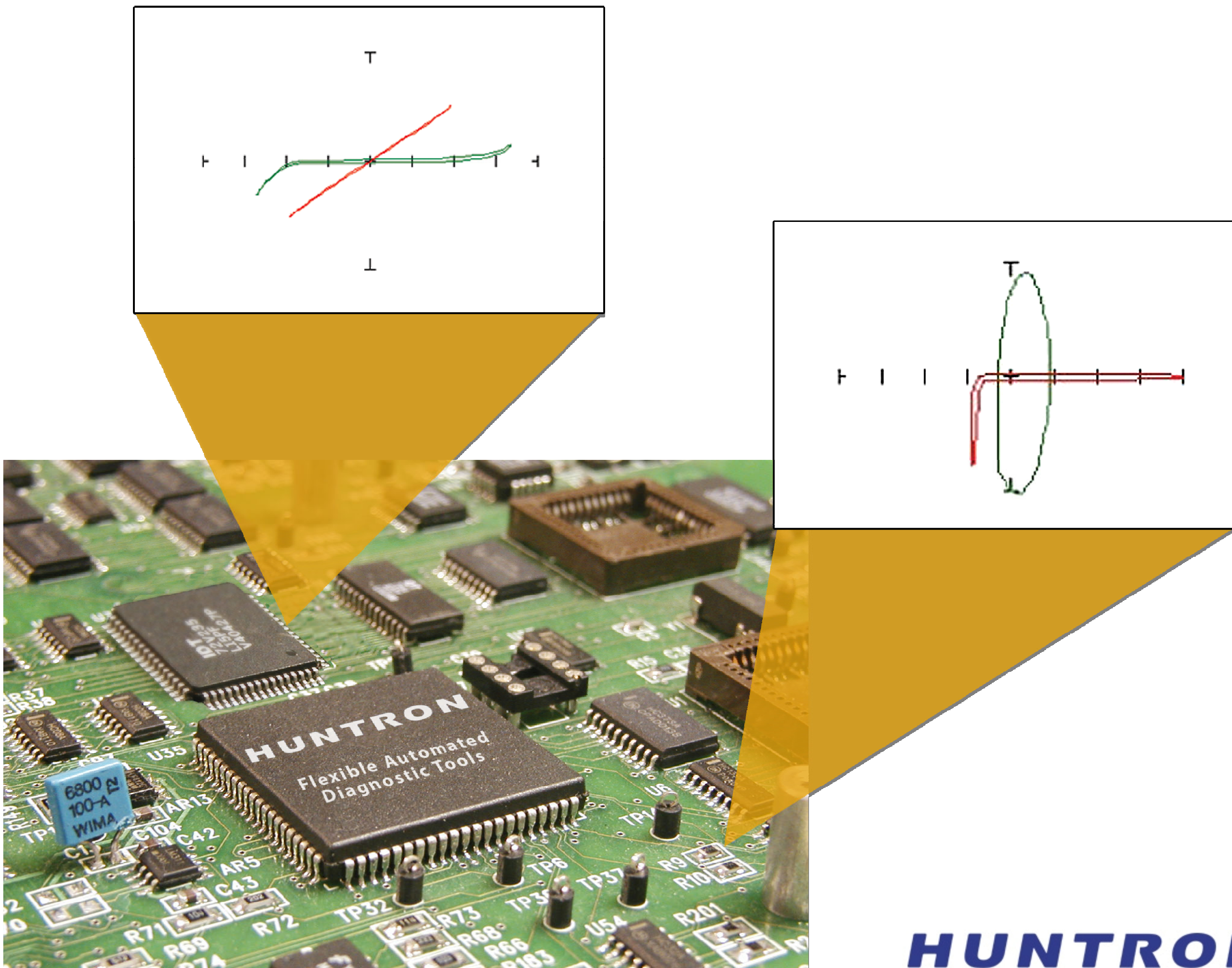
Fundamentals of Signature Analysis

An In-depth Overview of Power-off Testing

Using Analog Signature Analysis



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Section 1. Introduction

Purpose

This document is for the purpose of providing a comprehensive explanation of the concept, use and application of Analog Signature Analysis commonly known by the acronym “ASA”.

The information presented here is intended to be general in nature and not necessarily product or manufacturer specific. However, it may be necessary to reference instrument or software products produced by Huntron, Inc. Huntron is the recognized leader in ASA troubleshooting instruments and systems and this document will draw on that experience and expertise.

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Analog Signature Analysis (ASA) Basics

A Huntron Tracker outputs a precision current-limited AC sine wave signal to a component and displays the resulting current flow, voltage drop and any phase shift on the instrument display. The current flow causes a vertical trace deflection on the display, while the voltage across the component causes a horizontal trace deflection. This resultant trace on the display is called an analog signature.

Understanding the ASA core circuit is the key to understanding how analog signatures respond to different types of components. ASA is sometimes referred to as “V/I Test” and since the induced current is a function of the impedance of the circuit, the analog signature displayed can be thought of as a visual representation of Ohm’s Law.

V = IR where V = voltage, I = current and R = resistance

The next figure shows a simplified diagram of the ASA core circuit. The sine wave generator is the test signal source and is connected to a resistor voltage divider made up of R_s and R_L. The load impedance, R_L, is the impedance of the component under test. R_L is in series with the Tracker's internal or source impedance R_s. Because R_s is constant, both the voltage across the component under test and the current through it is a sole function of R_L.

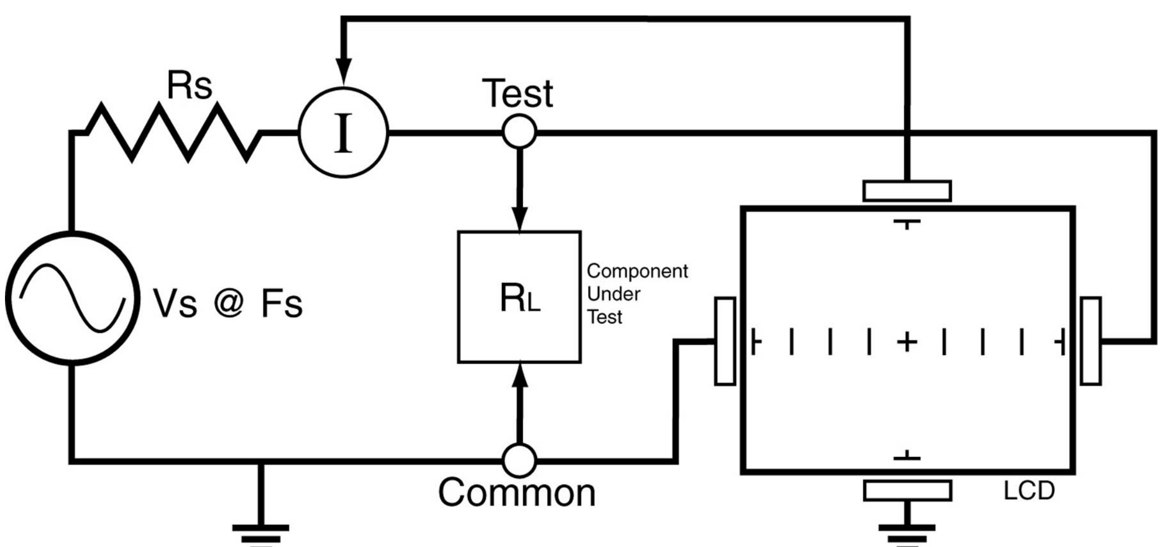


Figure 1-1: ASA Core Circuit Block Diagram

R_s= Source Resistance, V_s= Source Voltage, R_L= Load Resistance, F_s= Source Frequency

Each test signal or range has three parameters: source voltage V_s, resistance R_s and source frequency F_s. When using ASA for troubleshooting, the objective is to select the range that will display the most descriptive analog signature information. A Huntron Tracker can readily accomplish this by changing the proper range parameter. The source voltage V_s of the test signal can be used to enhance or disregard semiconductor switching and avalanche characteristics. The F_s or frequency of the test signal source can be used to enhance or disregard the reactive factor (capacitance or inductance) of a component or circuit node. The R_s or source resistance is used to match the impedance load under test and provide the most descriptive signature possible.

