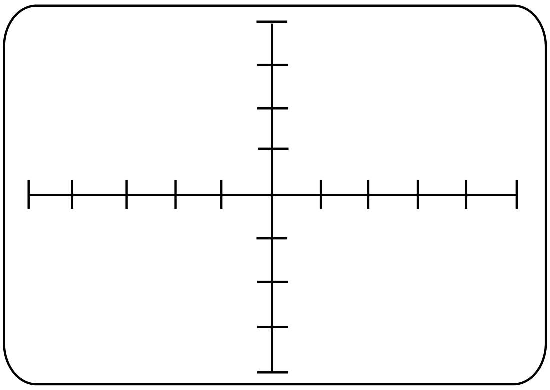
Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW

Connect the leads across the resistor marked 47R.

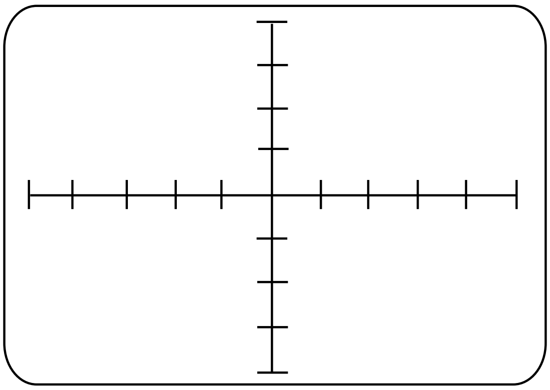
Note the slope of the signature.

Draw the signature in the box below.



47R resistor
Channel A
Voltage = LOW
Frequency = LOW

Connect the leads across the resistor marked 200R.



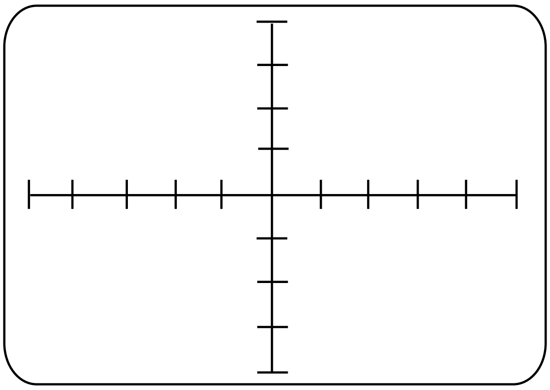
200R resistor
Channel A
Voltage = LOW
Frequency = LOW

Note how the signature has changed.

Connect the leads across the resistor marked 1K0.

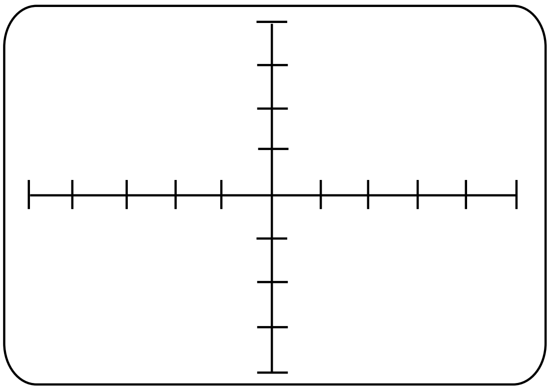
Note the change in slope as the resistors increase in value.

Draw the signature in the box below.



1K0 resistor
Channel A
Voltage = LOW
Frequency = LOW

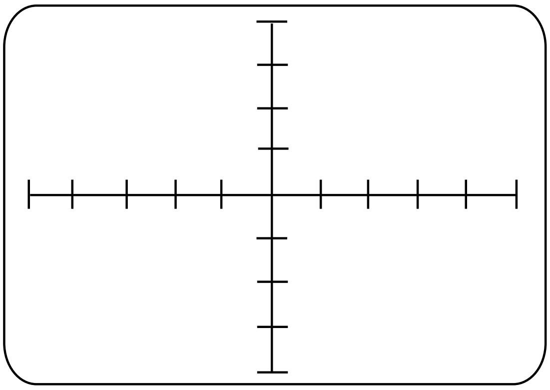
Connect the leads across the resistor marked 2K0.



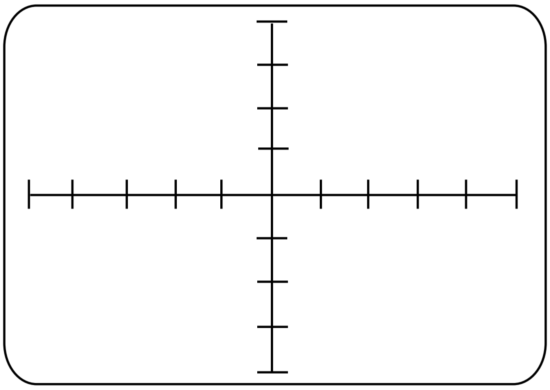
2K0 resistor
Channel A
Voltage = LOW
Frequency = LOW

Repeat the procedure for the corresponding resistors in the CHANNEL B (FAULTY) section.

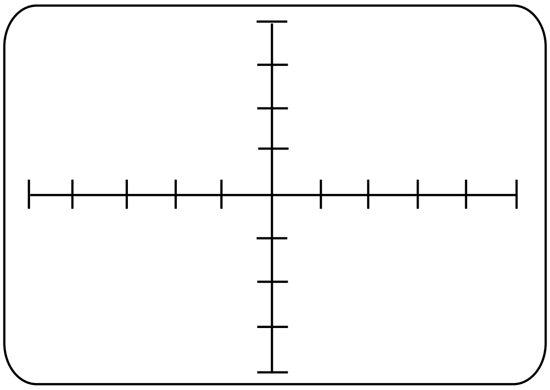
Draw the signature and label the box for each of the four resistors in the CHANNEL B (FAULTY) section.



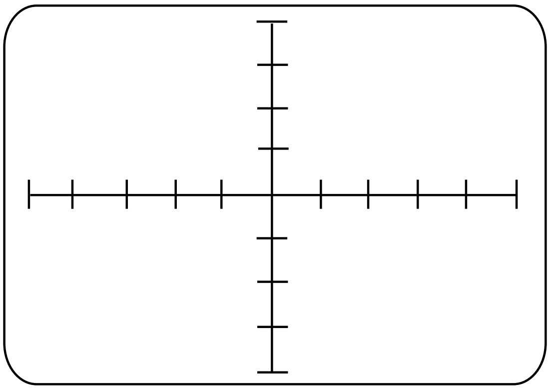
Channel A
Voltage = LOW
Frequency = LOW



Channel A
Voltage = LOW
Frequency = LOW



Channel A
Voltage = LOW
Frequency = LOW



Channel A
Voltage = LOW
Frequency = LOW

1. What did you notice about these four signatures?

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2. What can you say about the resistors in the CHANNEL B (FAULTY) section?

This exercise should illustrate how easy it can be to find what could prove a common yet subtle fault.

3-2 Using the other voltage ranges

You should have noticed that as the resistance increased, the slope of the signature decreased. This is because a high value of resistance will only pass a small current if a low test voltage is applied.

For very high resistance values the resulting signature may not be easily distinguishable from the open circuit horizontal trace.

By selecting a higher voltage range, the Fault Locator screen deflection factors are changed, a higher voltage is applied to the component and a more recognisable sloping signature is displayed.

Table 3-1 lists the suggested range for testing different values of resistor and gives the ranges against approximate resistor values for which signatures can be distinguished from a short circuit (vertical trace) or an open circuit (horizontal trace).

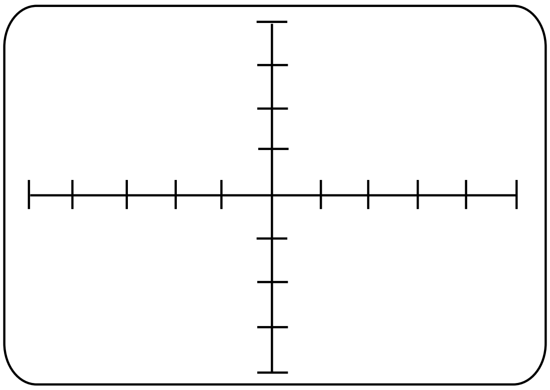
Range	Resistor Value (Ohms)
Junction	1K to 50K
Logic	300R to 6K
Low	16.5R to 300R
Med	5K to 60K
High	12K to 150K

Table 3-1 Resistance Ranges

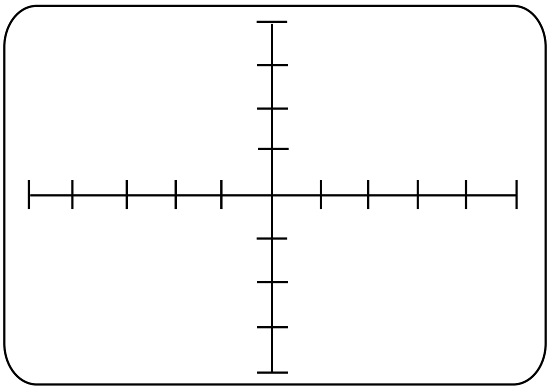
Exercise 3-2

Repeat the previous exercise with the LOGIC voltage range selected.

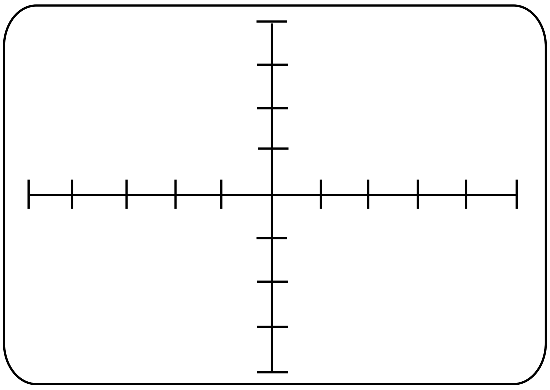
Draw the signatures of the resistors in *both* sections in the boxes below.



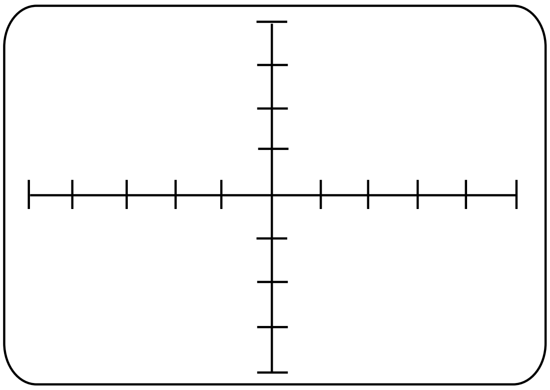
47R resistor
Channel A
Voltage = LOGIC
Frequency = LOW



200R resistor
Channel A
Voltage = LOGIC
Frequency = LOW



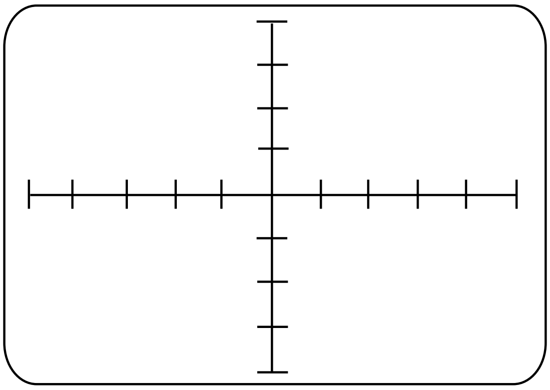
1K0 resistor
Channel A
Voltage = LOGIC
Frequency = LOW



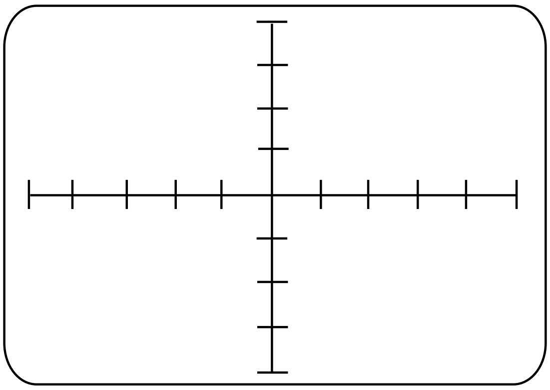
2K0 resistor
Channel A
Voltage = LOGIC
Frequency = LOW

1. Which range (LOW or LOGIC) made it easier to spot the error?

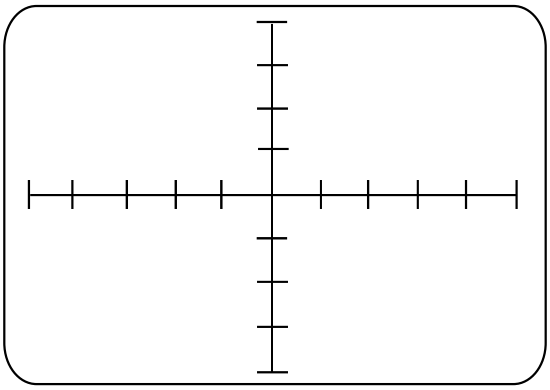
Repeat the previous exercise with the MED voltage range selected.



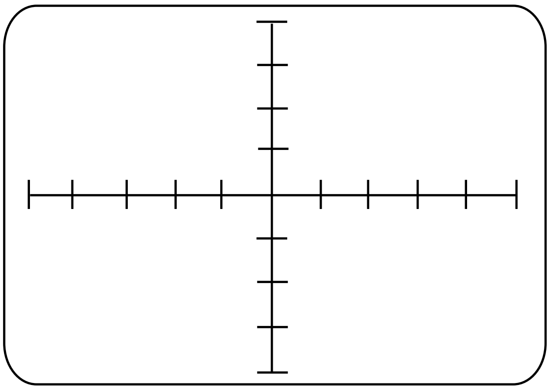
47R resistor
Channel A
Voltage = MED
Frequency = LOW



200R resistor
Channel A
Voltage = MED
Frequency = LOW

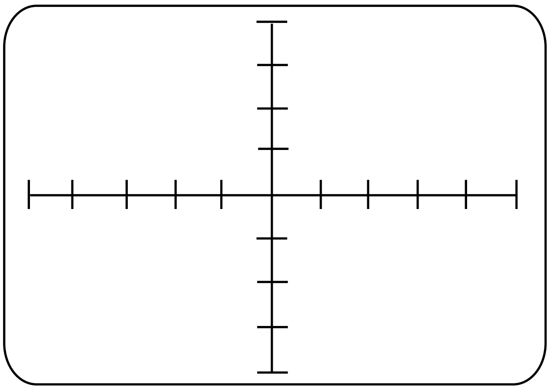


1K0 resistor
Channel A
Voltage = MED
Frequency = LOW

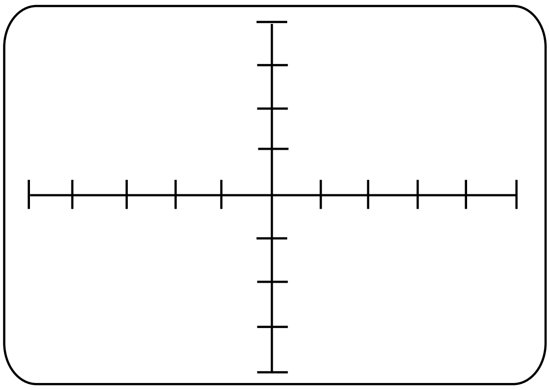


2K0 resistor
Channel A
Voltage = MED
Frequency = LOW

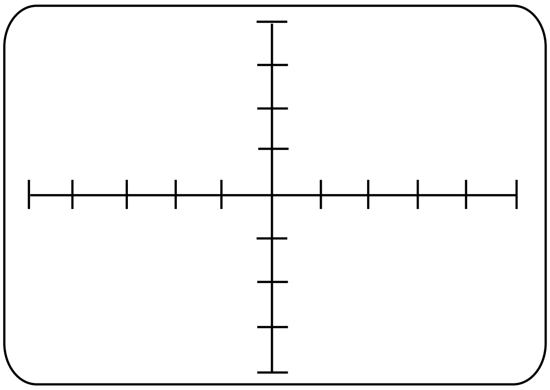
Repeat the previous exercise with the HIGH voltage range selected.



200R resistor
Channel A
Voltage = HIGH
Frequency = LOW



1K0 resistor
Channel A
Voltage = HIGH
Frequency = LOW



2K0 resistor
Channel A
Voltage = HIGH
Frequency = LOW

2. Which of the voltage ranges would you use to check low value resistances?

The exercise should have demonstrated the importance of trying more than one range when fault finding.

In general, when the signature approaches the vertical try a lower range.

Exercise 3-3

1. Check the other resistors for errors using whichever range you find appropriate. List the errors (if any) below.

3-3 Comparison testing

So far, we have performed device testing on devices whose signatures we could have predicted. In many cases, however, we won't know if the signature we see is correct.

The Fault Locator is designed to test components in circuit, so current from the Fault Locator will flow in components connected to the device under test as well as the device itself. The result may well be signatures quite different from those of the device in isolation.

Technicians will often encounter circuits with similar devices from different manufacturers. These will frequently show subtle differences between signatures; this can make it difficult to decide if devices are faulty.

To help us make decisions on suspect signatures, the Fault Locator includes a second channel so that two signatures can be compared *simultaneously.*

If a known good circuit or device is available, the signatures of both the good and suspect components can be displayed and compared directly.

The demonstration board simulates this situation with devices in two sections, labelled CHANNEL A (GOOD) and CHANNEL B (FAULTY), joined by a common earth connection.

We'll repeat some of the earlier tests using *both* channels of the Fault Locator.

Exercise 3-5

Set the instrument to the following settings:

Channel A & B
Voltage range = LOW
Frequency range = LOW

Connect a red probe to the input socket of Channel A.