Horizontal Axis

The voltage across the component under test controls the amount of horizontal trace deflection on the instrument display. When the component under test is removed, creating an open circuit (e.g., $R_L = \infty$), the voltage at the output terminals is at its maximum and thus the trace on the display is a straight horizontal line with its maximum width.

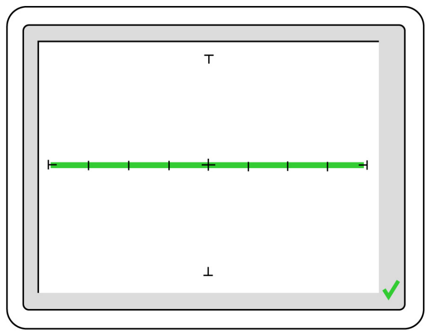


Figure 1-2 Display with Open Test Terminals

The horizontal axis is divided up by small graticule lines similar to those on a conventional oscilloscope CRT. Each mark is approximately 1/4 of the peak range voltage. For example, in the 10 V range, each division is approximately 2.5 V. You can use these graticule marks to get a rough estimate of the voltage drop across the component under test. Changing the V_s of the test range effectively acts the same as changing the Volts-per-division on an oscilloscope. Table 1-1 shows the volts per division for each instrument voltage range.

Range	Volts/Div
20V	5.00
15 V	3.75
10 V	2.50
5 V	1.25
3 V	0.75
200 mV	0.05

Table 1-1 Horizontal Scale per Voltage Range

The signature viewing area of the instrument display can also be set up in quadrants to show positive and negative current and voltage characteristics. Refer to figure 1-3.

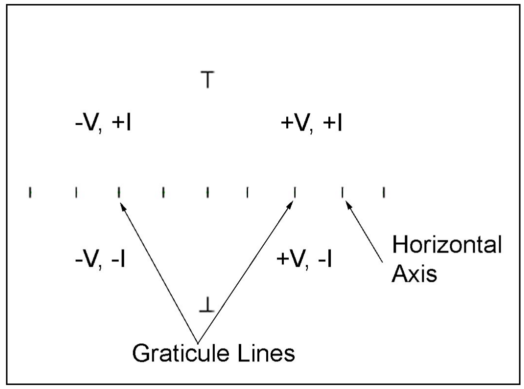


Figure 1-3. Display Horizontal Axis and Graticule Lines.

When the test signal is positive, this means that the voltage and current are positive so the signature's trace is on the right hand side of the instrument display. When the test signal is negative, the voltage and current are negative so the trace is in the left hand side of the display.

Vertical Axis

The amount of vertical trace deflection on the instrument display is controlled by the voltage dropped across the internal impedance R_s of the instrument. Because R_s is in series with the load R_L, this voltage will be proportional to the current flowing through R_L. This current that flows through the component under test is the vertical part of the signature.

When the R_L is zero ohms (0Ω) by shorting the output terminal to the common terminal, there is no voltage dropped across R_L causing no horizontal component displayed in the analog signature. This short circuit signature is a vertical line trace on the instrument display as shown in Figure 1-4.

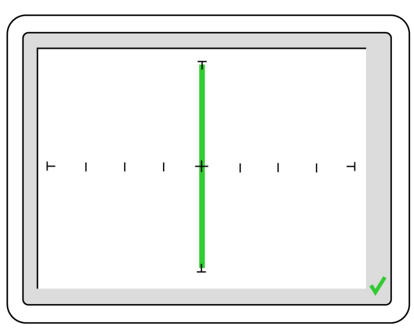


Figure 1-4 Display with Vertical Axis, Graticule Lines displaying a short circuit

Four Basic Component Analog Signatures

All analog signatures are a composite of one or more of the four basic component signatures which are: resistance, capacitance, inductance and semi-conductance. Refer to Fig 1-5. Each one of these basic components responds differently to the instrument's test signal. Recognizing these four basic unique signatures on the instrument display is one of the keys to successful ASA troubleshooting. When components are connected together to form a circuit, the signature at each circuit node is a composite of the basic component signatures in that circuit. For example, a circuit with both resistance and capacitance will have a signature that combines the analog signatures of a resistor and capacitor. The signature of a resistor is always indicated by a straight line at an angle from 0 to 90 degrees. The signature of a capacitor is always in the form of a circle or ellipse shape. The signature of an inductor is also a circle or ellipsoid shape that may also have internal resistance. Finally, the semiconductor diode signature is always made up of two or more linear line segments that generally form an approximate right angle. Semi-conductance signatures can show conduction in both forward and reverse-bias. This will form a zener semiconductor pattern which will show both junctions.

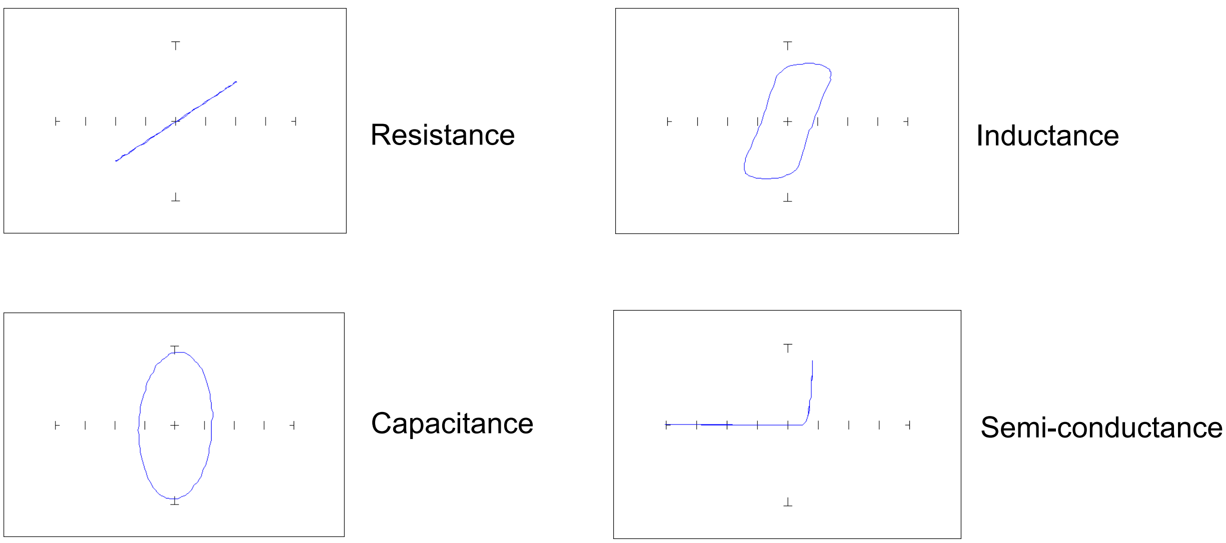


Figure 1-5 Analog Signatures of the Four Basic Components

How Analog Signatures are Obtained

The signatures shown in this document were obtained using ASA instruments manufactured by Huntron, Inc.

For most of the signatures shown in this document, a simple two probe approach is used. Probes are held either directly across a component or from between a component pin and a common reference such as ground or Vcc on the circuit board.

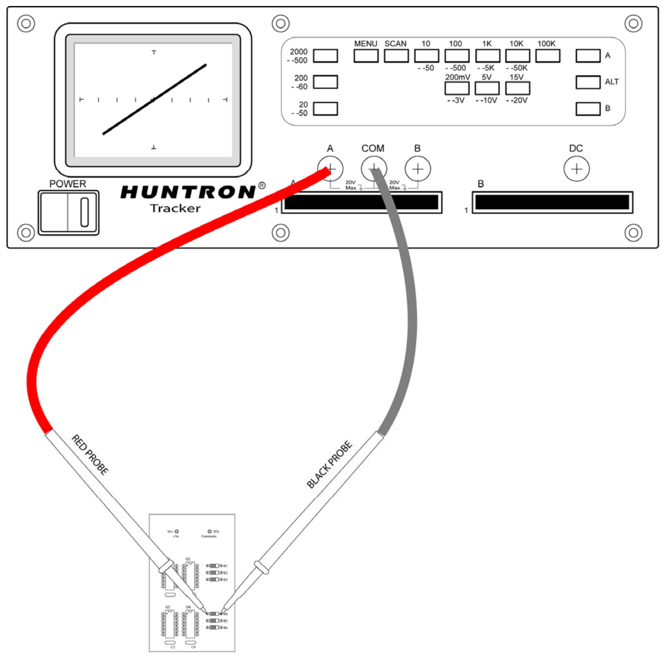


Figure 1-6 Typical two probe application testing a component such as a resistor. One probe (red) is connected to channel A and the other probe (black) is connected to Common.