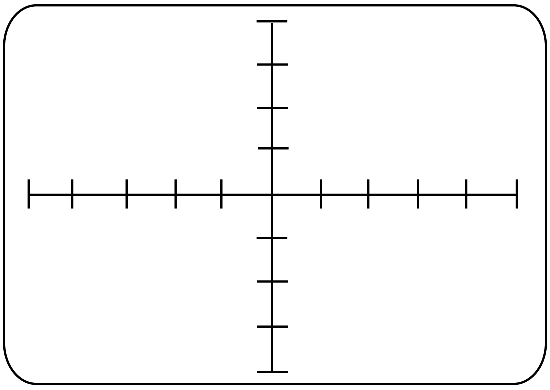
Connect a black probe to the input socket of Channel B.

Connect a test lead to the COM socket .

Connect the test lead clip to an earth point on the demonstration board.

Attach a probe to each of the unearthed ends of the 47R resistors in the GOOD and FAULTY sections.

Draw the screen display in the box below.

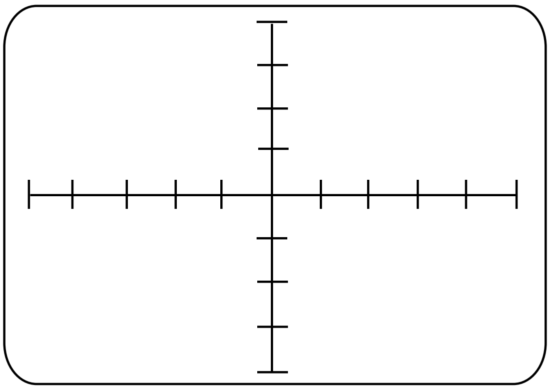


47R resistors
Channel A & B
Voltage = LOW
Frequency = LOW

You should see *two* identical signatures on screen.

Use the position controls to adjust the signatures for convenient viewing.

Move the probes to the next pair of resistors (200R).

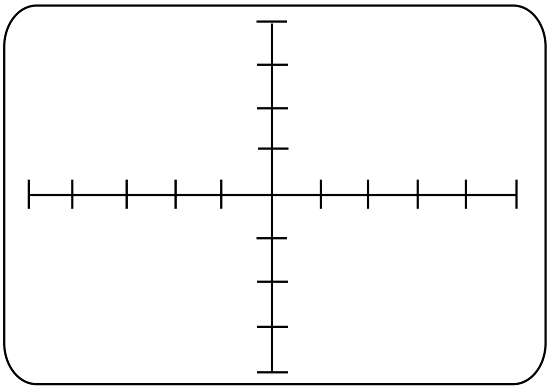


200R resistors
Channel A & B
Voltage = LOW
Frequency = LOW

Draw the screen display.

Move the probes to the next pair of resistors (1K0).

Draw the screen display.



1K0 resistors
Channel A & B
Voltage = LOW
Frequency = LOW

1. How did the displays differ?

You should have noticed how much easier it was to detect the wrong components using *comparison testing*.

Continue the exercise with the other resistors, selecting the higher voltage ranges as necessary.

3-4 Summary

Every electrical component displays a characteristic pattern of electrical behaviour.

Behaviour patterns are distinct for different components and can quickly identify the type (and soundness) of a component.

The Fault Locator displays the electrical response of a component or circuit by applying an alternating voltage to the component and displaying the resulting current/voltage response on a CRT.

This response is the component's *impedance signature*.

The usefulness of the Fault Locator stems from its ability to test devices *without removing the device from the circuit*.

The Fault Locator allows the operator to make approximate measurements of resistance.

The Fault Locator incorporates two identical channels to enable *comparison testing* of good and suspect devices.

SECTION 4 – TESTING CAPACITORS

Capacitor Testing Techniques

This lesson introduces the capacitor and capacitive reactance and shows how the capacitor produces its characteristic signature. We examine the effect of using the different voltage and frequency ranges on capacitor signatures. We also discuss the significance of leakage current in capacitors and see how leakage is displayed by the Fault Locator.

Objectives

At the end of this lesson you should be able to:

- Recognise capacitor signatures
- Explain why the Fault Locator produces the characteristic ellipse when testing capacitors
- Explain the effects of using different voltage and frequency ranges when examining capacitor signatures
- Recognise the presence of leakage in a capacitor

4-1 Capacitor signatures

In this section we apply the techniques we learned in the previous lesson to examine the signatures of capacitors.

We'll start by examining a capacitor signature, then discuss how and why it differs from the signatures of resistive components.

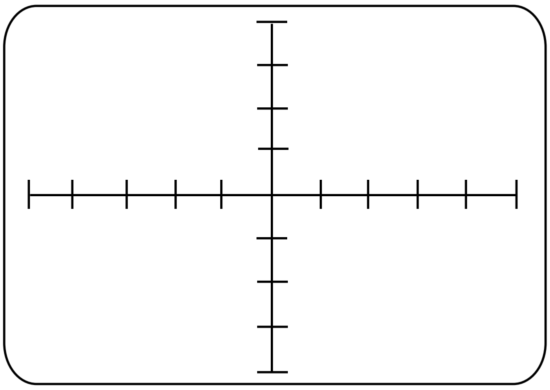
Exercise 4-1

Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW

Connect the test leads across the 10µF capacitor in the CHANNEL A (GOOD) section of the demonstration board.

Draw the signature you see



10µF capacitor
Channel A
Voltage = LOW
Frequency = LOW

Note the shape of the signature.

1. How does the signature differ from the signatures of resistive components?

You should have observed an ellipse on the screen.

The phase relationship between voltage and current

We described earlier how the Fault Locator produces a signature by applying a varying voltage across the component under test and displaying the current flow through the component.

We saw that as the voltage across resistive components was increased and decreased there was a corresponding simultaneous increase and decrease in the current.

In resistors the voltage and current move in the same direction, peak together and cross zero together. Where voltages and currents vary exactly in time with each other they are said to be *in phase*.

Pure resistors limit, and therefore control, the quantity of current in a circuit but do not alter the phase relationship between voltage and current.

In a resistor the current flowing depends directly on the applied voltage, so that we can predict the current from the linear equation $I = V/R$.

This linear relationship between voltage and current results in the straight line graphs we have already seen.

(Recall that the Fault Locator displays graphs of voltage and current *against each other*.)

In capacitors (as in other non-resistive components) voltage and current *do not rise and fall simultaneously*. When this is the case voltage and current are said to be *out of phase*.

In this section we will discuss the behaviour of voltage and current in capacitors, then study capacitive signatures using different voltage ranges and examine the effect of using different frequencies.

4-2 What is a capacitor?

Unlike a resistor, a capacitor is not a simple conductor but consists essentially of two closely placed metal plates that do not physically touch but are separated by an insulator.

The capacitor stores an electrical charge between its plates. This has the effect of *opposing any changes* in the voltage across the capacitor.

The charge–discharge cycle

Recall that the Fault Locator displays signatures by applying an alternating voltage across a component.

On each cycle, the voltage rises from zero to its maximum positive value, falls through zero to its maximum negative value, then rises back to zero.

If the alternating voltage is applied across a capacitor, a current (the charging current) flows rapidly to build up a charge on the capacitor which will equal the maximum applied voltage.

As the charge approaches the voltage maximum, the charging current decreases until the potential difference across the plates equals the applied voltage; at this point (the point of maximum voltage across the capacitor) the capacitor is said to be *charged* and the charging current has decreased to zero.

Figures 4-1 to 4-4 illustrate the charging and discharging current through a capacitor as an alternating voltage is applied across it.

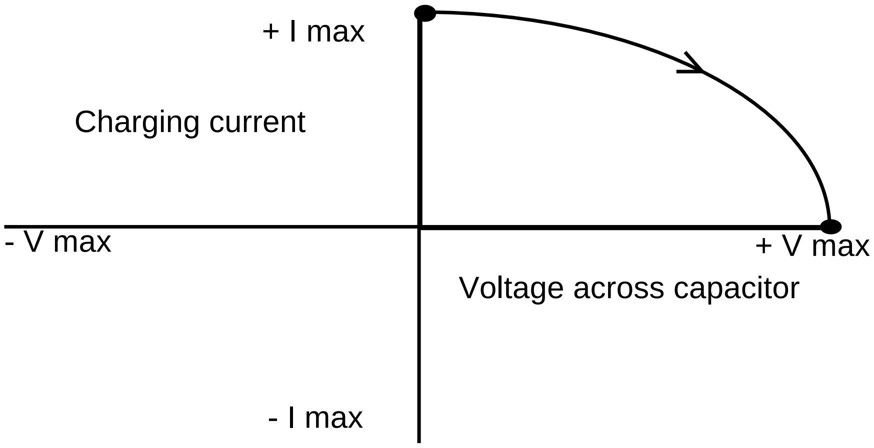


Figure 4-1

From the diagram above we can see that maximum charging current flows when the voltage across the capacitor is zero. When the capacitor has charged to its maximum voltage, the charging current has reached zero.

As the applied voltage falls, the charge on the capacitor decreases, the result is a reversed (discharging) current which reaches a maximum negative value as the applied voltage passes through zero.

See Figure 4-2

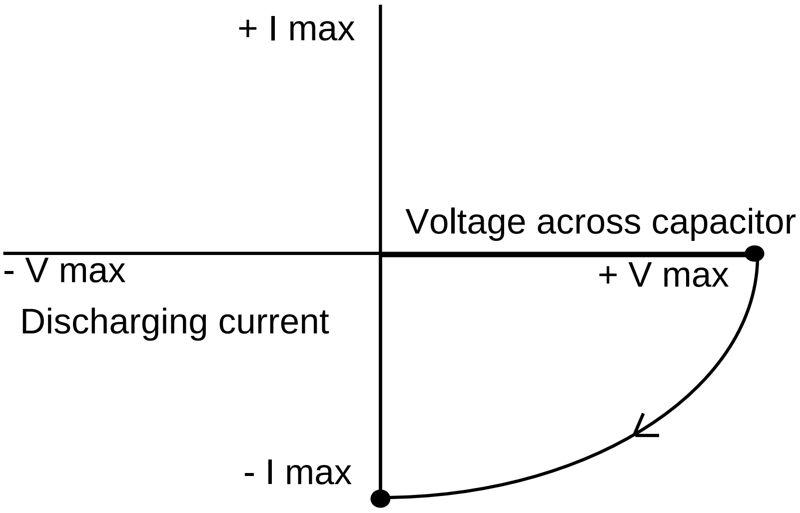


Figure 4-2

As the applied voltage continues to its maximum negative value the discharging current decreases to zero as the charge on the plates approaches the applied voltage — Figure 4-3.

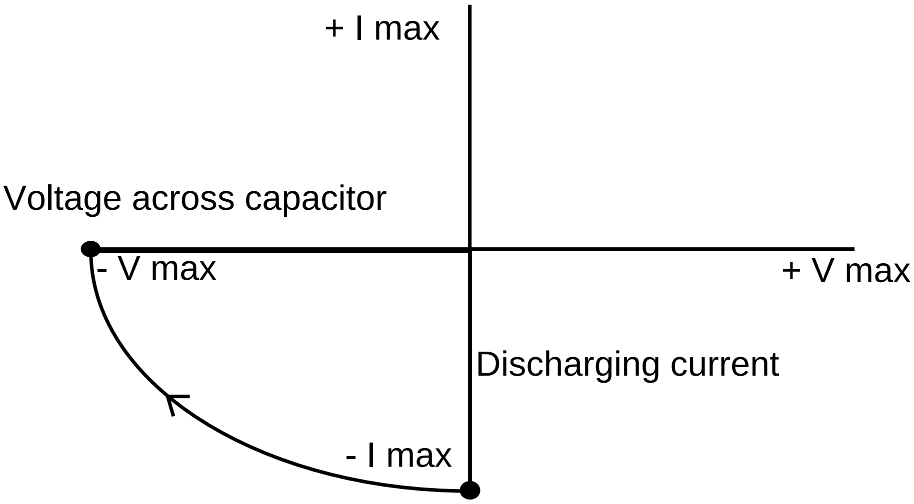


Figure 4-3

As the applied voltage returns to zero (to begin the next cycle) charging current again flows, reaching a maximum just as the applied voltage passes through zero — Figure 4-4.

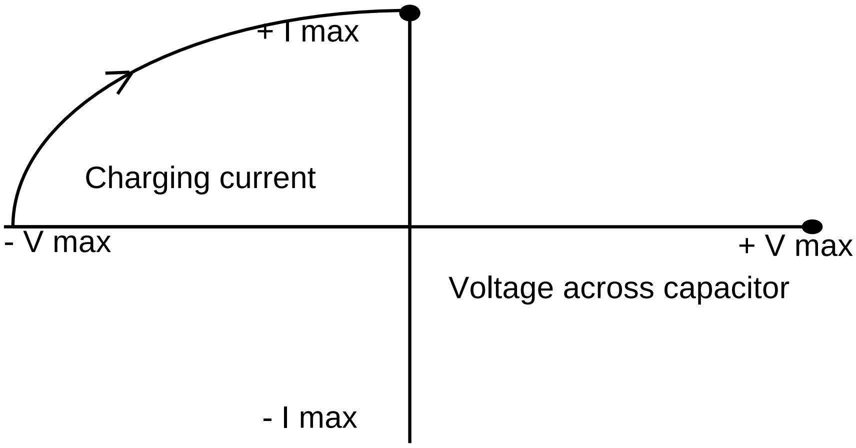


Figure 4-4

The resulting Voltage–Current graph for a continuously alternating applied voltage is thus an ellipse — Figure 4-5

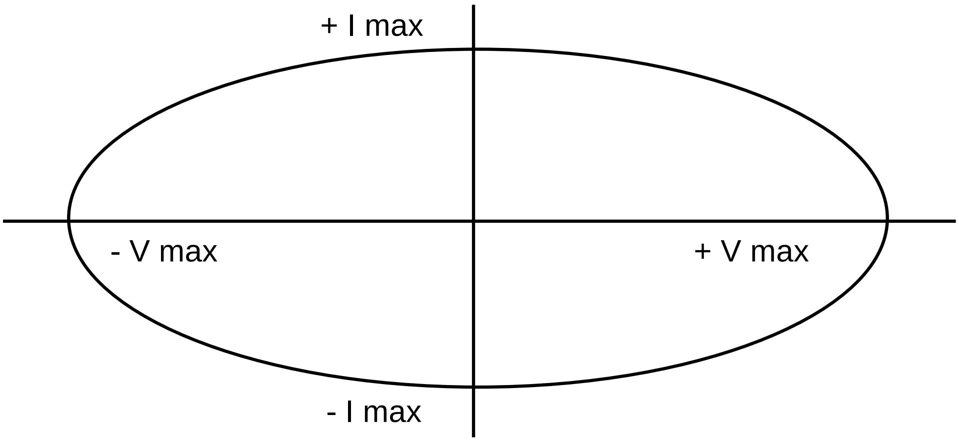


Figure 4-5

We can see from the diagram that although current depends on the applied voltage, when voltage is at a maximum current is at its minimum; when the voltage passes through zero the current is at its maximum. The result is that in a capacitor voltage and current do not rise and fall together. The magnitude of the current determines how "open" the ellipse will be. For a pure capacitance the ellipse is aligned with the display axes.

4-3 Capacitive reactance

To understand the signatures displayed by capacitors we need to recall that the Fault Locator displays the resistance, or impedance, of the device under test.

In circuit a capacitor impedes the flow of current. This impedance is known as *capacitive reactance*.

Capacitive reactance (X_C) is measured in ohms and depends on two quantities:

the value of the capacitor
the frequency of the applied voltage

Mathematically we express it as

$$X_C = 1/2\pi fC$$

where f is the frequency in Hertz of the applied voltage and C is the value of the capacitance in Farads.

From the expression for reactance we can see that if either the capacitance or frequency increases, the reactance will decrease, so for a given applied voltage circuit current will increase.

An increase in current will have the effect of giving the ellipse a taller shape.

Exercise 4-2

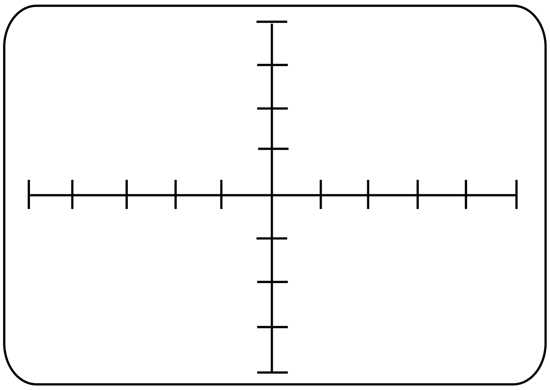
Let's study the effect of increasing circuit current on the capacitors in the good and bad sections of the demonstration board, first by increasing the frequency of the voltage applied to the capacitor and then by switching to the higher voltage ranges.

Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW

Connect the test leads across the 10µF capacitor in the CHANNEL A (GOOD) section.

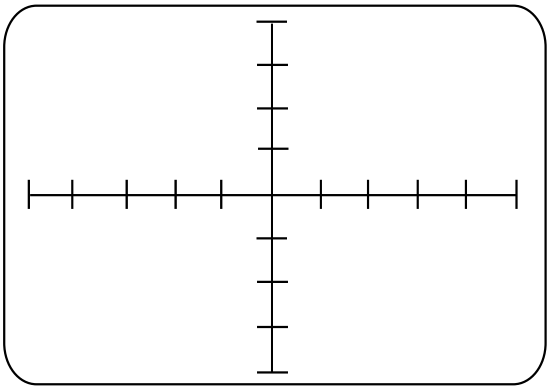
Draw the signature displayed.



10µF capacitor
Channel A
Voltage = LOW
Frequency = LOW

Repeat the test on the capacitor in the CHANNEL B (FAULTY) section.

Draw the new signature.



? capacitor
Channel A
Voltage = LOW
Frequency = LOW

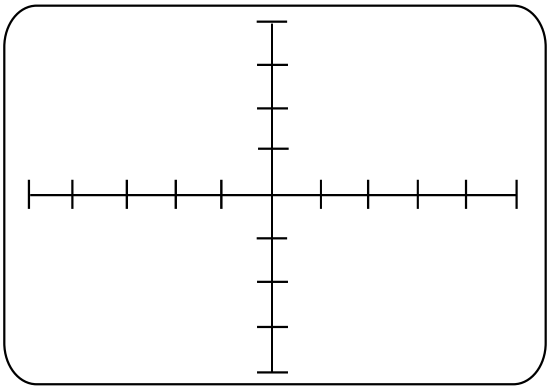
1. Describe the difference between the signatures.

2. What has happened to the maximum current that flows?

3. Can you explain why the signatures differ in the way they do?

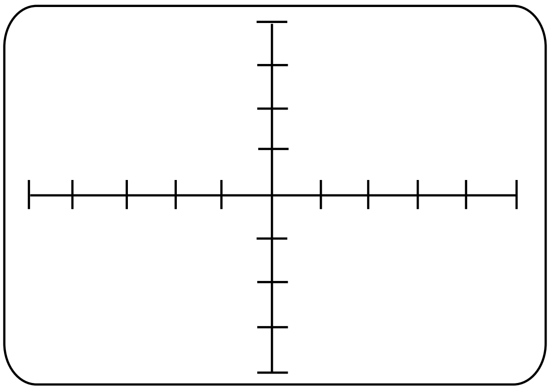
Reconnect the test leads across the 10µF capacitor.

Now switch to the MED frequency range and draw the new signature.



10µF capacitor
Channel A
Voltage = LOW
Frequency = MED

Repeat the test at the HIGH frequency range and draw the signature.



10µF capacitor
Channel A
Voltage = LOW
Frequency = HIGH

4. Describe the difference in the two signatures.

5. What happens to capacitive signatures as the frequency is increased?

6. From the signatures, what can you deduce about the change of capacitive reactance with frequency?

4-4 Changing the voltage range

In this exercise we observe the effect of changing the voltage range on a capacitor signature.

Exercise 4-3

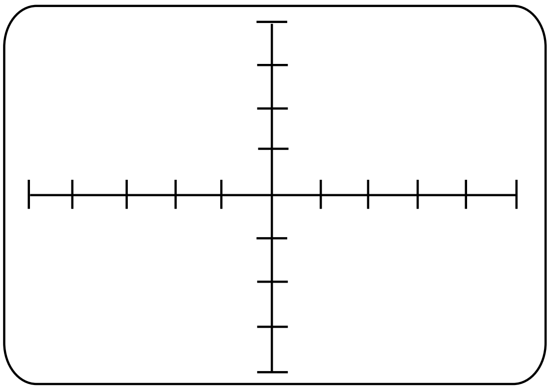
Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW

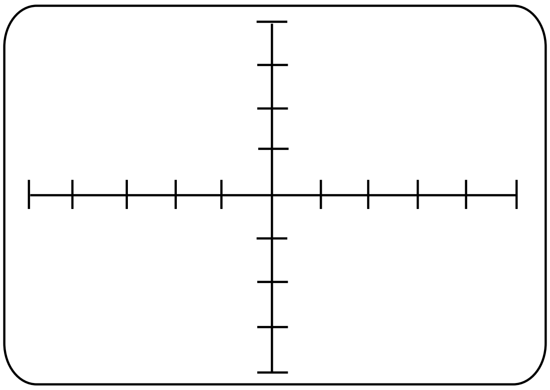
Connect the test leads across the 10µF electrolytic in the CHANNEL A (GOOD) section.

In this exercise we will display the device signatures at the LOW, LOGIC, MED and HIGH voltage ranges.

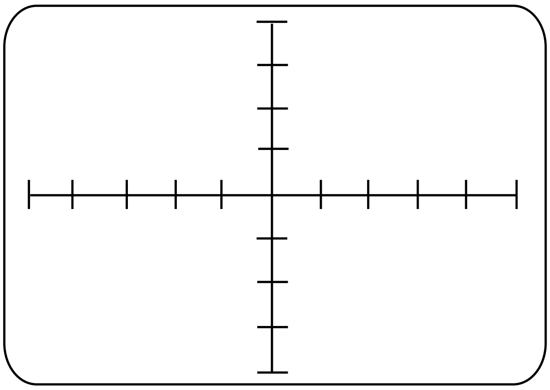
Draw the signatures displayed by all four voltage ranges.



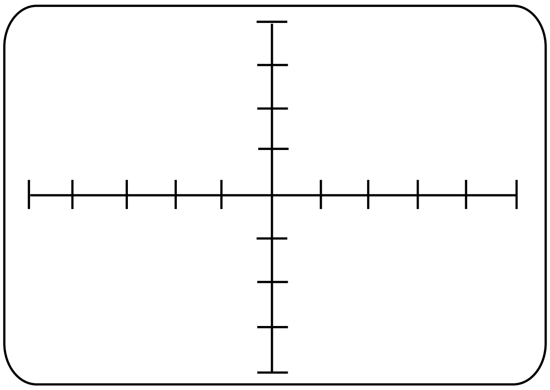
10µF capacitor
Channel A
Voltage = LOW
Frequency = LOW



10µF capacitor
Channel A
Voltage = LOGIC
Frequency = LOW



10µF capacitor
Channel A
Voltage = MED
Frequency = LOW



10µF capacitor
Channel A
Voltage = HIGH
Frequency = LOW

You will have noticed that at the higher voltage ranges the signatures look very similar to a short circuit.

As a general rule, start testing components using the LOW frequency and LOW voltage ranges.

Using the higher voltage ranges

If we consider the expression for capacitive reactance, X_C = 1/2?fC, we can see that very small values of capacitance produce high values of reactance, so circuit current will be small at the frequencies used by the Fault Locator.

At the lower voltage ranges the signature may well approximate to an horizontal line. The higher voltage ranges will cause greater vertical deflection and make subtle differences in signatures easier to detect.

For very small values of capacitance use the HIGH voltage range.

Table 4-1 shows the range of capacitors covered by each combination of frequency and drive voltage.

Frequency

Range	Low	Med	High
LOGIC	300nF – 6uF	56nF – 1uF	15nF – 300nF
LOW	6uF – 100uF	1uF – 20uF	300nF – 5uF
MED	30nF – 300nF	5nF – 68nF	1.5nF – 15nF
HIGH	10nF – 150nF	2nF – 30nF	500pF – 7nF

Table 4-1

4-5 Leakage current in capacitors.

So far, we have assumed that capacitors are pure capacitances with no losses. A perfect capacitor would hold its charge forever.

In practice, however, a charged capacitor will lose its charge over time because the insulator separating the plates of a charged capacitor will conduct a small amount of discharge current, called *leakage current.*

The result is that a real capacitor will behave as if it were a perfect capacitor with a resistor connected between its plates. Leakage currents represent a power loss in capacitors and, if large enough, lead to problems in a circuit.

The amount of leakage current that is acceptable will depend on the circuit, but should normally be very much smaller than capacitive current. Leakage current is greatest in electrolytic capacitors because of their construction and impurities in the insulating material.

Total current is thus made up of capacitive current and leakage current, and we can consider a real capacitor as consisting of a pure capacitance in parallel with a high value resistor.

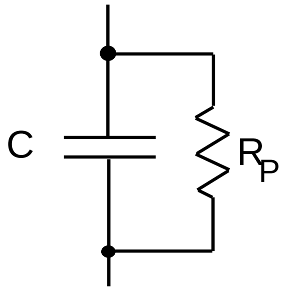


Figure 4-6 Equivalent circuit of a capacitor

Figure 4-6 illustrates the equivalent circuit of a "real" capacitor, comprised of capacitance C and parallel resistance R_P.

In a good capacitor the value of R_P will be high, so leakage current will be negligibly small (R_P is effectively open circuit).

As we have seen, a good capacitor will display an elliptical signature (Figure 4-7). Note that the major and minor axes of the ellipse align with the vertical and horizontal graticule lines.

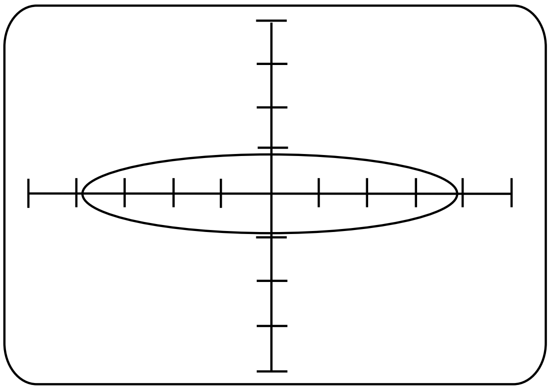


Figure 4-7 Signature of a good capacitor

To understand the effect of leakage in a capacitor, consider the equivalent circuit, Figure 4-6. The Fault Locator causes current to flow through both the capacitance and the parallel resistance. The resulting signature will be the sum of the resistive and capacitive components — Figure 4-8.

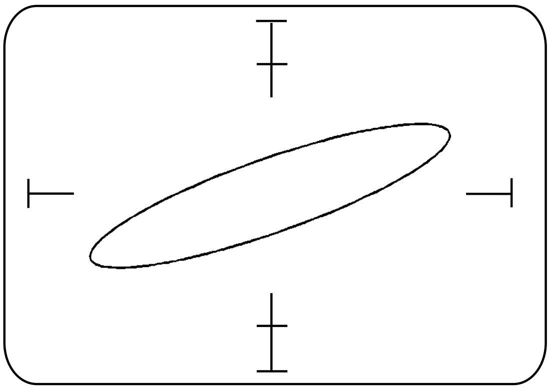


Figure 4-8 Signature of a "leaky" capacitor

Note the slight tilt in the ellipse. This is due to resistive current in the capacitor and indicates a faulty capacitor.

In general, if the leakage current in a capacitor is significant compared with the capacitive current, the elliptical signature will be tilted.

4-6 Other capacitor faults

Some types of capacitor are prone to short circuits between the plates, particularly polystyrene capacitors which may have been subjected to excessive heat during assembly or repair. The insulation in these components can easily melt at normal soldering temperatures, bringing the plates into physical contact.

Capacitors in parallel

In many applications capacitors are connected in parallel, with small capacitors connected across large electrolytics. In such cases it will probably be necessary to disconnect one of the capacitors from the circuit and test the capacitors separately.

1. What signature would you expect to see while testing a capacitor with shorted plates?

SECTION 5 – TESTING INDUCTORS

Inductor Testing Techniques

In this lesson we introduce the concepts of electromagnetic induction and the inductor.

We examine inductive signatures at different frequencies by testing a mains transformer with open and short circuited secondaries.

Objectives

At the end of this lesson you should:

? Have a basic understanding of electromagnetic induction.
? Understand the term "inductive reactance".
? Know how to use the Fault Locator to test inductors and transformers.
? Appreciate that the load on a transformer secondary winding can affect the signature seen on the primary.

5-1 Inductors

Inductors are essentially coils of insulated wire wrapped around a cylinder (the core) which may be hollow (hollow cores are sometimes known as air cores) or solid and made of some type of iron.

The demonstration board contains a widely used inductive device which we will use to examine inductive signatures — a small circuit board mounted mains transformer.

An inductor has magnetic properties, so let's take a moment to briefly review some of the concepts of electromagnetic induction

`5-2 Electromagnetic induction

As we consider the signatures of inductors, we recall that inductance is the result of two properties of electro-magnetism:

> A voltage is induced in a conductor which is in a changing magnetic field. The magnitude of this voltage depends on the rate at which the magnetic field changes.
>
> Current flowing in a conductor produces a magnetic field — the greater the current, the stronger the magnetic field.

Assume an alternating current is passing an through a length of wire.

As the current is *increasing*, the resulting increasing magnetic field cuts through the conductor and induces a voltage that *opposes* the voltage producing the initial current. So the induced voltage produces a current in a direction *opposite* to the initial current; this current opposes the change in the initial current.

As the current is *decreasing*, the induced voltage is of a polarity which will *oppose the decrease* of the initial current, i.e. keep the current flowing.

Inductive action, then, in the circuit opposes any change in current, tending to hold current steady. This is analogous to the physical property of inertia.

Inductance of a coil

If the length of wire is now wound into a coil, the magnetic lines of flux cut through the wire producing the magnetic field *and* adjacent turns of the coil, multiplying the inductive action. The number of turns (along with other factors including the cross section area of the coil, coil length and core material) determines the inductance value of the coil.

5-3 Inductive reactance

The opposition to the flow of current in a coil is called *inductive reactance* and is dependent on the inductance value of the coil and the frequency of the applied voltage, not the "ohmic" resistance of the coil.

So the magnitude of the current flowing depends on:

- The inductance of the coil
- The frequency of the applied voltage

Mathematically stated, I = V/2?fL

where f is the frequency of the applied voltage and L is the value of the inductance in henrys.

The expression 2?fL represents the reactance of the inductor.

From the expression we can see that reactance rises with frequency and inductance, so current will fall with rising frequency or inductance.

Voltage and current in inductors

Compare the action of the inductor with the actions of resistors and capacitors.

When a voltage is applied to a resistor, the full value of current flows immediately and continues as long as the voltage is applied.

In a capacitor, maximum current flows the instant a voltage is applied, reducing as the voltage on the plates approaches the applied voltage.

In an inductor, the induced voltage opposes any sudden increase in current so current builds up slowly towards a maximum value.

So capacitors oppose changes in *voltage*, inductors oppose changes in *current*.

The result of inductive action is that, as in capacitors, the voltage and current do not increase and decrease simultaneously. This is reflected in their signatures.

Signatures of inductors

Inductors exhibit time delay between voltage and current in a manner similar to capacitors, and similarly display elliptical signatures, but there are significant differences.

Inductors are not simple inductances but are a combination of inductance and resistance.

Because they are coils of wire, they are able to pass current directly so at low frequencies appear as very low value resistances.

At high frequencies, reactance increases compared with the resistance, so the signature looks more inductive than resistive, taking on a more elliptical shape.

However, the signature can be difficult to predict (for example, inductors with iron cores can "saturate") and signatures can show considerable distortion.

For this reason, the best technique for testing inductors is the comparison technique described earlier.

5-4 Testing a power supply circuit

The demonstration board includes a simple power supply comprising a mains transformer, rectifier diodes and smoothing capacitor.

We will examine the signature of the transformer primary and simulate open and short circuit diode conditions on the secondary

Exercise 5-1

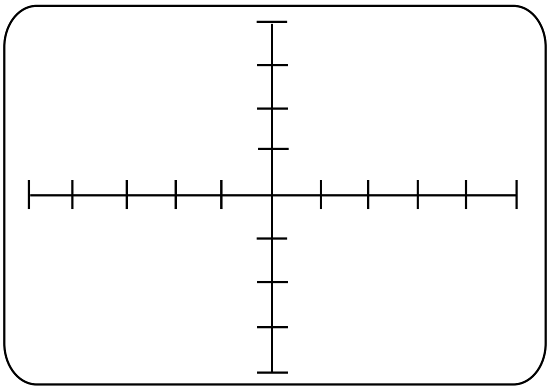
Set the two switches in the power supply section of the demonstration board to the NORMAL position.

Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW

Connect the test leads across the primary test points.

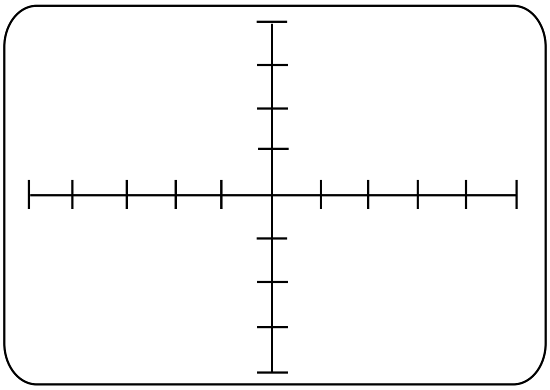
Draw the signature.



Mains transformer primary
winding
Channel A
Voltage = LOW
Frequency = LOW

Switch to the MED voltage range.

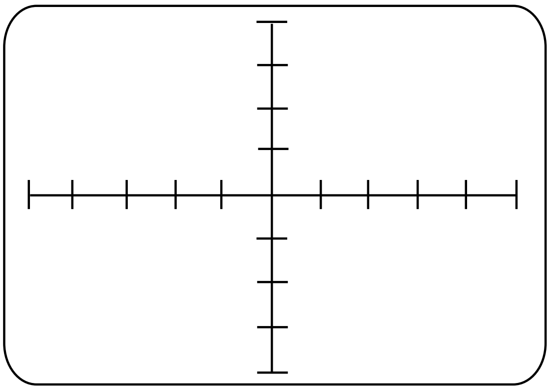
Draw the signature



Mains transformer primary
winding
Channel A
Voltage = MED
Frequency = LOW

Switch to the HIGH voltage range.

Draw the signature.



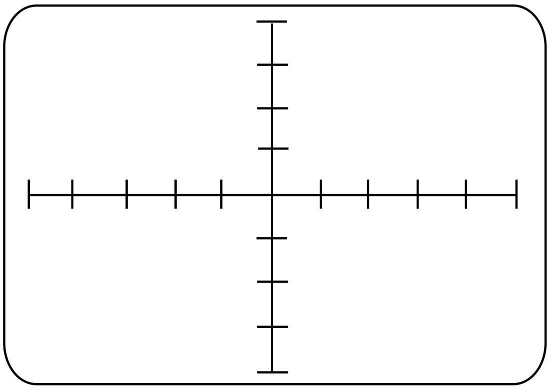
Mains transformer primary winding
Channel A
Voltage = HIGH
Frequency = LOW

Briefly describe the signature.

Leave the Fault Locator on the HIGH voltage range.

Switch the OPEN DIODE–NORMAL switch to the OPEN DIODE position.

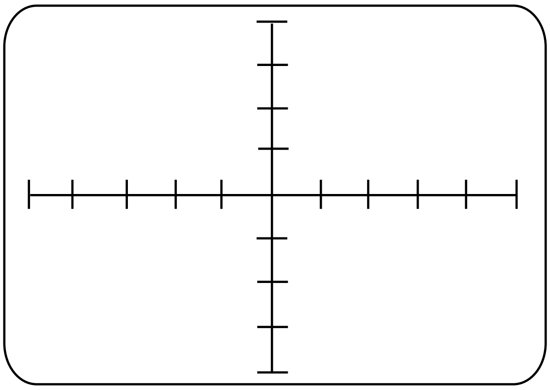
Draw the signature.