The Channel A and Channel B connections are the “test” or signal connections. The actual test signal is applied through these connections.

The Common connection is the common signal reference or “signal return”. This is sometimes referred to as “ground” although Common can be attached to any point on the circuit board.

Good versus Suspect Comparison

In most cases, analog signature analysis is used for comparison troubleshooting. This means that the signatures of a good printed circuit assembly (PCA) are compared to those of a suspect PCA. Signature differences can indicate a potential problem. In general practice, Channel A is used for the good PCA and the B Channel is used for the suspect PCA.

There are two channels on a Huntron Tracker, channel **A** and channel **B**. These are selected by pressing the appropriate front panel button or select the desired channel in Huntron Workstation software.

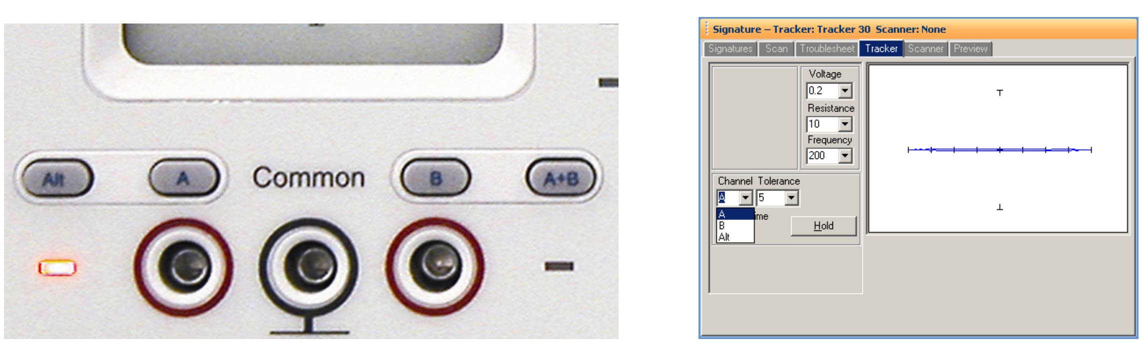


Figure 1-7 Channel A and Channel B shown on a Huntron ProTrack and in Workstation software

When using a single channel, the red probe should be plugged into the corresponding channel test terminal and the black probe or common test lead should be plugged into the common test terminal. When testing, the red probe should be connected to the positive terminal of a device (i.e. anode, +V, etc.) and the black probe should be connected to the negative terminal of a device or a common reference (i.e. cathode, ground). Following this procedure should assure that the signature appears in proper quadrant of the display.

Typical comparison signatures are displayed in figures 1-8 and 1-9. The green is the good "reference" signature and the red in the suspect signature.

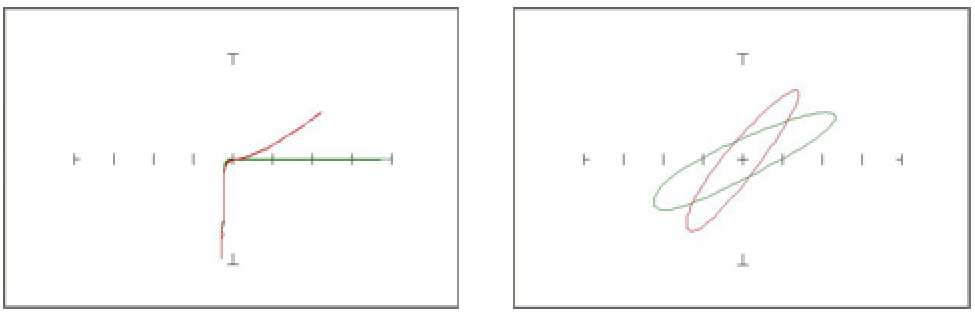


Figure 1-8 Good versus bad signatures

These images show good versus bad signatures (good is green and bad is red). The signatures on the left show a damaged transistor (leakage) compared to a working device. The signatures on the right show a good inductor and one with shorted windings.

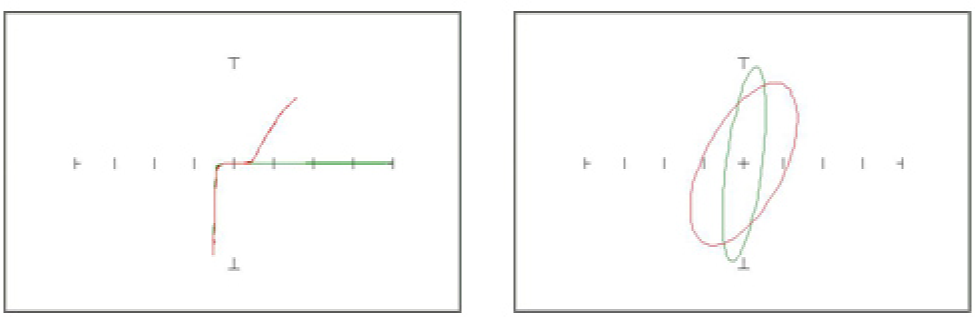


Figure 1-9 Good versus bad signatures

These images show good versus bad signatures (good is green and bad is red). The signatures on the left show a good output 74S04 IC pin and an output pin with a damaged junction. The signatures on the right show a good capacitor and one with internal leakage.

Resistance Selection

A ASA test instrument is typically designed with multiple resistance ranges varying from **10Ω** to **100kΩ.** A resistance range is selected by pressing the appropriate button on the instrument front panel, turning a encoder knob (Huntron ProTrack and Huntron Tracker 4000) or by selecting a resistance setting from the Resistance drop menu in the Huntron Workstation Tracker window (figure 1-10).

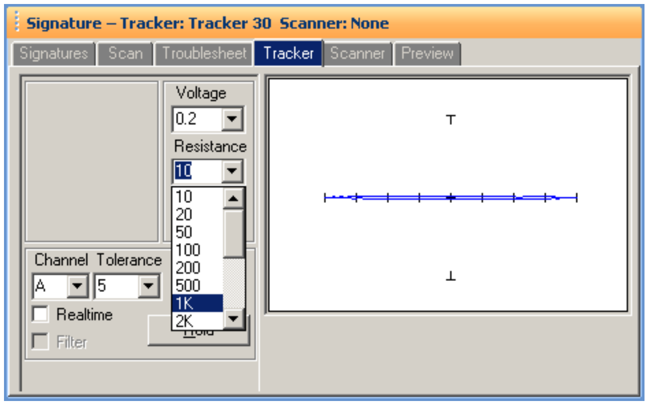


Figure 1-10 Selecting Resistance in the Workstation Tracker Tab

It is best to start with one of the middle resistance values **(i.e. 100Ω or 1kΩ).** If the signature on the display is close to an open (horizontal trace), set the Tracker to the next higher resistance for a more descriptive signature. If the signature is close to a short (vertical trace), go the next lower resistance. An optimum resistive signature is approximately at a 45° angle to the horizontal and vertical lines of the graticule.

Frequency Selection

The instrument test signal frequencies will vary from **20Hz to 5000Hz** and can be selected by pressing the appropriate button on the front panel, turning a encoder knob or by selecting a setting from the Frequency drop menu in the Workstation Tracker window (figure 1-11).

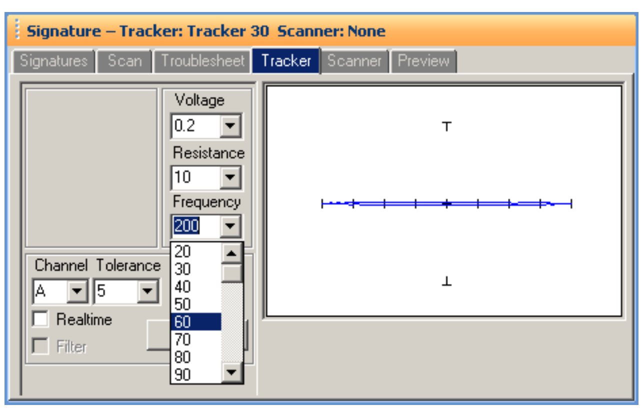


Figure 1-11 Selecting Frequency in the Huntron Workstation Tracker tab

Frequency is typically changed when testing reactive components such as capacitors or inductors. Changing frequency will affect the elliptical shape of the signatures displayed.

Voltage Selection

The test instrument voltage selection varies from **200mV** to **20V**. This controls the peak applied sine-wave voltage. The voltage setting can be selected by pressing the appropriate button on the front panel, turning a encoder knob or by selecting a setting from the Voltage drop menu in the Workstation Tracker window (figure 1-12).

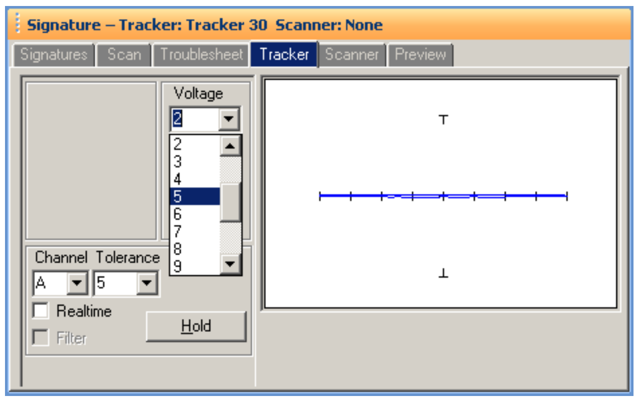


Figure 1-12 Selecting Voltage in the Workstation Tracker tab

Pulse Generator and DC Voltage Source

Some models of ASA test instruments have a built-in DC (direct current) voltage source or Pulse Generator that allows for in-circuit testing of certain devices in their active mode. In addition to using the red and black probes, the output of the DC voltage source or Pulse Generator is connected to the control input of the device to be tested with the clip lead provided with your instrument. In general use, a DC level from the DC voltage source or Pulse Generator is used. Figure 1-13 shows how to connect a Huntron Tracker to the device under test, using the DC voltage source.

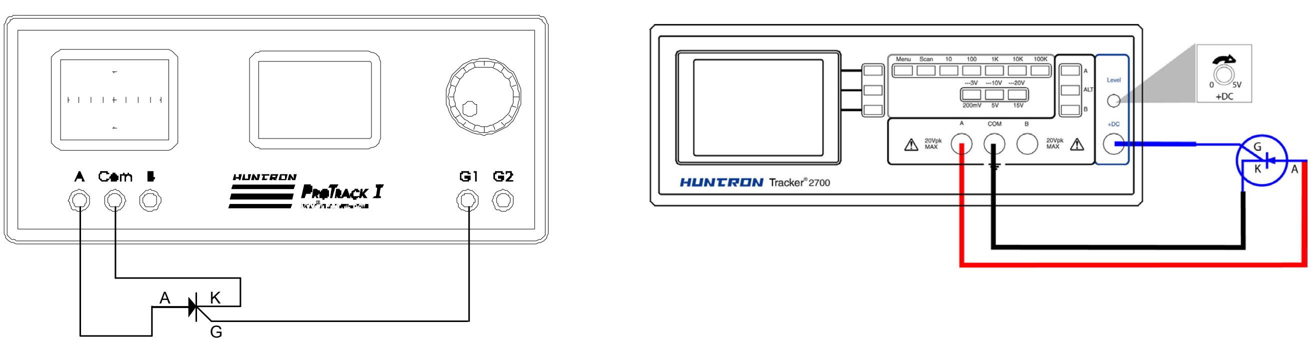


Figure 1-13 Typical Tracker Pulse Generator or DC Source Setup using a SCR

The DC Voltage Source or Pulse Generator output is set using a Level control on the instrument front panel, using front panel encoder or using the Pulse Level setting in the Workstation Tracker tab. The level control varies the magnitude of output voltage from zero to 10 volts.

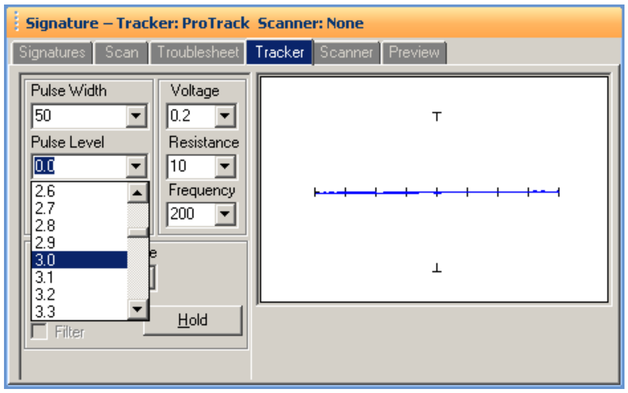


Figure 1-14 Selecting Voltage Level in Huntron Workstation Signature Pane/Tracker tab

SECTION 2 TESTING RESISTORS

Testing Resistors - Introduction

The signatures displayed on an ASA test instrument are a visual representation of Ohm's Law as it relates to the circuit under test. The amount of voltage applied to the circuit is shown along the horizontal axis and the induced current is shown along the vertical axis. Resistors will display a straight line signature because the relationship between voltage and current is linear. The slope of the signature changes as the ASA test instrument resistance range changes or if the amount of resistance across the test leads changes.

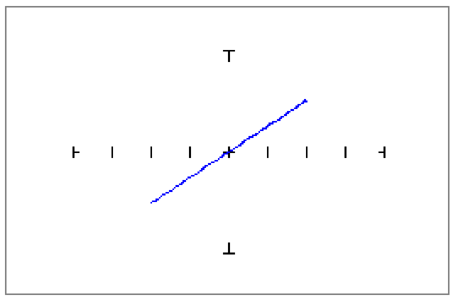


Figure 2-1 Typical Resistive Signature

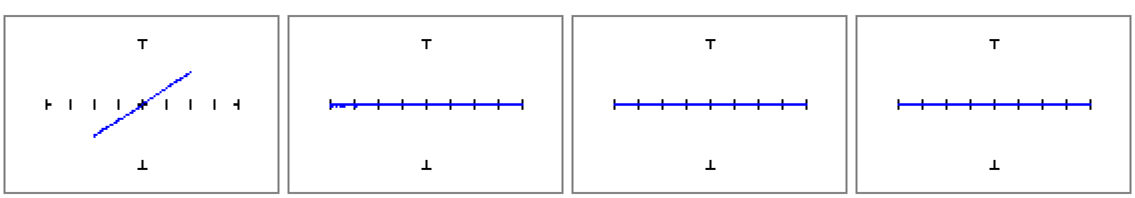
This section will explore how different ASA ranges interact with different resistance values. The following examples are designed to show how resistive signatures relate to changes in test range voltage, resistance and frequency.

Changing Component Resistance Value

The following examples illustrate how changing the resistor value under test affects the signatures shown on the instrument display.

Testing at the 10Ω resistance range

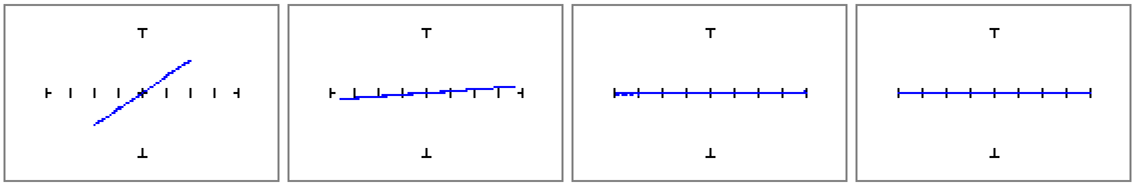
10Ω Resistance range setting



10Ω 1KΩ 10KΩ 100KΩ

In the signatures above note that as the value of the resistance being tested increases, the signature displayed becomes more horizontal.