Mains transformer primary winding — open diode on secondary
Channel A
Voltage = LOW
Frequency = LOW

Switch the SHORTED DIODE–NORMAL to its SHORTED DIODE position.

Draw the signature.



Mains transformer primary
winding — shorted diode
on secondary
Channel A
Voltage = LOW
Frequency = LOW

In a real instrument, this fault-finding could have been done without even removing the instrument covers because the transformer primary leads are connected to the mains power cord connector.

5-6 Choosing voltage and frequency ranges

The most effective voltage and frequency ranges will quickly be learned by experiment, but the following table provides a summary of recommended settings for a range of inductor values.

Frequency

Range	**Low**	**Med**	**High**
LOGIC	500mH – 11H	100mH – 2H	25mH – 500mH
LOW	30mH – 500mH	6mH – 100mH	1.5mH – 25mH
MED	10H – 110H	2H – 10H	500mH – 5H
HIGH	20H – 300H	4H – 50H	1H – 12H

Table 5-1 Inductor Range

SECTION 6 – TESTING DIODES

Diode Testing Techniques

In this lesson we examine the semiconductor diode.
We discuss forward and reverse bias and use the Fault Locator to measure zener diode breakdown voltage.
We use comparison techniques to verify that diodes have been correctly inserted and discuss some special purpose diodes.

Objectives

At the end of this lesson you should:

- Understand basic diode operation.
- Understand the terms "threshold voltage" and "breakdown voltage".
- Recognise the signatures of signal diodes.
- Be able to explain the signatures of the zener diode.
- Recognise the signature of the light emitting diode.

6-1 Diode signatures

The Fault Locator is especially useful when semiconductor devices are to be tested. Discrete semiconductors such as diodes, transistors, etc. display signatures which are non-linear, and the Fault Locator can give the user useful information regarding the soundness of the device.

Integrated circuits which contain many devices can be virtually impossible to verify other than by direct replacement. Comparing the signatures of adjacent leads can rapidly pinpoint obscure faults on, for instance, a microprocessor bus.

In this section we will examine the signatures of semiconductor diodes.

6-2 Diode operation

The majority of semiconductor devices have at least one *p-n junction*.

A p-n junction is a semiconductor region where there is an abrupt change between n-type and p-type semiconductor.

When a junction is created between n-type and p-type semiconductor material the result is a semiconductor diode.

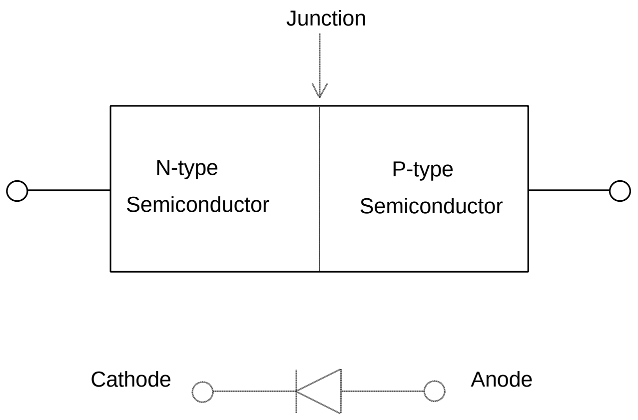


Figure 6-1 Semiconductor diode schematic and circuit symbol

The diode possesses two terminals, a positive terminal, the anode, and a negative terminal, the cathode.

Current passes easily in one direction (the *forward* direction) if a voltage is applied across the junction terminals so that the anode is positive with respect to the cathode (this voltage is called the *forward* voltage). If the polarity of the voltage is reversed, current flow is negligible, and the diode is virtually an open circuit.

The threshold voltage

Unlike the resistor, there is no simple relationship between current flow through the diode and the voltage applied to the diode.

To cause the diode to conduct, we need to apply a *forward* voltage which exceeds a small *threshold voltage* (for a silicon diode this value is about 0.6V). Below this threshold voltage little or no current flows. As the threshold voltage is reached, current begins to flow; above the threshold voltage, even a small increase in forward voltage causes a large increase in current.

The point at which current increases sharply is called the *knee.* The sharpness of the knee is an important indicator of the condition of a diode. The shape of the diode's signature is what makes the diode such a useful circuit device.

6-3 The forward biased diode

Exercise 6-1

Set the instrument to the following settings:

Channel A
Voltage range = LOGIC
Frequency range = LOW

Plug the red test lead into the Channel A socket.

Plug the black test lead into the COM socket.

Set the NORMAL–OPEN DIODE switch to its OPEN DIODE position to allow us to view the signature of a diode out of circuit.

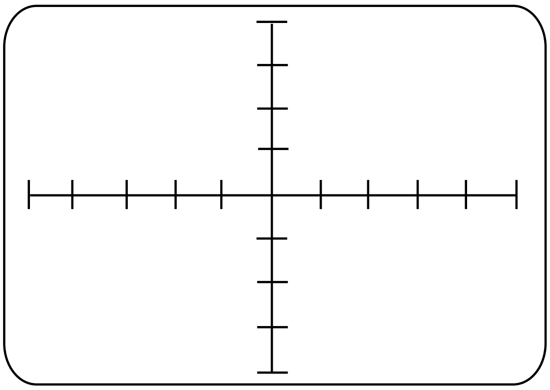
Before connecting the test leads, adjust the vertical position of the trace so that it aligns exactly with the horizontal graticule line.

Short the two test lead tips and adjust the horizontal position of the trace so that it aligns exactly with the vertical graticule line.

Connect the *red* test lead to the anode terminal (the unmarked end) of the upper right rectifier diode.

Connect the *black* test lead to the cathode terminal of the same diode (marked with a white stripe).

Draw the signature below.



Forward biased signal diode
Channel A
Voltage = LOGIC
Frequency = LOW

You should have seen a signature whose slope was horizontal on the left of the screen and which changed sharply to vertical just to the right of the centre vertical graticule line.

On the LOW voltage range each of the graticule markings on the horizontal graticule line represents a 2 volt voltage change across the diode. You should observe the slope change from horizontal to vertical at around 0.6 – 0.7V.

Repeat the test using the other voltage and frequency ranges.

1. Did you notice any significant differences?

2. Describe the signature of a short circuit diode.

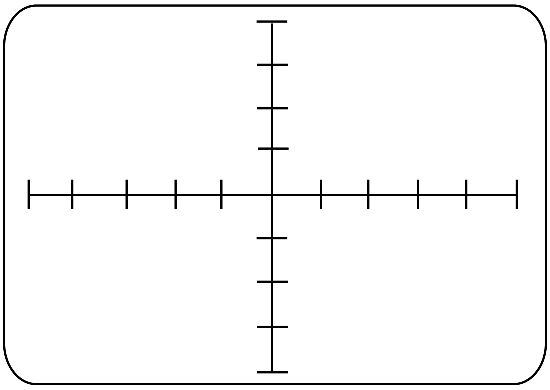
3. Describe the signature of an open circuit diode.

6-4 The reverse biased diode

Can you predict what will happen to the signature if you reverse the test leads across the diode (red to cathode, black to anode)?

Now repeat the test with the leads reversed and check your answer.

Draw the signature below.



Reverse biased signal diode
Channel A
Voltage = LOGIC
Frequency = LOW

Did you guess correctly? Briefly explain how and why the signature changed.

6-5 Light emitting diodes

The demonstration board contains two light emitting diodes (LEDs). In numerous applications LEDs have replaced incandescent lamps as indicators because of their low voltage (1.5 – 2.5V) and long life.

In an ordinary forward-biased diode, as current flows, energy is radiated in the form of heat. In a light emitting diode the energy radiates as light. By manufacturing the diode from elements like gallium, arsenic and phosphorus the diode can be made to emit light of different colours.

LEDs behave like ordinary silicon diodes except for their light emission and higher forward voltage threshold.

We'll examine the two LEDs on the demonstration board using the comparison technique.

Exercise 6-2

Set the instrument to the following settings:

Channel A & B
Voltage range = LOGIC
Frequency range = LOW

Plug the red test lead into the Channel A input socket.

Plug the black test lead into the Channel B input. socket

Connect the COM input to an earth point on the demonstration board.

Connect the red test lead to the test point adjacent the LED in the CHANNEL A (GOOD) section.

Connect the black test lead to the test point adjacent the LED in the CHANNEL B (FAULTY) section.

1. What happens to the LED in the CHANNEL A (GOOD) section?

---

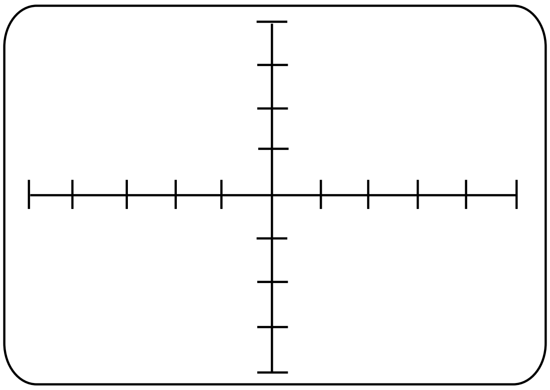
2. What happens to the LED in the CHANNEL B (FAULTY) section?

---

3. What can you say about the way the LEDs are wired in circuit?

4a. Can you explain why the LEDs behaved as they did?

Draw the signatures below (you may have to adjust the position of one of the signatures on screen).



Light emitting diodes
Channel A & B
Voltage = LOGIC
Frequency = LOW

4b. Now that you've seen the signatures can you explain the action of the LEDs?

6-6 Breakdown voltage in diodes

Current flow in diodes

So far we've assumed that current only flows in one direction in a diode. This region of forward current flow is known as the *forward region.*

If the diode is *reverse biased*, no current flows so the diode acts as an open circuit. (Actually, a very small quantity of reverse current, called *leakage current*, does flow in the reverse direction. This region of very low current is called the *leakage region*.)

Breakdown voltage

All junction diodes also possess a region in the reverse direction where large reverse currents can flow if the reverse voltage exceeds a value known as the *reverse breakdown voltage*.

In other words, if we apply enough voltage in the reverse direction, we will drive the diode into a region called the *breakdown region*. The breakdown voltage ranges from a few volts in small-signal diodes to several hundred volts in power diodes.

Breakdown is not of itself destructive or irreversible, and diodes can return to normal action when the voltage is reduced below the breakdown level, but the large currents and voltages associated with breakdown can cause permanent damage due to overheating.

6-7 Zener diodes

Ordinary diodes are normally not intentionally operated in the breakdown region.

Zener diodes, however, are diodes that have been specifically optimised to operate in their breakdown region.

In the forward direction, zener diodes behave as ordinary diodes, conducting forward current as the applied voltage exceeds the 0.6 – 0.7V threshold.

In the reverse direction, the zener conducts virtually no current until driven into its breakdown region.

The transition from the leakage to the breakdown region is marked by a "knee" whose shape depends on the mechanism of breakdown (see **Breakdown mechanisms in zener diodes**), followed by an almost vertical increase in reverse current (i.e. the reverse voltage is held more or less constant across the diode over a wide range of reverse current).

Summarising, the zener diode has three main regions of operation:

? the forward region, where current begins to flow strongly at forward voltages above the threshold

? the leakage region, where, in a good diode, only an extremely small reverse current flows

? the breakdown region, where large variations in reverse current can flow for almost no increase in reverse voltage.

Let's use the Fault Locator to examine the zener diodes on the demonstration board.

Exercise 6-3

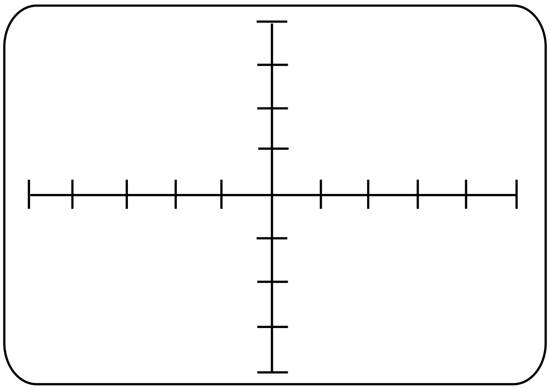
Set the instrument to the following settings:

Channel A
Voltage range = LOGIC
Frequency range = LOW

Connect the earth test lead between the COM socket and an earth point on the demonstration board.

Connect the red test lead to the test point adjacent to the zener diode in the CHANNEL A (GOOD) section.

Draw the signature.



Zener diode
Channel A
Voltage = LOGIC
Frequency = LOW

Its unique characteristics allow the zener diode to be used in wave shaping and voltage limiting circuits, to limit voltages to specific levels, protect components in circuits, provide reference voltages for power supplies, and in many more applications.

6-8 Measuring zener diode breakdown voltage

Correct zener diode breakdown voltage is normally critical to the proper operation of a circuit.

We can determine (approximately) the breakdown voltage of a zener diode from its signature by referring to Figure 6-1. For example, the horizontal scale is ? 1V for the JUNCTION range, ? 10V for the LOGIC range, etc. so we can estimate the zener breakdown voltage, V_Z, by proportion.

Range	**Peak Voltage**	**Peak Current**
JUNCTION	1V	500?A
LOGIC	10V	5mA
LOW	10V	150mA
MED	20V	1mA
HIGH	50V	1mA

Table 6-1 Fault Locator Drive Ranges

1. What is the breakdown voltage of the zener in the CHANNEL A (GOOD) section?

Comparing zener diodes

We'll use the dual channel facility of the Fault Locator to compare the zener diodes in the CHANNEL A (GOOD) and CHANNEL B (FAULTY) sections of the demonstration board.

Exercise 6-4

Switch Channels A and B on.

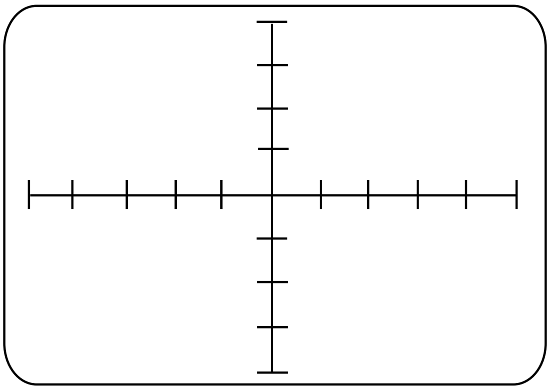
Connect the earth test lead between the COM socket and an earth point on the demonstration board.

Connect the red test lead to the test point adjacent to the zener diode in the CHANNEL A (GOOD) section.

Connect the black test lead to the test point adjacent to the zener diode in the CHANNEL B (FAULTY) section.

2. What do you notice about the signature of the zener diode in the CHANNEL B (FAULTY) section?

Draw the signature.



Zener diodes
Channel A & B
Voltage = LOGIC
Frequency = LOW

3. What is the breakdown voltage of the "bad" zener?

4. How would you determine the polarity of an unmarked zener diode?

Breakdown mechanisms in zener diodes

You will have noticed from the signatures of the two zener diodes that the breakdown knee of the diode in the CHANNEL A (GOOD) section was considerably "softer" than that of the diode in the CHANNEL B (FAULTY) section. This is because there are actually *two* types of breakdown which can occur in diodes – *zener* breakdown, which occurs at voltages below about 6 volts and *avalanche* breakdown which occurs at higher voltages. Avalanche breakdown (exhibited by the "bad" zener) occurs more suddenly than zener breakdown and displays a sharper knee.

SECTION 7 – TESTING TRANSISTORS

Transistor Testing Techniques

In this lesson we discuss the *bipolar junction transistor* and describe its action. We show that transistor signatures are similar to those of diodes and also describe how to test and identify unknown devices.

We introduce the concepts of three terminal testing using the Fault Locator's Pulse Generator and verify the switching action of the transistor.

The lesson also describes how the pulser may be used to test *field effect transistors.*

Objectives

At the end of this lesson you should be able to:

- Differentiate between NPN and PNP transistors.
- Appreciate that the transistor can be tested as two back-to-back diodes.
- Recognise emitter-base junction signatures, collector-base junction signatures and collector-emitter signatures.
- *Perform basic identification and testing of unknown devices?*
- Use the Fault Locator’s pulse generator (pulser) to test transistor switching action.
- Test field effect transistors with the pulser

7-1 The bipolar junction transistor

Up to this point we have considered devices with only two terminals; in this chapter we consider a three terminal device, the transistor.

We will see that transistors can be made to appear as diodes to the Fault Locator, so we can use the techniques we learned in the previous chapter to verify their operation.

Later in the chapter we discuss ways in which the Fault Locator may even be used to identify unknown and unmarked devices.

Transistor construction

The transistor, as you can see from the diagram, is composed of three layers of semiconductor material, almost always silicon, but other materials are sometimes used for special applications.

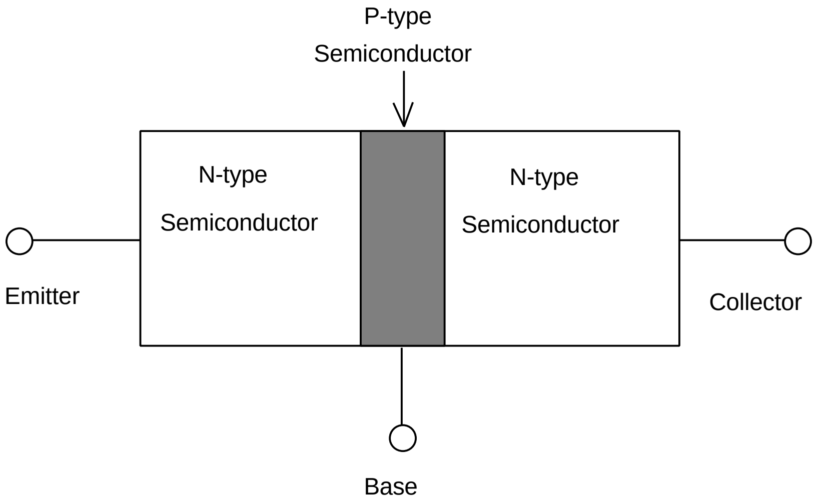


Figure 7-1 NPN Transistor

There are two basic types of transistor, the NPN type shown above, in which two layers of n-type semiconductor sandwich a thin layer of p-type semiconductor, and the PNP type, in which two layers of p-type semiconductor sandwich a thin layer of n-type semiconductor.

The PNP transistor is shown below.

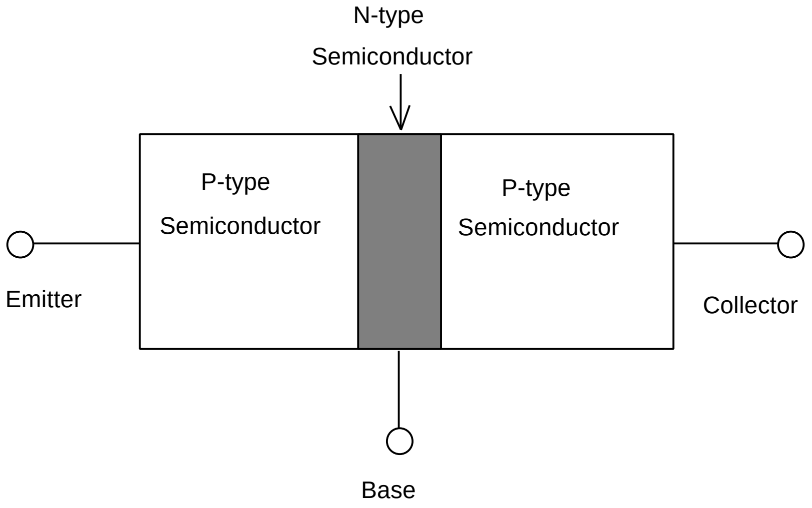


Figure 7-2 PNP Transistor

We can see from the diagrams that the arrangement of the transistor results in *two* semiconductor junctions, one between the emitter and base and the other between the collector and base.

7-2 The two-diode model

The transistor is thus *similar to two diodes*, and in fact the the emitter-base junction is often referred to as the emitter-base diode (or just *emitter diode*). Similarly the collector-base junction is referred to as the collector-base diode (or simply *collector diode*). The symbol and two-diode model for an NPN transistor is shown below.

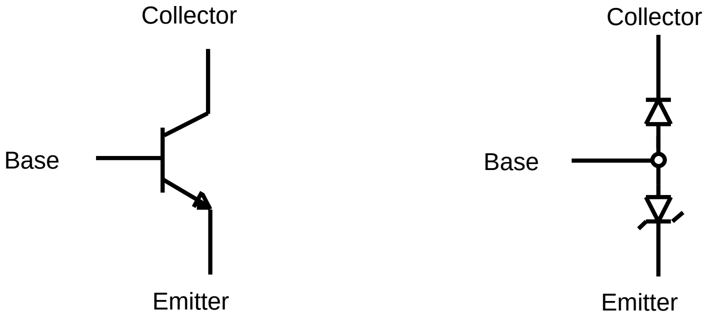


Figure 7-3 Symbol and model for NPN transistor

Note that the collector-base junction appears as an ordinary diode, and the emitter-base junction is represented by a zener diode.

The symbol and two-diode model for a PNP transistor is shown below.

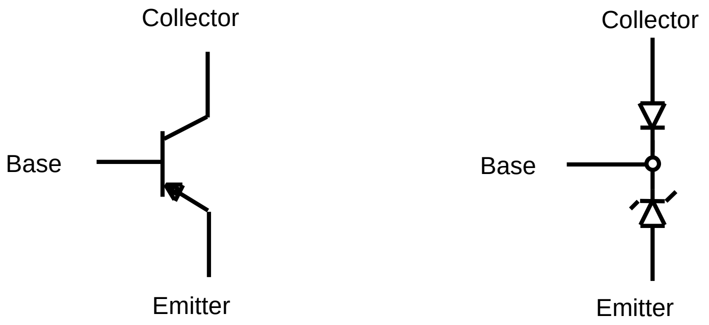


Figure 7-4 Symbol and model for PNP transistor

7-3 Transistor operation

To obtain a basic understanding of transistor operation and how it affects signatures let's briefly consider the case of the NPN transistor.

In operation, the transistor is normally powered up so that the emitter-base junction is *forward* biased (recall that if we apply 0.6 – 0.7V in the forward direction to a diode it will conduct current) and the collector-base junction is *reverse* biased, usually by a relatively high reverse potential. The collector-base junction, then, needs to have a high breakdown voltage. Under these conditions, the transistor is said to be in its *active region*.

With the transistor correctly biased, current, in the form of large numbers of electrons, flows into the emitter-base junction as if it were a normal forward biased diode.
We might expect these electrons to flow out of the base, but *because the base is extremely thin*, most of these electrons do not flow out of the base but are drawn into the collector region by its high positive potential, even though the collector-base junction is reverse biased. (Only a small proportion of the emitter current will, in fact, flow out of the base lead.)

The emitter-base junction, then, acts as a diode controlling the current flowing into the transistor; the magnitude of emitter current flowing through to the collector is controlled by the emitter-base voltage. The emitter is the "source" of current in the transistor and made of semi-conductor material heavily "doped" with current carriers, so the emitter region is highly conductive

7-4 Transistor signatures

We can use the Fault Locator to test transistors by treating the transistor as two diodes; the transistor will display signatures similar to those of the diodes described in the previous section.

In order for the transistor to operate as described earlier, the levels of semiconductor *doping* (i.e. the number of current carriers in the semiconductor material and therefore the conductivity) will be different in the three regions and will affect the breakdown characteristics of the junctions. This, as we will see, will affect the signatures displayed by the transistor.

We will examine the NPN transistor in the CHANNEL A (GOOD) section.

Exercise 7-1 NPN Collector-base junction signatures

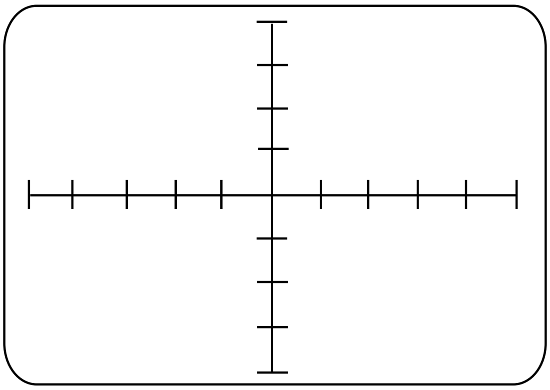
Set the instrument to the following settings:

Channel A
Voltage range = MED
Frequency range = LOW

Connect the black test lead to the collector terminal (marked with a C)

Connect the red test lead to the base terminal (marked with a B)

Draw the signature of the collector-base junction.



NPN Transistor
Collector-base junction
Voltage = MED
Frequency = LOW

1. Which device signature does the collector-base junction signature resemble?

Exercise 7-2 NPN Base-emitter junction signatures

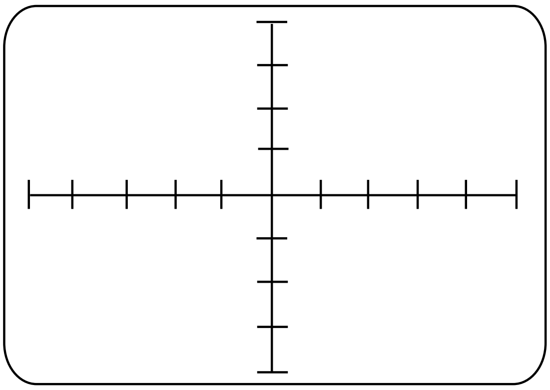
Set the instrument to the following settings:

Channel A
Voltage range = LOGIC
Frequency range = LOW

Connect the black lead to the emitter terminal of the NPN transistor in the CHANNEL A (GOOD) section

Connect the red lead to the base terminal of the transistor.

Draw the signature.



NPN Transistor
Emitter-base junction
Voltage = LOGIC
Frequency = LOW

1. Which device signature does the emitter-base junction signature resemble?

Caution: Emitter-base junctions frequently exhibit low reverse breakdown voltages (usually ranging from approximately 5 to 30V). High frequency small signal transistors should not be operated in their breakdown region for long periods or permanent damage can occur.

2. At approximately what reverse voltage does breakdown occur?

Exercise 7-3 NPN Collector-emitter signatures

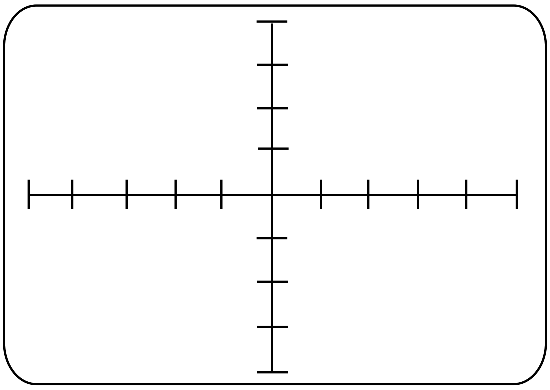
Set the instrument to the following settings:

Channel A
Voltage range = MED
Frequency range = LOW

Connect an earth lead between an earth point on the demonstration board and the COM socket.

Connect the red lead to the collector of the NPN transistor in the CHANNEL A (GOOD) section.

Draw the signature.



NPN Transistor
Collector-emitter
Voltage = MED
Frequency = LOW

Note the shape of the signature.

In the right quadrant, the drive voltage is positive so the collector-base junction is reverse biased and the emitter-base junction is forward biased. The collector-emitter is now reverse biased and no current flows so the display in this quadrant is a horizontal line.

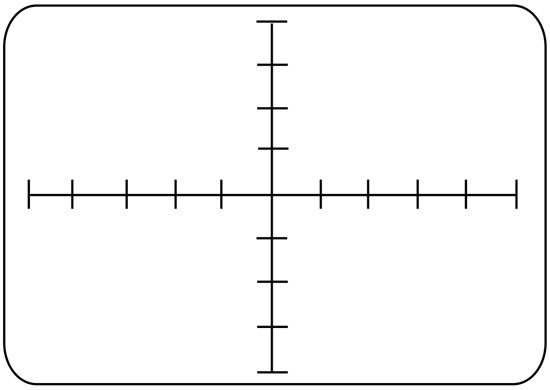
In the left quadrant, the negative drive voltage forward biases the collector-base junction and reverse biases the emitter-base junction. The emitter-base junction exhibits the low reverse breakdown we saw in the previous section.

The result is a signature which looks similar to the signature of a normal diode in series with a zener diode, with the reverse breakdown knee at approximately –8 volts.

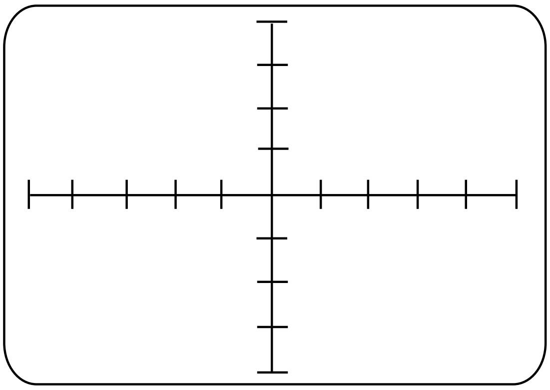
Exercise 7-4 Testing unknown transistors

Determine the type of transistor in the CHANNEL B (FAULTY) section.

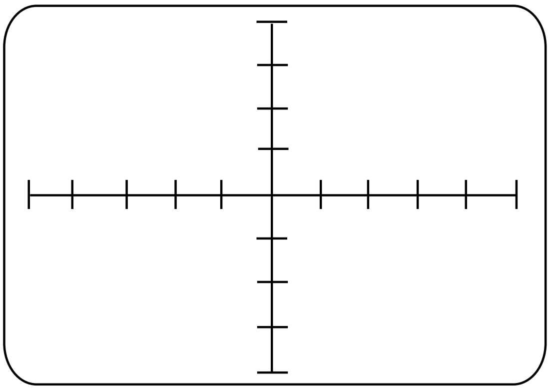
Probe each of the pairs of terminals (i.e. probe across collector-base, emitter-base and collector-emitter) and draw the signatures below.



Unknown Transistor
Collector-base junction
Voltage = MED
Frequency = LOW



Unknown Transistor
Emitter-base junction
Voltage = LOGIC
Frequency = LOW



Unknown Transistor
Collector-emitter
Voltage = LOGIC
Frequency = LOW

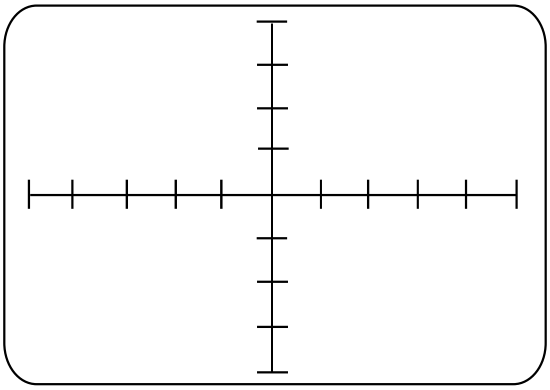
1. Deduce the transistor type (NPN or PNP) from the signatures.

Note that many small-signal transistors will yield very similar signatures, so use the comparison technique to detect subtle differences between devices.

Exercise 7-5 PNP Collector-base junction signatures

Repeat the collector-base junction exercise with the transistor in the CHANNEL B (FAULTY) section.

Draw the signature.



PNP Transistor
Collector-base junction
Voltage = MED
Frequency = LOW

1. Describe the differences between the signatures.

2. Briefly explain the differences between the signatures.

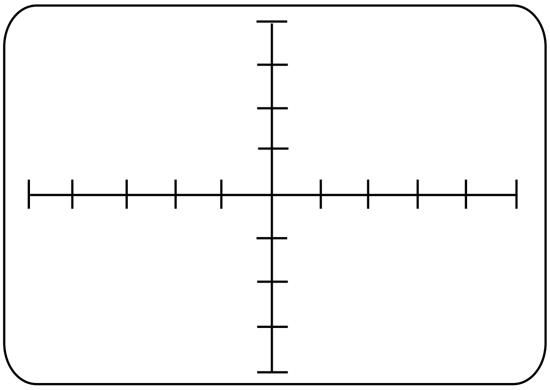
3. How could you make the signatures similar in appearance?

We have tested the collector-base junction signature; to fully test the transistor we need to examine the signatures of the other junctions. As you examine these signatures compare them with their equivalents for the transistor in the CHANNEL A (GOOD) section.
Next we look at the transistor’s emitter-base junction.

Exercise 7-6 PNP Base-emitter junction signatures

Repeat the base-emitter test for the transistor in the CHANNEL B (FAULTY) section.

Draw the signature below.



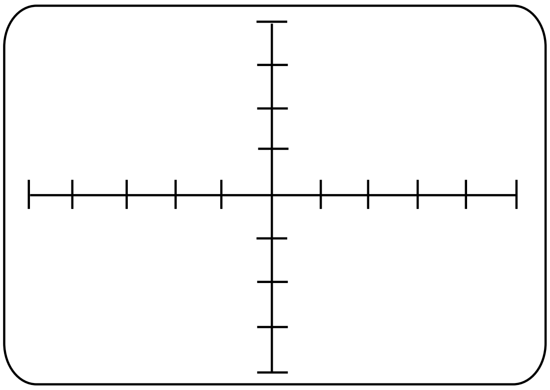
PNP Transistor
Emitter-base junction
Voltage = LOGIC
Frequency = LOW

1. What do you notice about the signature?

Exercise 7-7 PNP collector-emitter junction signatures

Repeat the collector-emitter junction signature test.

Draw the signatures below.



PNP Transistor
Collector-emitter
Voltage = LOGIC
Frequency = LOW

Compare the two transistors and verify that the signatures of the PNP transistor appear as mirror images of the NPN transistor.

In practice, comparing signatures to those of known devices is the easiest and quickest way of fault-finding.

7-5 Three terminal testing of transistors

Note: *The signatures in this section require the use of the pulse generator section of the Fault Locator. If your instrument does not contain a pulser, skip this section and continue with the next lesson*

In our earlier discussion of transistor operation we noted that the flow of current through a transistor was controlled by the polarity and magnitude of the voltage across the emitter-base junction.
Applying 0.6 – 0.7V in the forward direction allows the transistor to conduct, reversing the direction of the applied voltage prevents current flow.

This fundamental property of transistor operation allows the transistor to be used as an *amplifier* or a as a *switch*.

The transistor as an amplifier

When the transistor is to be used as an amplifier, the circuit is designed so that the "output" signal is a faithfully rendered version of the "input" signal; though usually of greater amplitude; i.e. the pattern of the input signal is preserved.

In an amplifier circuit, we apply a *small* signal across the suitably biased emitter-base junction so that the variations in current flow through the transistor precisely correspond to the input signal variations. The output signal will then be a "magnified" or amplified version of the signal across the emitter-base junction

The transistor as a switch

We can also control current flow in the transistor so that the transistor operates either at the point of maximum current (the transistor is then said to be *saturated*) or the point at which current is negligibly small (i.e. the transistor is *cut off*). To a close approximation, these two points correspond to short circuit and open circuit conditions respectively.

In this mode of operation we are not so interested in preserving the shape of the input signal; rather we are using the transistor to switch current on and off.

We will use the Fault Locator to examine the action of the transistor as it switches from open circuit to short circuit.

Simulating transistor switch action

Using the Fault Locator's pulse generator, we can simulate a transistor's operation as a switch by applying a control voltage to the base of the transistor and alternating the transistor between full conduction and complete cutoff. As a general rule, we can infer that if the transistor operates correctly in this mode, it will probably be functioning normally.