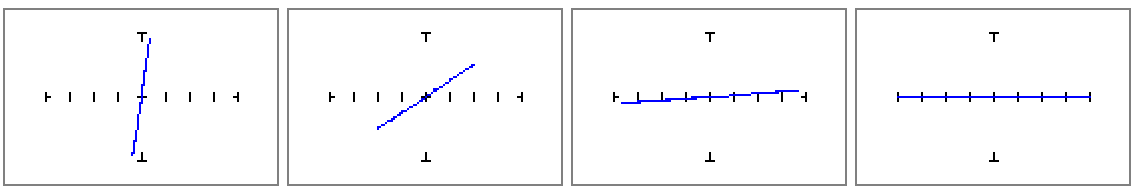
100Ω Resistance range



100Ω 1KΩ 10KΩ 100KΩ

Note that the signature of the 100Ω resistor is showing a typical angled, straight line resistive signature but the other resistor signatures are still relatively flat.

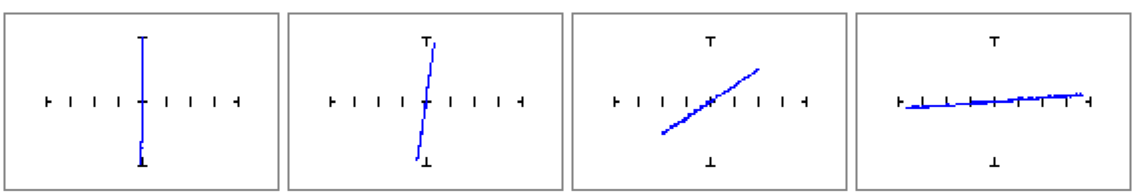
1KΩ Resistance range



100Ω 1KΩ 10KΩ 100KΩ

Note that the signature of the 100Ω is now more vertical. The 1KΩ resistor is showing typical angled, straight line resistive signature but the other resistor signatures are still relatively flat.

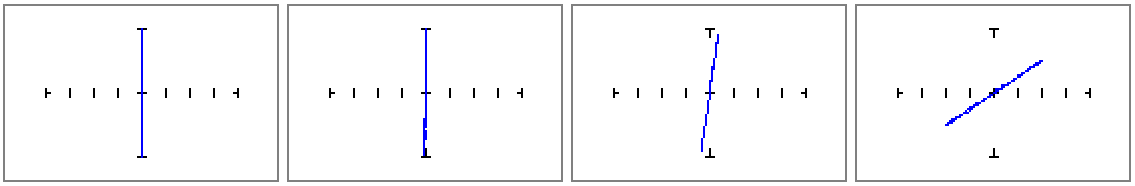
10KΩ Resistance range



100Ω 1KΩ 10KΩ 100KΩ

Note that the signatures of the 100Ω and 1KΩ resistors are showing almost vertical, straight line resistive signatures. The 10KΩ resistor is showing a typical straight line angled signature and the 100KΩ resistor is relatively flat.

100KΩ Resistance range



100Ω 1KΩ 10KΩ 100KΩ

Note that the signatures of the 10KΩ and 100KΩ resistors are showing typical angled, straight line resistive signatures but the 100Ω and 1KΩ resistor signatures are almost vertical. You may also see slight capacitance (loop signature) as the resistance value is increases. This happens as the internal capacitance of the instrument begins to show in the signature.

Resistive Signatures - Changing Voltage and Frequency

The analog signature of a resistor does not change when voltage is varied. The resistive load across the test leads remains unchanged compared to the internal source resistance of the instrument.

The analog signature of a resistor does not change when frequency is varied. Resistors are not a reactive device and the resistive load across the test leads remains unchanged compared to the internal source resistance of the instrument.

Review for resistive signatures

- The signature of a purely resistive circuit will display a straight line signature because the relationship between voltage and current in a purely resistive circuit is linear.
- This straight line signature can vary from a completely horizontal (open circuit) to completely vertical (short circuit).
- As resistance across the test leads increases, the current decreases and the signature will become more horizontal.
- As the ASA test instrument range resistance increases, a resistive signature becomes more vertical.

SECTION 3 Testing Capacitors

Introduction

Unlike resistive circuits, the relationship between induced voltage, current and capacitance is not linear. In a capacitive circuit, current is at its maximum when voltage across the component is at zero. When voltage across the component is at its maximum, current in the circuit is at zero. This "time delay" is a function of the capacitive reactance where the current leads the voltage. This relationship and the resulting analog signature is shown in figure 3-1.

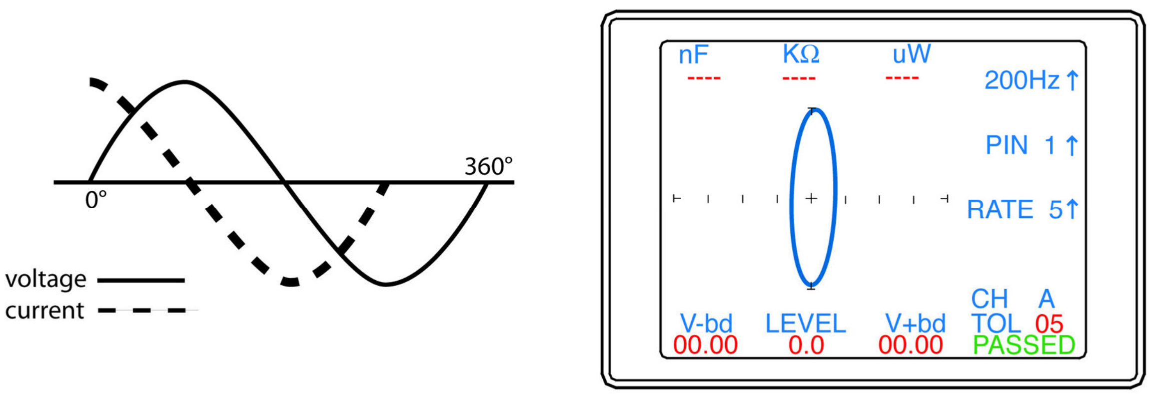


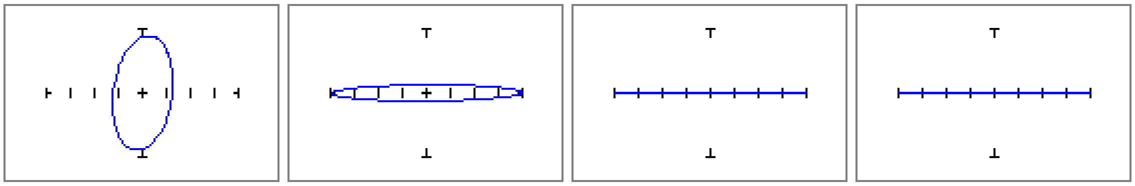
Figure 3-1 Waveforms and signature of typical capacitor

The time delay in a capacitive circuit causes the analog signature to be displayed as an elliptical shape. The width of the ellipse is directly related to the value of the capacitor being tested and the range parameters set on the instrument.

Changing Component Capacitance Value

The following examples illustrate how changing the capacitor value under test affects the signature displayed on the instrument display.

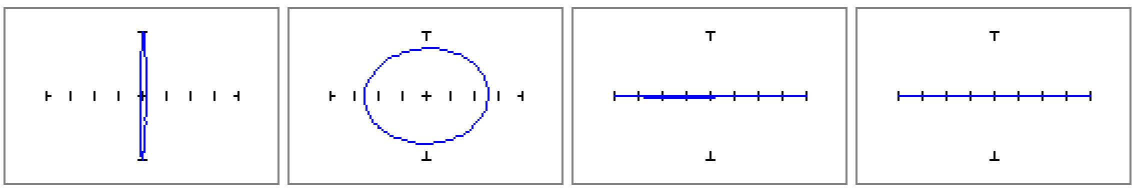
10Ω Resistance range



220uF | 10uF | 0.01uF | 0.001uF

Note from the signatures shown above that as the value of the capacitance being tested decreases, the signature displayed becomes more horizontal. This range is best suited for large capacitor values.