7-6 The pulse generator

The pulse generator section of the Fault Locator allows the operator to apply a dc voltage or pulse to the base of a transistor and observe the resulting signature at the collector.

In pulse mode the conduction of the transistor can be controlled by adjusting the level, width, polarity and time delay of the pulse output.

We will see later that the pulse generator can be used to test other more complex devices.

We can select the dc voltage or pulse polarity and magnitude applied to the base of a transistor via the + , – and LEVEL controls.

Applying a dc voltage

In the next exercise we will apply a dc voltage to the transistor base and observe the effect of manually varying the voltage.

The polarity and magnitude of the dc voltage to be applied to the transistor base is selectable from the Fault Locator front panel.

Exercise 7-8

Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW

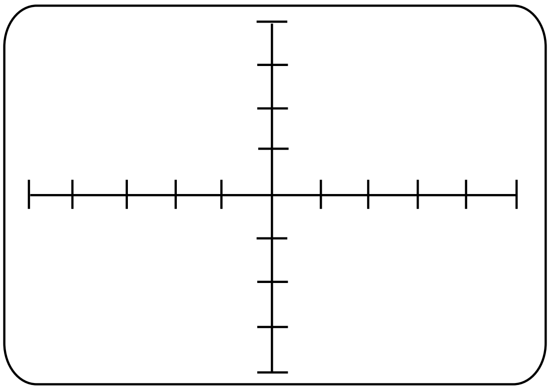
Pulse Output DC
Polarity +

Connect an earth lead between the COM socket and an earth point on the demonstration board.

Connect the red test lead between Channel 1 input and the collector of the NPN transistor in the USE PULSER section.
Connect a test lead between the PULSE OUT socket of the Fault Locator and the base of the transistor.

Rotate the LEVEL control fully counter-clockwise.

Draw the signature.



NPN Transistor
Collector-emitter
Pulser = DC
Level = 0V
Voltage = LOGIC
Frequency = LOW

In this instance we are only interested in the portion of the signature *in the upper right quadrant.* The portion of the signature in the lower left quadrant shows current flowing in the collector-base junction when the Fault Locator voltage swings negative *regardless of the pulser output voltage*.

This 3rd quadrant portion of the signature may be ignored, but for completeness is explained below.

With the pulser connected, a current path exists between the input channel of the Fault Locator and the COM terminal. (See Figure 7-5).

This current path consists of the collector-base junction diode and the internal resistance (R_P) of the pulser (the pulser voltage source appears as a short circuit). The *negative* half cycle of the applied voltage forward biases the collector-base junction and allows current to flow *even with the pulser output set to 0V.*

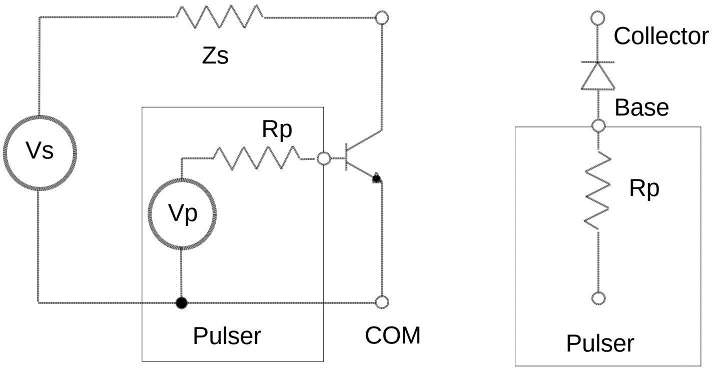
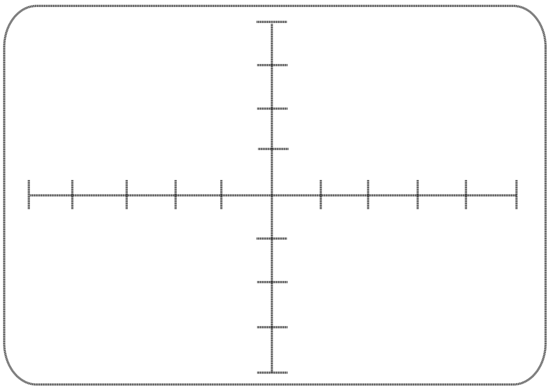


Figure 7-5 Fault Locator – Pulser schematic

1. What do you infer from the shape of the signature in the 1st quadrant?

Rotate the LEVEL control to its mid-range position.

Draw the signature.



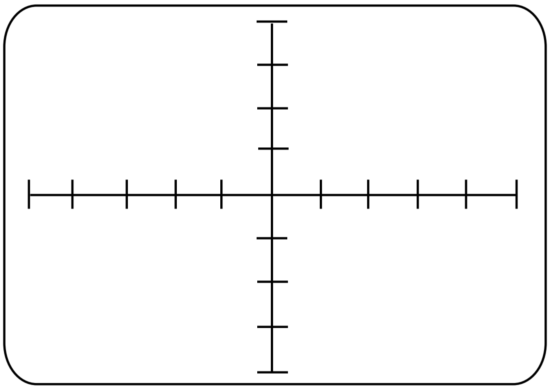
NPN Transistor
Collector-emitter
Pulser = DC
Level = MID RANGE
Voltage = LOGIC
Frequency = LOW

2. Why has the signature changed?

Select the Pulse1 button on the pulse generator.

Set the WIDTH control to mid-range

Draw the signature.



NPN Transistor
Collector-emitter
Pulser = PULSE 1
Polarity = +
Voltage = LOGIC
Frequency = LOW

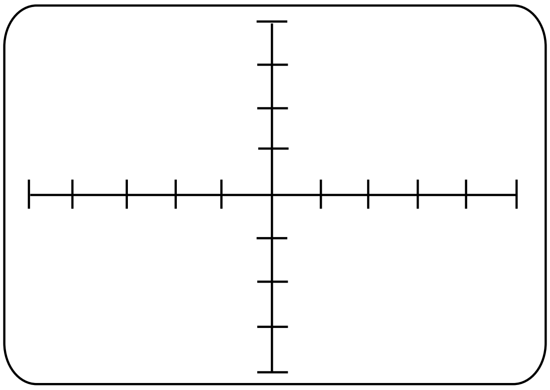
You should see both transistor states on screen.

Try varying the LEVEL control and observing the effect on the signature.

Repeat the exercise for the PNP transistor in the same section.

Remember to use the – pulser polarity.

Try to predict the signatures before viewing them on screen.



PNP Transistor
Collector-emitter
Pulser = PULSE 1
Polarity = –
Voltage = LOGIC
Frequency = LOW

Draw the signature when the PNP transistor is driven by PULSE1.

7-7 Field effect transistors

Field effect transistors are an important class of transistor in which the current flow through the transistor is controlled by the size of an electric *field*.
There are two types of field effect transistor (FET), the junction FET and the insulated gate FET (IGFET), or more commonly, metal-oxide-semiconductor FET (MOSFET).
In the MOSFET the controlling electrode, the *gate*, is insulated from the conducting channel by a layer of oxide.

In this section we will examine the signatures displayed by the MOSFET.

The diagram shows a schematic representation of an n-channel MOSFET.

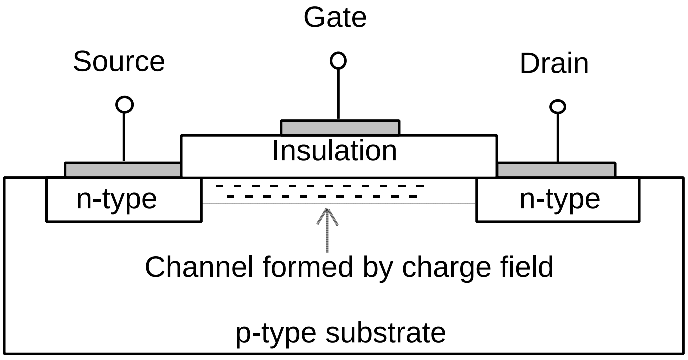


Figure 7-5 N-channel MOSFET

With the gate open circuited there is essentially no conducting path between *source* and *drain*. Back to back semiconductor junctions are formed where the n-type source and drains meet the p-type substrate, so one or other of the junctions is reverse biased whatever the polarity of source-drain voltage.

When the gate electrode is made positive with respect to the source and drain, an electric field is produced in the insulating layer under the gate, drawing electrons under the insulation from the n-type source and drains. This provides a conducting *n-channel* between source and drain. The conductance of the channel depends on the voltage on the gate.

Note that as no appreciable current flows in the gate circuit (because of the oxide insulation), very little power is required to control current flow between drain and source.

7-8 MOSFET signatures

CAUTION: Observe the standard precautions against damage by static electricity when handling MOSFETs. Use only the LOW and LOGIC voltage ranges. Do not use the MED or HIGH ranges.

From the foregoing discussion we can see immediately that gate-drain and gate-source tests should display open circuit signatures, though some manufacturers fit protection diodes between gate and source and this will affect the signatures.

Exercise 7-9

Set the instrument to the following settings:

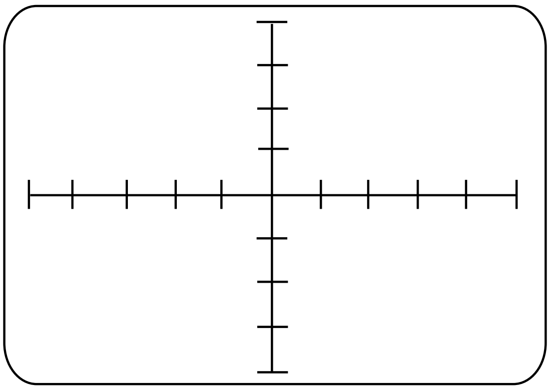
Channel A
Voltage range = LOW
Frequency range = LOW

Connect a test lead between the COM socket and the gate terminal (marked with a G) of the VMOS FET.

Connect the red probe to Channel A.

Place the probe on the source (marked with an S) of the FET.

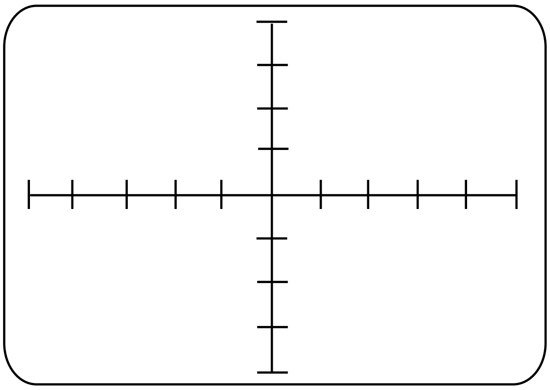
Draw the signature below.



VMOS FET
Gate-source
Voltage = LOGIC
Frequency = LOW

Place the probe on the drain (marked with a D)

Draw the signature below



VMOS FET
Drain-source
Voltage = LOGIC
Frequency = LOW

Verify that both signatures indicated open circuit.

7-9 Using the pulse generator to test FETs

We can test the operation of the FET by applying a voltage to the gate of the FET and monitoring the drain-source signature.

Exercise 7-10

Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW
Pulser output = DC
Pulser polarity = +
LEVEL = 0

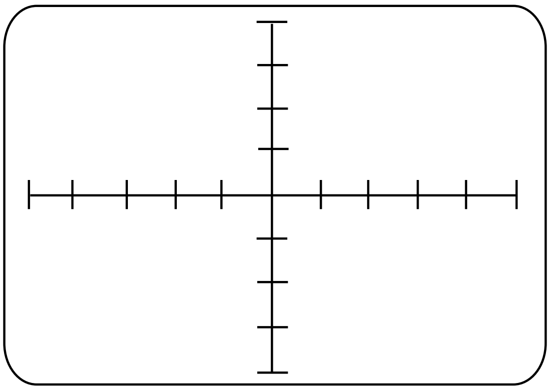
Connect a test lead between the COM socket and the source terminal (marked with an S) of the VMOS FET.

Connect the red probe to Channel A. Place the probe on the drain (marked with a D) of the FET.

Connect a test lead between the pulse output and the gate (marked with a G).

Examine the portion of the signature in the *upper right quadrant* of the display. Note the signature when the LEVEL control is at its 0V position.

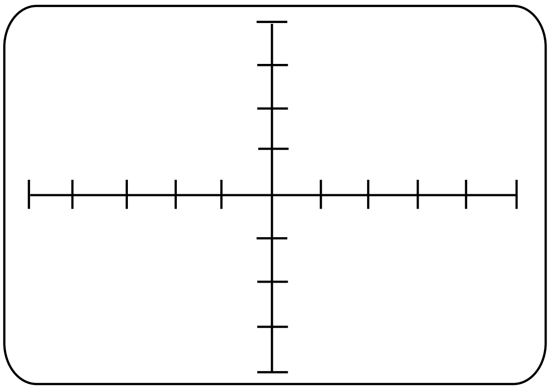
Draw the signature below.



VMOS FET
Drain-source
Pulser = DC
LEVEL = 0V
Voltage = LOGIC
Frequency = LOW

Rotate the LEVEL control fully clockwise, observing the change in signature as the FET conducts.

Draw the signature below.



VMOS FET
Drain-source
Pulser = DC
LEVEL = 10V
Voltage = LOGIC
Frequency = LOW

The exercises were designed to test N-channel MOSFETs. P-channel devices would display similar, though inverted, images in the lower left quadrant.

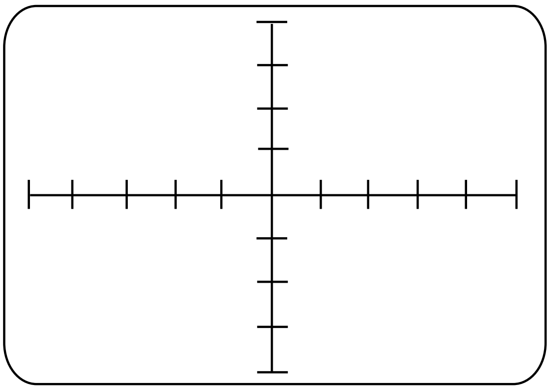
7-10 Identifying transistor connections

Exercise 7-11

We can use the Fault Locator to identify the collector, base and emitter terminals of an unknown transistor.

In this exercise we test the transistor in the CHANNEL B (FAULTY) section of the demonstration board.

Probe across the two outer terminals (place the black probe on the earthed terminal for reference) and draw the signature.



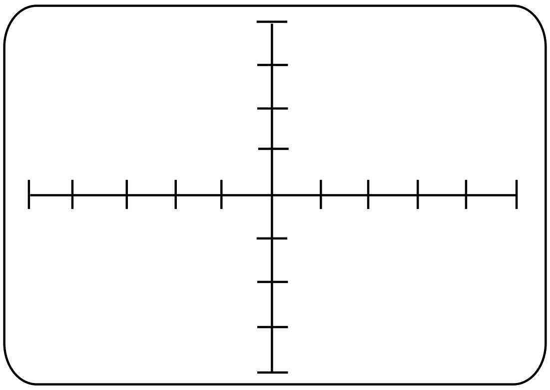
Unknown Transistor

Voltage = LOGIC
Frequency = LOW

What terminal pair is displayed?

Move the red probe to the centre terminal.

Draw the signature.

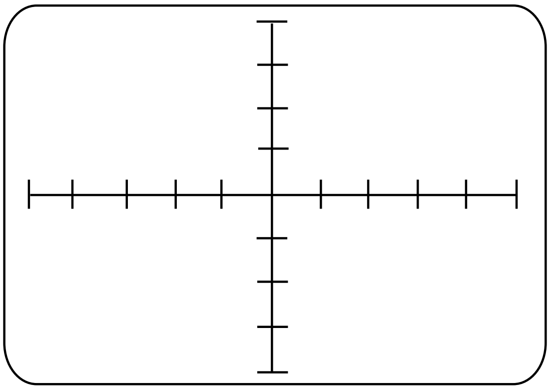


Unknown Transistor

Voltage = LOGIC
Frequency = LOW

What terminal-pair is displayed?

To which terminal is the black probe connected?



Unknown Transistor

Voltage = LOGIC
Frequency = LOW

Return the red probe to the outer terminal (marked C) and move the black probe to the middle terminal.

Determine the identity of the other two terminals.

What type of transistor is this (NPN or PNP)?

SECTION 8 – TESTING SPECIAL DEVICES

Opto-couplers, SCRs and triacs

In this lesson we examine the signatures of opto-couplers and four-layer devices, including SCRs and triacs.

Objectives

At the end of this lesson you should be able to:

- Verify the operation of the opto-coupler with and without the pulser.
- Use the Fault Locator to check the operation of the silicon-controlled rectifier.
- Use the Fault Locator to check the operation of the triac.

The Fault Locator can be used to inspect the signatures of devices considerably more complex than we have looked at so far.

However, as we examine the devices in this section we will see that most devices can be examined in terms of the signatures we have already seen.

8-1 Opto-couplers

The Opto-coupler, or opto-isolator, is a special device widely used to allow one circuit to control another whilst providing electrical isolation between the two circuits.

A typical opto-coupler is shown below.

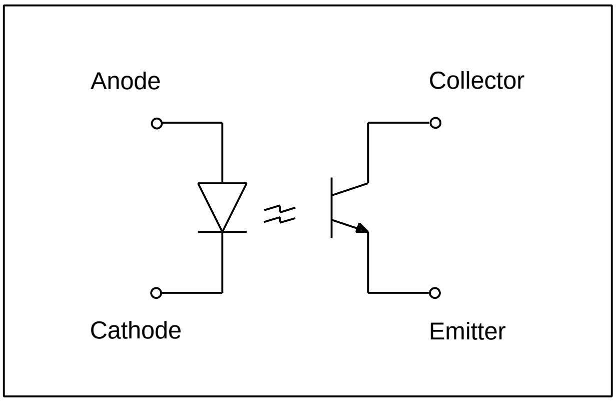


Figure 8-1 Schematic diagram of opto-coupler

As we can see from the diagram, the opto-coupler consists of a light-emitting diode and photo-transistor (note the unconnected transistor base) in a common package.