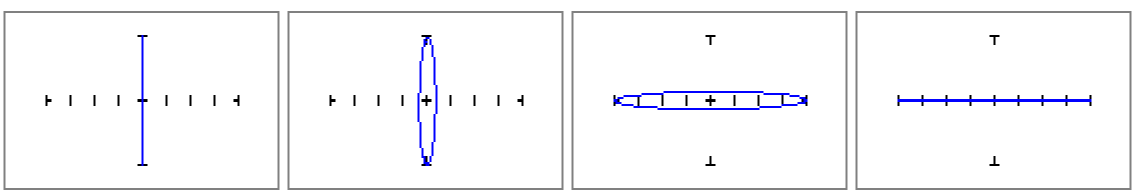
100Ω Resistance range



220uF | 10uF | 0.01uF | 0.001uF

Note that elliptical signatures are displayed for the 220uF and 10uF.

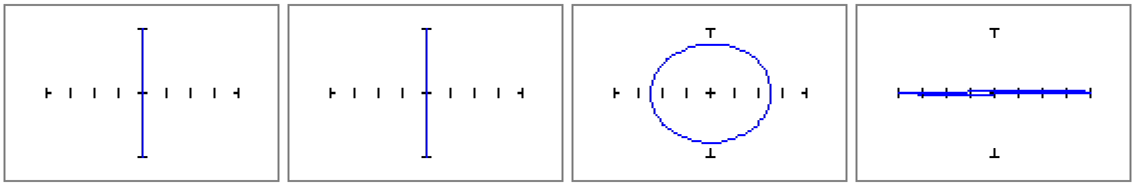
1KΩ Resistance range



220uF | 10uF | 0.01uF | 0.001uF

Note that the 10uF and 0.01uF capacitors display a typical elliptical signature. The signatures displayed for the other components appear either as a vertical or horizontal line.

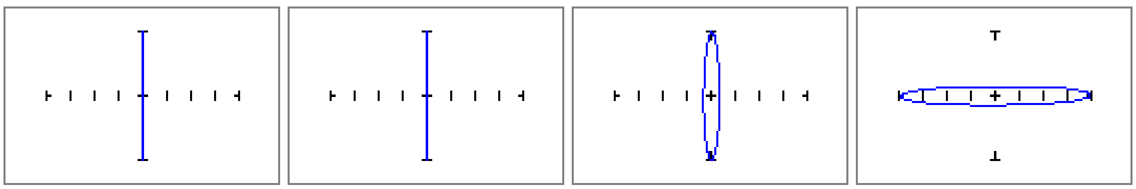
10KΩ Resistance range



220uF 10uF 0.01uF 0.001uF

Note that the signature of the 0.01uF capacitor displays a typical elliptical signature and the .001uF capacitor is now showing a very slight elliptical shape.

100KΩ Resistance range



220uF 10uF 0.01uF 0.001uF

Note that the signatures of the 0.01uF and .001uF capacitors display an elliptical signature. The signatures displayed for the other components will appear as a vertical line.

The analog signature of a capacitor does not change when voltage is varied. The capacitive reactance across the test leads remains unchanged compared to the internal source resistance of the instrument.

Effects of changing range frequency on capacitive signatures

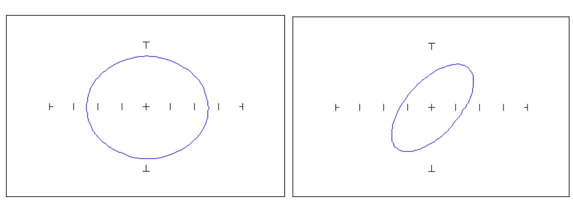
The analog signature of a capacitor changes when the test frequency is varied since the capacitive reactance is a function of frequency. Lower frequencies work better for testing larger capacitances.

The analog signature of a capacitor changes when the instrument frequency is varied since the capacitive reactance is a function of frequency. Higher frequencies work better for testing smaller capacitances.

Capacitive Leakage Failure

A typical failure for capacitors is component leakage. This is especially true for electrolytic capacitors as they age. This example shows a capacitive leakage failure and the associated signatures

Capacitive Leakage



10uF – good 10uF - bad

Note that the signatures of the capacitors appear different from each other in that the bad capacitor is showing an angled orientation when compared to good one. Capacitive leakage or dielectric failure is a common type of failure especially in electrolytic capacitors.

Review for capacitive signatures

- The signature of a capacitor will display an elliptical or circular signature because the relationship between voltage and current in a capacitive circuit is out of phase.
- As the internal instrument test resistance changes, the reactive load across the test leads changes in relation to the internal source resistance and will cause the displayed signature to change.
- As test frequency increases, the signature will become more vertical due to decreasing capacitive reactance within the capacitor being tested. High frequencies work best for small capacitor while low frequencies work well for large capacitors. Use the information presented in table 3-1 as guide for the minimum and maximum limits at the extreme range combinations listed. These values will vary depending on the ASA test instrument used.

Instrument range settings	Minimum capacitive value	Maximum capacitive value
10Ω, 20Hz	100uF	15000uF
100KΩ, 5KHz.	100pF	.01uF

Table 3-1 Min/Max. Capacitance Values

- Radial lead electrolytic capacitors can be test by touching the exposed metal top of the component. This method is best utilized using the A versus B comparison of known good and suspect circuit boards.
- One common capacitive failure type is capacitive leakage where the signature will appear to be tilted at an angle. This is indicating internal resistance and is primarily an issue with electrolytic capacitors.

Section 4 Testing Inductors

Introduction

Similar to capacitors, the relationship between induced voltage, current and inductance is not linear. In an inductive circuit, voltage and current are out of phase with current lagging voltage. This “time delay” is a function of the inductive reactance where the voltage leads the current. This relationship and a common inductive analog signature are shown in figure 4-1.

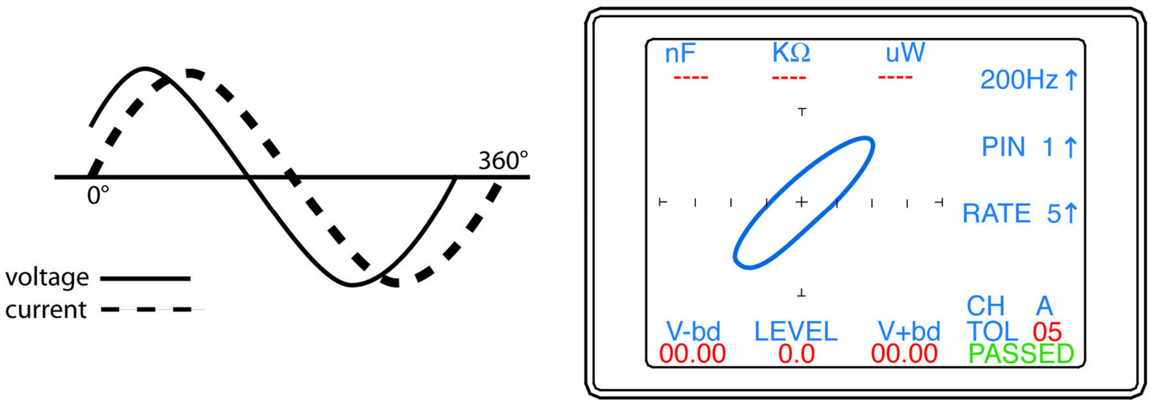


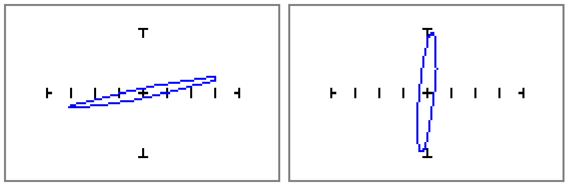
Figure 4-1 Waveform and Signature from Inductor

The time delay in an inductive circuit causes the analog signature to be displayed as an elliptical shape. The width of the ellipse is directly related to the value of the inductor being tested and the range parameters set on the instrument. Since pure inductors are theoretical, most inductive signatures exhibit a resistive tilt caused by the resistance of the wire used to construct the component and some degree of distortion such as the “egg” shape shown in figure 4-1 caused by inductive hysteresis.