As the LED conducts current, the emitted light stimulates "charge carriers" in the transistor and causes current to flow.

Testing the opto-coupler

When examining the opto-coupler, the opto-coupler can be treated as two separate devices, the input diode and the output transistor.

The input diode, the LED, can be tested as a conventional diode, and we can examine the output transistor as if it were the collector-base junction of a conventional transistor.

The input diode

Exercise 8-1

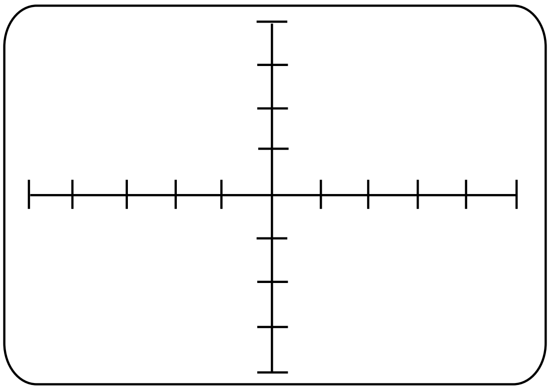
Set the instrument to the following settings:

Channel A
Voltage range = LOGIC
Frequency range = LOW

Connect the black test lead between the COM socket and the cathode of the opto-coupler input diode (marked with the letter K).

Connect the red test lead between the anode of the opto-coupler input diode (marked with the letter A) and Channel A.

Draw the signature below.



Opto-coupler
Input diode
Voltage = LOGIC
Frequency = LOW

Verify that the input diode displays a signature similar to a conventional diode.

1. At what forward voltage does the input diode of the opto-coupler begin to conduct current?

The output transistor

Exercise 8-2

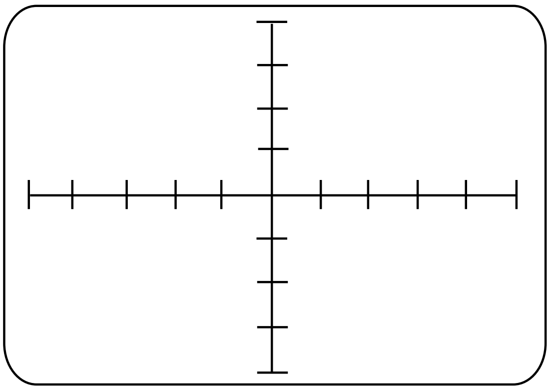
Set the instrument to the following settings:

Channel A
Voltage range = MED
Frequency range = LOW

Connect the black test lead between the COM socket and the emitter of the opto-coupler output transistor (marked with the letter E).

Connect the red test lead between the collector of the opto-coupler output transistor (marked with the letter C) and Channel A.

Draw the signature below.



Opto-coupler
Output transistor
Voltage = MED
Frequency = LOW

1. At what voltage does breakdown occur?

8-2 Testing the opto-coupler with the pulse generator

We can also check the operation of the opto-coupler by driving the input diode into conduction with the pulse generator and monitoring the signature at the output.

If your Fault Locator has no Pulse Generator, proceed to the next section.

Exercise 8-3

Set the instrument to the following settings:

Channel A
Voltage range = LOGIC
Frequency range = LOW
Pulser output = DC
Pulse polarity = +
LEVEL = 0

Connect the black test lead between the COM socket and the emitter of the opto-coupler output transistor (marked with the letter E).

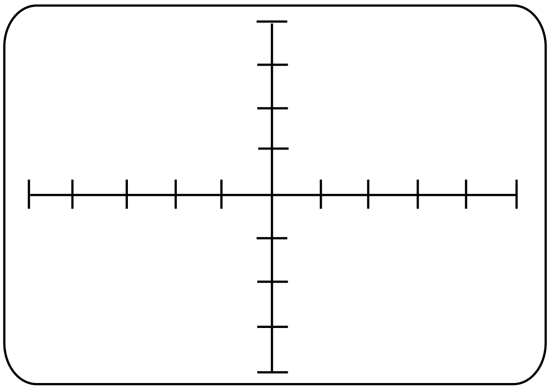
Connect the red test lead between the collector of the opto-coupler output transistor (marked with the letter C) and Channel A.

Connect a test lead between the pulser output socket and the anode of the input diode (marked with the letter A)

Note the signature at this setting of the LEVEL control.

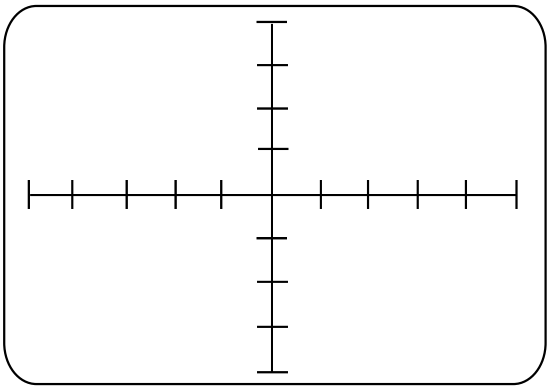
Rotate the LEVEL control until the output transistor shows signs of strong conduction (approximately mid-range on the LEVEL control).

Draw the signature.



Opto-coupler
Output transistor
Pulser = DC
Polarity = +
Voltage = LOGIC
Frequency = LOW

Note the changes in the signature as the LEVEL control is rotated from 0, where no current flow takes place to the point where the output transistor is saturated. Switch the pulser output to PULSE1 and draw the signature.



Opto-coupler
Output transistor
PULSE 1
Polarity = +
Voltage = LOGIC
Frequency = LOW

8-3 *Four-layer diodes*

In this section we examine some components of the *p-n-p-n* diode type, the silicon-controlled rectifier (SCR) and the TRIAC.

The silicon-controlled rectifier

The schematic representation and equivalent circuit of the SCR is shown in Figure 8-2.

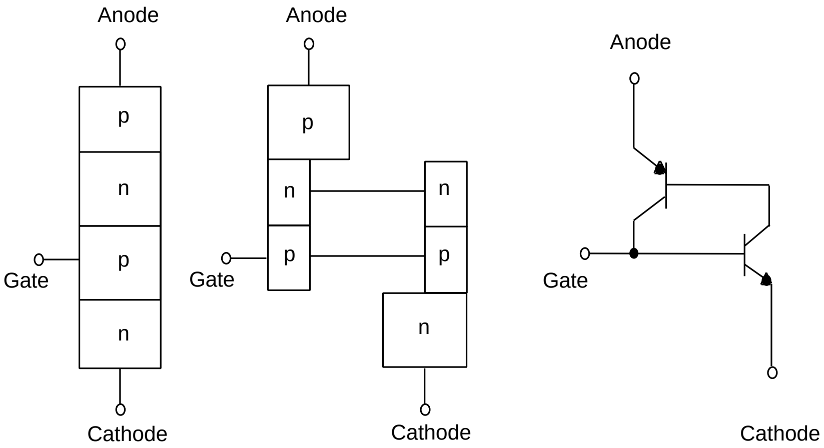


Figure 8-2 Schematic representation of an SCR

From Figure 8-2 we can see that the SCR is effectively two transistors, one n-p-n, one p-n-p, connected back to back.

SCR operation

The device has two stable states, one with both transistors *off* and and the other with both transistors *on*.

Assuming no voltage is applied between gate and cathode:

with a positive voltage applied to the anode, the middle p-n junction is reverse biased, so the SCR is open circuit; with a negative voltage applied to the anode the upper p-n junction is reverse biased, so once again, no current flows; i.e. the SCR *blocks* the flow of current.

If a large enough voltage is applied to the anode, however, *breakover* will occur as one of the collector diodes breaks down causing *both* transistors to saturate — the result is a short circuit.

If we apply a voltage to the gate so that the n-p-n transistor conducts, this will forward bias the p-n-p device, in turn increasing conduction in the n-p-n device; this will further increase conduction in the p-n-p device.

This *positive feedback* causes both transistors to saturate, holding them both in heavy conduction, so the SCR is now effectively short circuit. The SCR is held in this state (i.e. *closed*) even though the input signal is removed and is said to be *latched.*

Even a pulse of very short duration is sufficient to trigger the SCR into conduction. In practice most SCRs are designed to be closed by a narrow pulse and remain closed until anode current falls below the *holding current.*

The symbol and diode equivalent circuit are shown below.

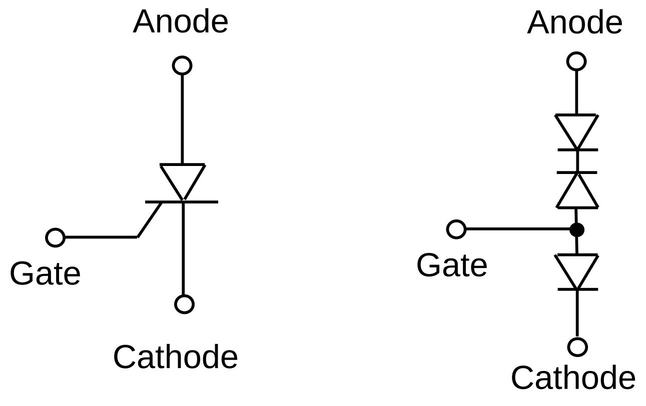


Figure 8-3

From the diagram above we should be able to deduce the appearance of the signatures of the SCR.

Before moving on to the exercise try to draw the signatures for the gate-cathode terminals and the anode-cathode terminals.

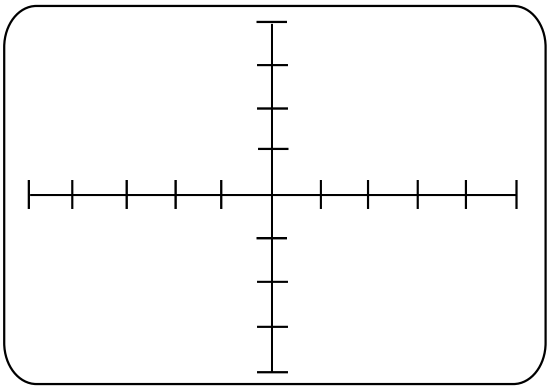
Exercise 8-4

Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW

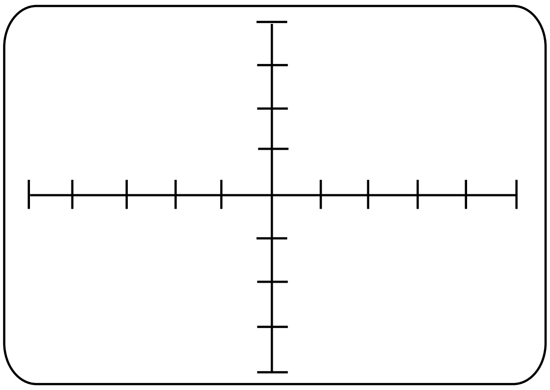
Check your predictions for the signatures as you probe the gate-cathode terminals.

Draw the signature



SCR
Gate-cathode
Voltage = LOGIC
Frequency = LOW

Now probe the anode-cathode terminals and draw the signature.



SCR
Anode-cathode
Voltage = LOGIC
Frequency = LOW

Using the pulse generator to test scrs

The operation of the SCR can be tested using the pulse generator.

Exercise 8-5

Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW
Pulser output = DC
Pulse polarity = +
Level = 0

Connect the black test lead between the COM socket and the cathode of the SCR (marked with the letter C).

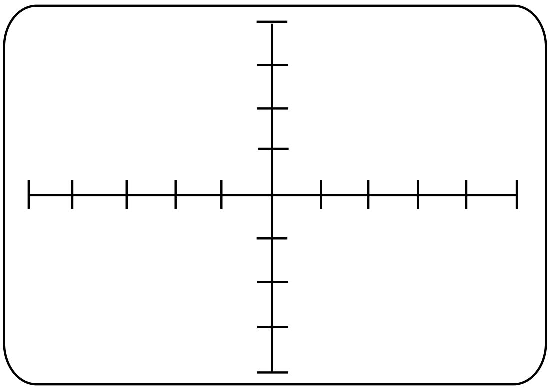
Connect the red test lead between the anode of the SCR (marked with the letter A) and Channel A.

Connect a test lead between the pulser output socket and the gate of the SCR (marked with the letter G).

Note the signature at this setting of the LEVEL control.

Rotate the LEVEL control until the SCR shows signs of conduction (at approximately the nine o'clock position on the LEVEL control).

Draw the signature.

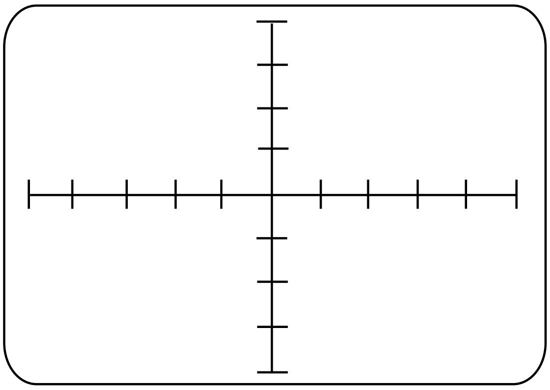


SCR
Anode-cathode
Pulser = DC
Polarity = +
Voltage = LOGIC
Frequency = LOW

Switch the pulse generator to the PULSE 2 output.

Rotate the LEVEL control until current flows; rotating the WIDTH control will allow you to observe the conducting and non-conducting modes.

Draw the signature below.



SCR
Anode-cathode
PULSE 2
Polarity = +
Voltage = LOGIC
Frequency = LOW

The Triac

The triac acts like two back to back SCRs connected in parallel — see Figure 8-4. So the triac can conduct current in either direction; it can be triggered into conduction when the gate is either positive or negative with respect to the cathode.

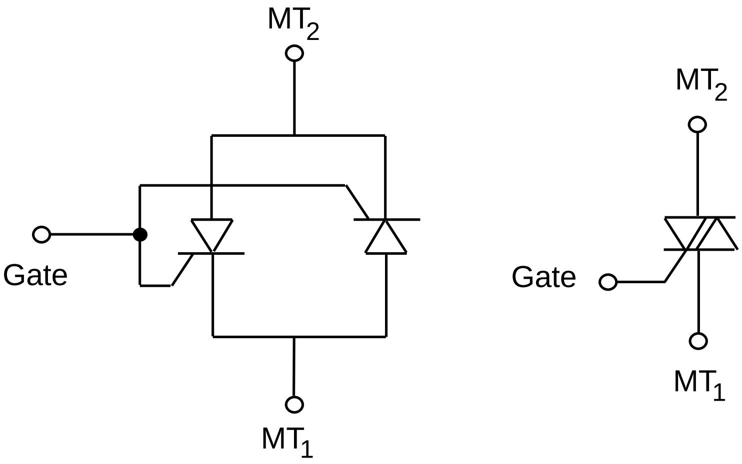


Figure 8-4 Triac equivalent circuit and schematic symbol

Exercise 8-6
Set the instrument to the following settings:

Channel A
Voltage range = LOW
Frequency range = LOW
Pulser output = DC
Pulse polarity = +
Level = 0

Connect the black test lead between the COM socket and the MT1 terminal of the triac.

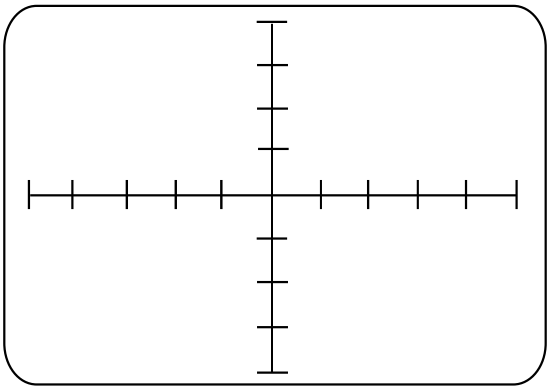
Connect the red test lead between the MT2 terminal of the triac and Channel A.

Connect a test lead between the pulser output socket and the gate of the triac.

Note the signature at this setting of the LEVEL control.

Rotate the LEVEL control until the triac shows signs of conduction.

Draw the signature.



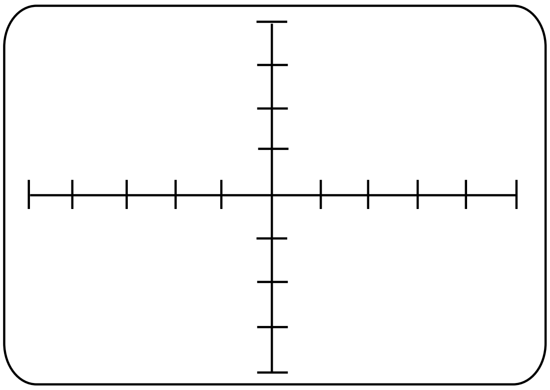
Triac
MT_2–MT_1
Pulser = DC
Polarity = +
Voltage = LOW
Frequency = LOW

Notice the triac conducts in both directions.

Return the LEVEL control to the 0V position.

Change the pulse generator polarity to – and rotate the LEVEL control until the triac conducts.

Draw the signature below.



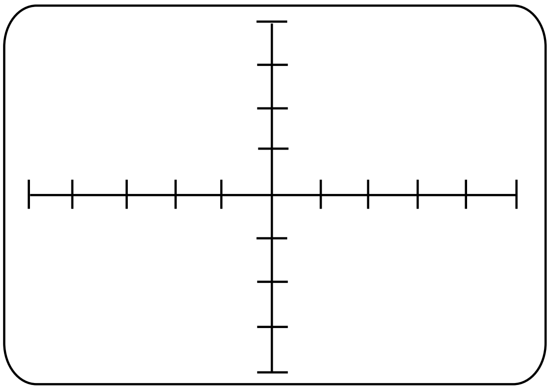
Triac
MT_2–MT_1
Pulser = DC
Polarity = –
Voltage = LOW
Frequency = LOW

Change the pulse generator polarity to +.

Select PULSE 2.

Rotate the LEVEL control and observe current flow.

Draw the signature.

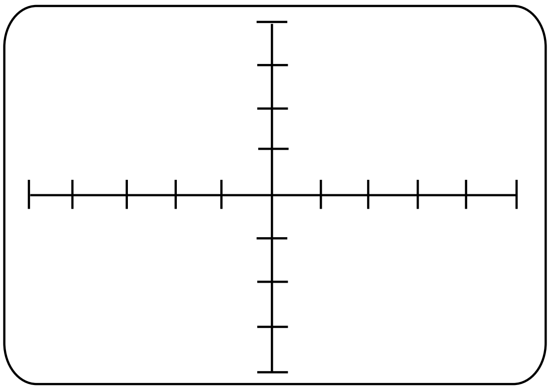


Triac
MT_2–MT_1
PULSE 2
Polarity = +
Voltage = LOW
Frequency = LOW

Note the similarity with the signature of the SCR.

Change the polarity of the pulse generator to – .

Draw the signature.

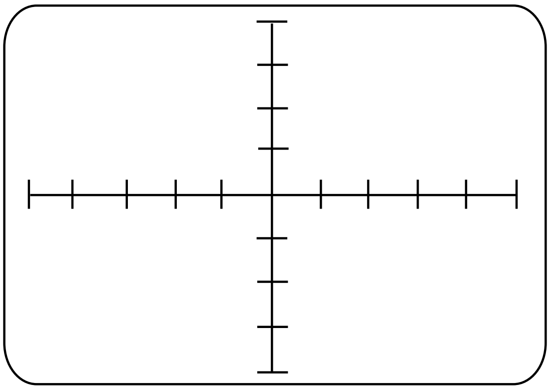


Triac
MT_2–MT_1
PULSE 2
Polarity = –
Voltage = LOGIC
Frequency = LOW

1. Compare this signature with the previous signature.

Select the + and – polarity switches on the pulse generator and display the signature – rotate the WIDTH control and observe the effect.

Draw the signature.



Triac
MT_2–MT_1
PULSE 2
Polarity = + & –
Voltage = LOGIC
Frequency = LOW

2. What can you infer from the signature?

SECTION 9 – TESTING INTEGRATED CIRCUITS

Analog and Digital Integrated Circuits

In this lesson we use the principles learnt in earlier lessons to examine the signatures of some typical analog and digital integrated circuits (ICs).

We show that even very complex devices can be effectively tested using comparison techniques.

Objectives

At the end of this lesson you should:

- Appreciate that the signatures on many IC pins will resemble those of the simple p-n junction.
- Recognise that the signature comparison technique is especially applicable when testing digital integrated circuits.
- Understand why there only a few distinct signatures even on multi-pin ICs.

9-1 Testing analog and digital integrated circuits

Using ASA to locate faulty integrated circuits

During our examination of the signatures of the semiconductor devices we have tested so far, you will probably have noticed that most of them exhibited the characteristic signature of the p-n junction across at least some of the terminals.

In this section we locate faults in *integrated circuits (ICs)*, circuits made up of many components encapsulated within a single package.

The component count within an IC may vary from as few as half a dozen devices on a "chip" to many thousands of components in, for instance, a modern microprocessor.

Because of the need to package so many components into an extremely small space, components within an IC are often microscopically small. As a result, modern ICs contain components and connections which are susceptible to damage from electrical stress and static discharge at levels far lower than those which would damage normal components. For this reason, many ICs incorporate protection diodes on their signal input and output pins.

Experience has shown that many of the faulty components in an IC which is defective are in the Input/Output region of the IC (i.e. where the internal circuit is brought out to the external pin connections).

Regardless of how complex, the construction of a great many devices within ICs will be based on the simple p-n junction.

For this reason, many IC defects will be shown up by signature analysis techniques.

In this section we will examine both digital and analog integrated circuits.

Note: In general you should test ICs using the LOGIC and JUNCTION voltage range and the LOW frequency range.

Using the MED and HIGH frequency ranges may result in loops in the signature due to capacitance within the IC.

9-2 Digital integrated circuits

Many digital circuits consist of groups of signal and control lines which move data around in parallel (e.g. the data and address buses on a microprocessor). Data lines in a bus will usually display identical signatures. This makes it appropriate to use comparison techniques when testing complex ICs.

We'll begin by testing a widely-used device from a popular logic family, the 74HC00, a quad two-input NAND gate.

Exercise 9-1
Set the instrument to the following settings:

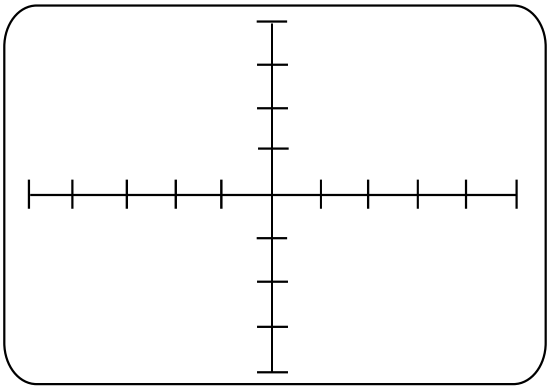
Channels A and B
Voltage range = LOGIC or JUNCTION
Frequency range = LOW

Connect a test lead between the COM socket and an earth point on the demonstration board.

Connect the red test lead between pin 1 (one of the NAND gate inputs) of the 74HC00 in the CHANNEL A (GOOD) section and Channel A.

Connect the black test lead between pin 1 of the 74HC00 in the CHANNEL B (FAULTY) section and Channel B.

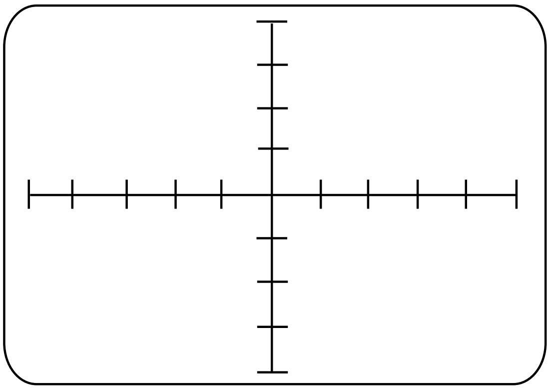
Draw the signatures below.



74HC00
Pin 1 (input pin)
Channels A & B
Voltage = LOGIC
Frequency = LOW

The signature of the good device will be dominated by the input protection diode circuitry.

Check the signatures of both devices by moving the probes to pin 2 of both devices. Draw the signatures



74HC00
Pin 2 (input pin)
Channels A & B
Voltage = LOGIC
Frequency = LOW

Repeat the tests for all the other pins.

Note the difference between the gate inputs and outputs. (Pins 1, 2, 4, 5, 9, 10, 12 and 13 are inputs; pins 3, 6, 8 and 11 are outputs.)

Notes when testing integrated circuits

In general, if you do not have a good circuit available, if the device type is known and documentation is available you can choose the pins to use for comparison purposes. For example, all the inputs on the device just tested should look very similar. Likewise, all the data bus pins on a bus buffer chip, or on a microprocessor should look identical.

The ground (earth) connection of a digital IC is usually a suitable reference point for the COM probe when testing the IC, so it is normally appropriate to connect the COM probe to this pin of the IC.

The COM probe can also be connected to the power supply pin if necessary.

Repeat the tests with the COM probe connected to the power supply pin. Verify that the signatures are exactly similar.

In some cases, you may see signatures which appear unstable. If you experience problems, try connecting the ground and power supply connections together to the COM probe. For convenience, there is a switch on the Demo board, the NORMAL-VCC-SHORT TO COMMON switch, that connects ground to Vcc.

Note: You will frequently notice differences in the signatures between similar ICs from different vendors or which have been manufactured using different technologies. Compare the signature on a suspect pin with signatures from other pins on the same device before regarding the device as faulty.

9-3 Testing complex integrated circuits

We can use the same technique to locate faults in ICs which are large and very complex, such as memory chips and microprocessors. The pin arrangement of such complex ICs means that it is especially appropriate to use comparison techniques to test these devices.

When testing these devices in commercial circuits we will find that, despite the large number of pins, there are only a few distinct signature patterns on a digital IC.

Microprocessor circuits

In microprocessor-based circuitry signal lines are grouped into *buses* which route data or control signals in parallel around a system.

These buses can be routed to many devices within a system, often connected in parallel. During normal operation the system depends on precise timing and address control to avoid conflicts between devices.

Because the devices are connected in parallel with common lines, however, it can sometimes prove difficult to isolate a fault to one particular device as the fault will manifest on all of them. Some models within the Polar Instruments range incorporate circuitry to allow the user to disable devices sharing a bus to isolate the device under test.

9-4 Testing analog integrated circuits

In this section we consider the signatures of analog integrated circuits.
Analog integrated circuits form the building blocks of many complex circuits.
The demonstration board contains a typical example of an analog IC, the LF351 operational amplifier (op amp).

As with digital devices, variations in manufacturing processes between vendors will often cause the signatures of similar good devices to appear different.
The most effective method of testing these devices is via the comparison method.

The usual technique is to compare the suspect device signatures with the signatures of the corresponding device in a good circuit.

The good circuit may be on a separate board or on a similar circuit on the same board (e.g. you may be able to compare two channels of a four channel amplifier).

We will compare the signatures of the op amps in the CHANNEL A (GOOD) and CHANNEL B (FAULTY) sections.

Exercise 9-2

Set the instrument to the following settings:

Channel A and B
Voltage range = LOGIC or JUNCTION
Frequency range = LOW

Connect a test lead between the COM socket and an earth point on the demonstration board.

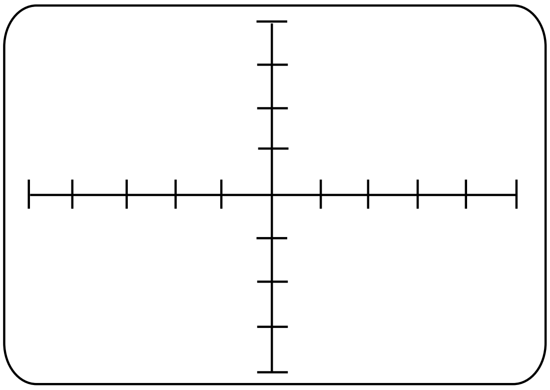
Connect the red test lead between pin 1 of the LF351 in the CHANNEL A (GOOD) section and Channel A.

Connect the black test lead between pin 1 of the LF351 in the CHANNEL B (FAULTY) section and Channel B.

Compare the two signatures.

Move the probes to pin 2 of the ICs.

Compare the signatures and draw them in the box below.



LF351
Pin 2
Voltage = LOGIC
Frequency = LOW

1. Can you guess the reason for the signature shape of the suspect IC pin?

When a device is tested in circuit, it is frequently the case that *several* pins display signatures that differ from good signatures. A severe fault on one pin can affect the signatures displayed on the other pins. The faulty pin can often be identified by its signature looking conspicuously worse than the other suspect pins.

Probe the other pins on both devices.
It is good practice to gather as much information as possible about a problem before attempting to draw conclusions, so where you see a difference in a comparison test,

probe the immediate vicinity of the suspect signature. Where the worst signatures occur is a good place to start looking for a fault.

SECTION 10 – REPAIRING CIRCUIT BOARDS

Board Repair

In this lesson we summarise some of the techniques we have learned and suggest ways to apply analog signature analysis to locate faults you are likely to encounter in field repair.

We suggest a methodical approach to troubleshooting and list common circuit faults.

Objectives

At the end of this lesson you should be able to:

- Describe when to use comparison techniques when fault-finding.
- Describe when to use "expected signature" techniques.
- Develop a logical approach to troubleshooting undocumented circuit modules.

Now you are conversant with the type of signature presented by most electronic components or networks, here are some suggestions on using ASA techniques for board repair.

10-1 ASA techniques

There are two basic ASA techniques:

The first, and most common, is the *comparison technique.* Here you will have access to a known good, or reference, board.

The second relies upon information you have available, schematics, etc., and your experience of typical component signatures.

We'll deal with each technique separately, taking the comparison method first as it is probably used in 95% of cases.

10-2 The comparison technique

The primary object of the comparison technique is to look for *differences* between signatures. You should generally use this technique if known good boards are available for comparison

It is best to start by testing components connected to connectors, etc., as these are the most common failures encountered when servicing boards. Next, test the components with most available connections first (e.g. 40-pin ICs then 20-pin and so on) then systematically work through until all the devices have been tested.

For example, on a board which has an edge connector, some analog and digital ICs and some discrete components, if possible test the edge connector first using an edge connector interface unit, then the ICs, followed by the discrete components.

By testing components with the most pins first, there is the highest chance of finding the faulty area on the board with the least amount of probing or test clipping of components.

Multi-channel boards

It is worth checking whether there are multiple similar circuits on the board under test, (for example, a dual-channel modem or 4-channel audio amplifier.
These types of boards may have their individual channels compared just as if they were separate boards.

In such cases, exercise caution, however, when differences do arise. Check that the separate channels are identical in the areas which show up different signatures — circuit differences may be intentional.

10-2 Expected signature technique

Technicians are often called upon to repair a circuit board without reference signatures; i.e. no good boards are available and the faulty board has no identical circuit areas. You will then have to rely for your fault diagnosis on your knowledge of expected signatures at any given node.

To begin with, on this type of board it is best to look at the signatures of nodes that connect to external circuits, as any damage to the board is quite often the result of some external influence. If this is the case some signatures on edge connectors and other inputs or outputs may lead to the fault.

Where reference boards are unavailable, it is important to try and obtain circuit diagrams so that you can attempt to predict with reasonable accuracy the signature of the nodes under test.

10-3 Troubleshooting without documentation

If diagrams and reference board are not available, predicting signatures is obviously more difficult, but it is still worth probing components like relays, known types of ICs and 3-terminal devices and looking for the appropriate signature shape.

Even when you do not have access to a reference board or to circuit diagrams you should be suspicious of digital devices with signatures that are not diode-like, i.e. signatures with sloping lines.

However you need to allow for the fact that some input protection diodes have a series resistance which will produce a noticeable slope if you switch to the LOW range.

Remember that on microprocessor buses, parallel ports, etc., you should expect to see similar signatures on all the lines.

If one is noticeably different from the others treat this line with suspicion.
However, if they *all* look a little strange, this is probably not a fault.

10-4 Typical faults

It is worth keeping in mind that faults are not confined to the "high technology" areas of the board.
Most faults will be in the "low technology" sections, e.g. intermittent connections, "dry" solder joints, reversed diodes.

For instance, the following faults are equally likely:

a relay coil has gone open circuit,
a printed circuit board trace has broken,
a transistor has a broken lead.

Remember that most service faults will be catastrophic device failures.

Many faults include broken connections of one sort or another (often resulting in open circuit signatures) or short circuits (e.g. solder "bridges") so pay particular attention to look for unexpected "straight line" signatures.

In general, when troubleshooting a complete circuit module such as a plug-in circuit card, examine signatures in the following order:

edge connectors
other connectors
large ICs
small ICs
other components

SECTION 11 – ANSWERS TO EXERCISES

Exercise 1-1

1. Signature B.

2. Signature B displays a shallower slope, i.e. less current flows.

3a. A horizontal line.

3b. A vertical line

Exercise 2-1

1. The signature will be displayed as a vertical line.

2. This is the signature of a short circuit, maximum current flows.

Exercise 3-1

1. The slope of the signatures did not progressively increase like those in the CHANNEL A (GOOD) section.

2. Two resistors are swapped.

Exercise 3-2

1. The difference in signatures will have been more noticeable on the LOGIC range.

2. Use the LOW and LOGIC ranges to test low value resistors.

Exercise 3-3

1. 200R swapped with the 1K0 resistor. 15R in place of 1M0 resistor.

Exercise 3-5

1. The slopes are different between resistors.

Exercise 4-1

1. The signature has an elliptical shape.

Exercise 4-2

1. The 22µF capacitor displays a rounder signature.

2. It has increased.

3. Capacitive reactance decreases with capacitance value.

4. The signature on the HIGH frequency range is taller than that on the MED range.

5. The signature gets "taller" with increasing frequency.

6. Reactance decreases with frequency.

Exercise 4-3

1. A capacitor with shorted plates would display a vertical signature.

Exercise 6-1

1. There should have been no significant differences between ranges.

2. A short circuit diode would display a vertical line.

3. An open circuit diode would display a horizontal line.

SECTION 6-4

The signature should have been a mirror image of the forward biased diode as current can now flow on the negative half cycle of the applied voltage.

Exercise 6-2

1 & 2 Both LEDs will light.

3. The LED in the CHANNEL B (FAULTY) section is reversed.

4a & b. Both LEDs lit because, with an alternating supply voltage, forward current will flow on one of the half cycles.

SECTION 6-8

1. Approximately 6 volts.

Exercise 6-4

2. The "bad" zener displays a "sharper" knee and a higher breakdown voltage.

3. Approximately 8 volts.

4. Use the red and black leads connected to Channel A and COM respectively. If the "breakdown" section is in the first quadrant, the red lead is on the anode (the "marked" end). Compare with a known diode, if available.

Exercise 7-1

1. A signal diode.

Exercise 7-2

1. The emitter-base junction signature resembles that of a zener diode.

2. Breakdown occurs at approximately –8V.

Exercise 7-4

1. The device is a PNP transistor.

Exercise 7-5

1. The signature is a mirror image of that of the NPN transistor.

2. The difference between the signatures occurs because the PNP collector-base junction diode is of opposite polarity.

3. Reverse the leads.

Exercise 7-6

1. The signature is a mirror image of that of the NPN transistor.

Exercise 7-8

1. The transistor is not conducting.

2. The transistor is conducting.

Exercise 8-1

1. Approximately 1V.

Exercise 8-2

1. 10V.

Exercise 8-6

1. Current now flows in a negative direction.
2. Current flows in both directions.

Exercise 9-2

1. Resistor between pins 1 and 4 of the op-amp in the CHANNEL B (FAULTY) section.