Changing Component Inductance Value

The following examples illustrate how changing the inductor value under test affects the signature displayed on the instrument display.

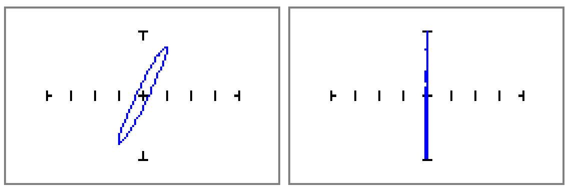
10Ω Resistance range



680uH 68uH

Note from the signatures shown above that as the value of the inductance being tested decreases, the signature displayed becomes more vertical. The width of the signature will also change.

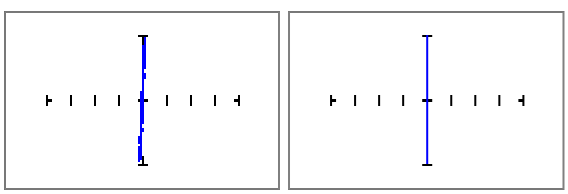
100Ω Resistance range



680uH 68uH

Note that the elliptical signatures have changed in both angle and shape when compared to the signatures using the 10Ω Tracker resistance setting.

1KΩ Resistance range



680uH 68uH

Note that the signatures are now very close to vertical. This particular resistance setting is not suitable for testing these two inductors. The 10KΩ and 100KΩ resistance settings will also display vertical signatures.

Effects of changing range voltage on inductive signatures

Inductive signatures will change very little when voltage is varied. The inductive reactance across the test leads remains relatively unchanged compared to the internal source resistance of the instrument.

Effects of changing range frequency on resistive signatures

Inductive signatures will change when the test frequency is varied since the inductive reactance is a function of frequency. Higher frequencies work better for testing larger inductances.

Review for inductive signatures

- The signature of an inductor will display an elliptical or circular signature because the relationship between voltage and current in an inductive circuit is out of phase. The signature will typically display a resistive tilt caused by the resistance of the wire used to construct the component.
- As the internal test resistance changes, the reactive load across the test leads changes in relation to the internal source resistance and will cause the displayed signature to change.
- As test frequency increases, the signature will become more horizontal due to increasing inductive reactance within the inductor being tested. High frequencies work best for large inductor values while low frequencies work well for small inductor values. Use the information presented in table 4-1 as guide for the minimum and maximum limits at the extreme range combinations listed. These values will vary depending on the ASA test instrument used.

Instrument range settings	Inductive value
10Ω, 20Hz	50uH
100KΩ, 2KHz.	10+ H

Table 4-1 Min/Max. Inductance Values

- Because inductors come in various types and values and can exhibit wide varieties of signature distortion, troubleshooting inductive components is best accomplished using A channel versus B channel comparisons.

Section 5 Testing Diodes

Introduction

Diodes semiconductors are the basic building block of all other semiconductors (i.e. transistors, integrated circuits). Diodes are formed by creating a junction between P-type and N-type semiconductive materials. The resulting component exhibits polarity and will conduct electrical current in one direction but not the other. Current flows in a diode when the voltage on the positive terminal (anode) is more positive than the negative terminal (cathode). This characteristic is reflected in the instrument signature displayed. The typical diode signature is shown in figure 5-1.

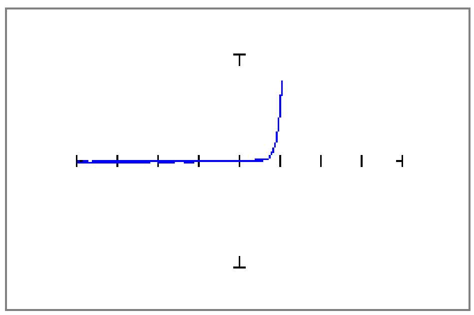


Figure 5-1 Typical Diode Signature

Diode signatures reflect the basic nature of a semiconductor junction. There is a threshold voltage at which the diode begins to conduct, typically 0.6V for a silicon based component. As long as the anode to cathode voltage differential remains below the threshold, the diode will act as an open circuit. As the anode to cathode voltage increases positively the diode will begin to conduct. Once the current flow begins, very small increases in anode voltage will cause very large increases in current flow. This is called the “knee” effect and is characteristic of a good semiconductor junction. The knee effect is reflected in the instrument signature between the horizontal and vertical portions of the signature. This is also referred to as the “breakdown” point.

The graticule of the instrument display is divided into divisions. Each side from the center has four divisions. The left side is negative voltage and the right side is positive voltage. Refer to figure 5-2.

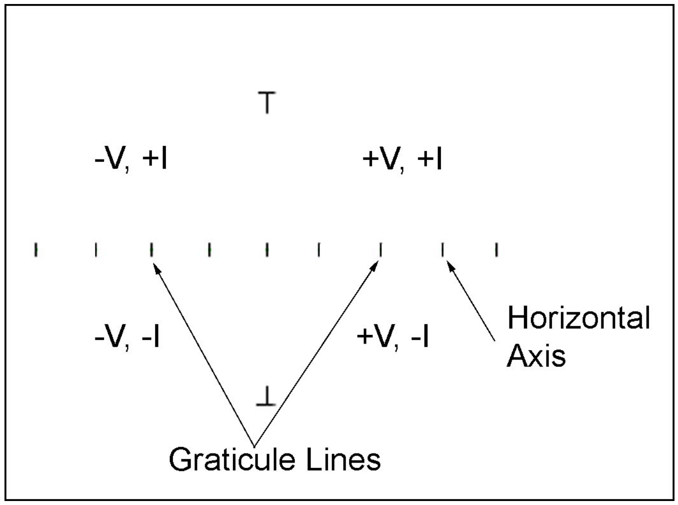
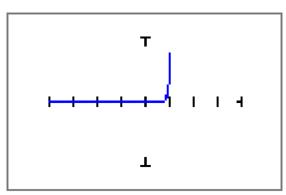


Figure 5-2 Graticule display

As an example, if the instrument voltage is set to 3V this means that the left side from center to the far left edge of the graticule is -3V. The center to the far right edge of the graticule is +3V. Dividing the voltage by four (the number of divisions on each side) will provide the "volts per division" value. In this example the volts per division would 3V divided by 4 which equals 0.75V. With this knowledge, you can calculate the voltage at which a diode will breakdown by observing where the diode conducts in relation to the graticule division marks.

Diode Signatures and Breakdown Voltage (Vbd)

The following example illustrates how a diode signature is displayed on the instrument display and how to calculate the diode breakdown voltage (Vbd).



Diode breakdown

Diode V-bd: 0.0V **Diode V+bd: 0.6V**

Breakdown voltage can be calculated visually by observing where the breakdown point occurs on the horizontal axis. In this example, the instrument voltage range was set to 3Vpk. This means that the voltage from the center of the graticule to the left or right edge is 3Vpk (see figure 5-3).

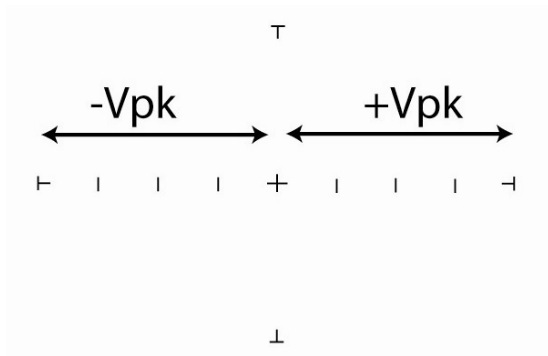


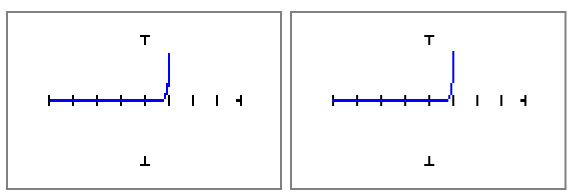
Figure 5-3 Tracker graticule

There are four divisions to each side of the graticule center (0.0Vpk) so if the peak voltage is divided by four, the voltage per division can be calculated. In this exercise the volts per division would be: 3Vpk/4 = 0.75V per division. The signature of diode shows the breakdown point occurring slightly before the first division mark so the visual breakdown voltage is roughly 0.6-0.7Vpk.

Effects of Changing Tracker Settings on Diode Signatures

The following exercises illustrate how a diode signature changes in response to variation of instrument frequency, resistance and voltage settings.

Changing Frequency – diode signatures

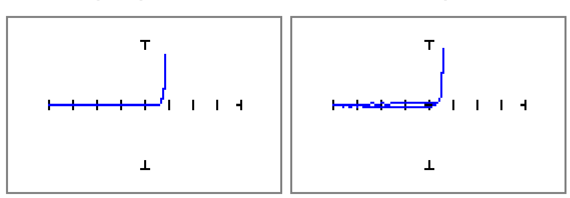


2000Hz 20Hz

Note that the signature changes very little when changing from a high frequency to its lowest. The voltage characteristics inherent to a diode are not sensitive to changes in frequency.

The effects of changing resistance

Changing Resistance – diode signatures

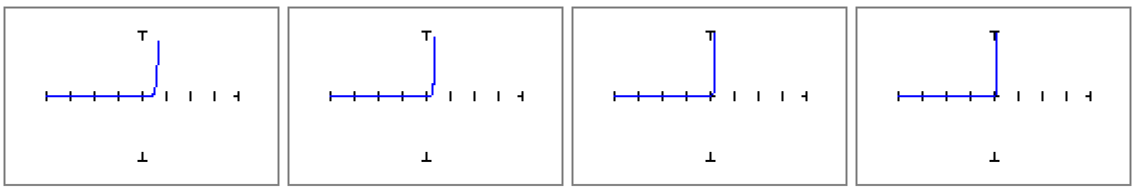


1KΩ 100KΩ

Note that the signature changes very little when the resistance is varied from a low setting to a high setting. The slight variation observed to due to the change in available current from the instrument. Since a diode has either very high or very low resistive characteristics depending on the voltage potential across the component, changing the instrument resistance setting will have little effect.

The effects of changing voltage

Changing Voltage – diode signatures



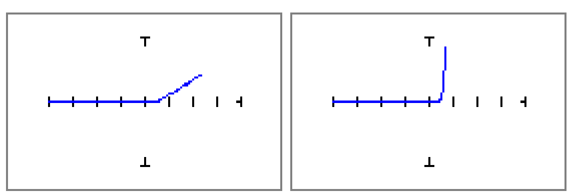
5V 10V 15V 20V

Note that the signature appears to change its breakdown point but what is actually happening is that the horizontal voltage scale is changing. As the voltage increases, the volts per division increases making the diode signature change. In the top voltage of 20Vpk the volts per division is 5V.

Diode Failures

Other than open or short circuits, semiconductor failures are generally resistive in nature.

Internal Resistance in a Diode

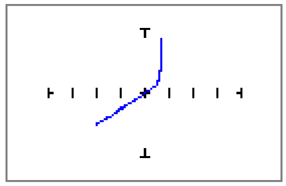


Internal Resistance No Internal Resistance

Note that the vertical portion of the first signature is angled indicating the presence of internal resistance. This is similar to the signature displayed when a resistance is added in series. The vertical portion of the signature returns to normal in the second signature when the series resistor is removed from the circuit.

Leakage in a Diode

Diode Leakage failure



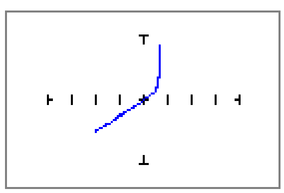
Diode leakage

Note that the horizontal portion of the signature is angled indicating the presence of diode leakage. This signature indicates that there is current flow through the device when it should be in a non-conducting state.

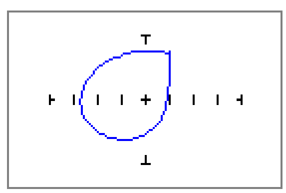
Composite Diode Signatures

Signatures that exhibit characteristics of several different types of components that are interconnected are called composite signatures. For example, a diode in parallel with a resistor will display a composite signature because characteristics of both a semiconductor and a resistor are shown in the signature. Composite signatures are more indicative of the signatures experienced in the "real world" of in-circuit troubleshooting.

Parallel Diode combinations



Diode and resistor



Diode and capacitor

By viewing the signature progression as components are added in parallel with the diode, you can see the effect of added resistance or capacitance on the horizontal portion of the signature. These types of signatures are common when troubleshooting components while in-circuit.

To illustrate the strength of variable ranges in the instrument to enhance or disregard various portions of a composite signature examine the following examples.

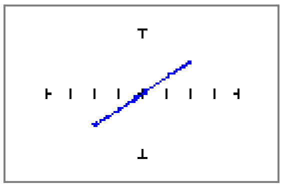
Adjusting Range with Parallel Diode combinations

Example 1: Diode with parallel 10KΩ resistor at low voltage (200mV)

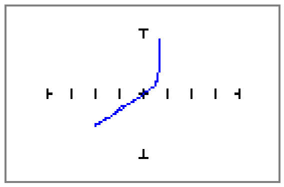
Example 2: Diode with parallel 10KΩ resistor at 3V

Example 3: Diode with parallel 10uF capacitor at low voltage (200mV)

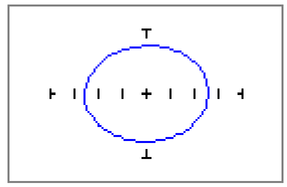
Example 4: Diode with parallel 10uF capacitor at 3V



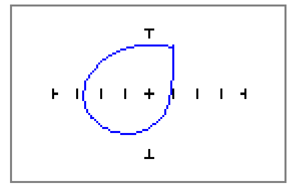
Ex. 1: 200mV, 10KΩ



Ex.2 : 3V, 10KΩ



Ex. 3:200mV, 100Ω



Ex. 4: 3V, 100Ω

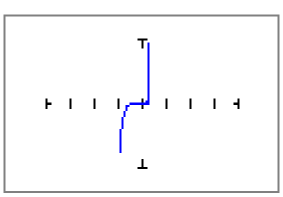
These steps illustrate how by manipulating the instrument range settings, signatures of the parallel components can be examined individually or in combination. Examples 1 and 3 are examples of “passive” testing where the test voltage is set below the 0.6V breakdown threshold of most silicon semiconductors. This essentially takes the diode out of the signature equation. Also observed is the method where by changing the resistance setting, the individual capacitor and resistor signatures can be isolated. An example of this is shown in Example 1 signature where the resistor is clearly displayed with little effect from the parallel diode.

Zener Diodes

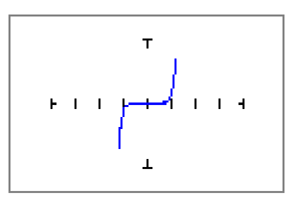
Standard diodes conduct when forward biased only and act as an open when reversed biased.

A zener diode is designed to conduct current when both forward and reversed biased. When forward biased it acts much like a standard diode and begins to conduct current with the forward voltage reaches approximately 0.6V. When reversed biased, they act as an open until the reverse voltage reaches the rated zener voltage at which time they begin to conduct current. For example, a 5V zener diode will begin to conduct reverse current when the reverse bias voltage reaches 5V. Even if the voltage increases higher than 5V, the measured voltage drop across the component will remain at 5V. This is a feature of zener diodes that allows them to be used for voltage regulation. Because they conduct in both directions, expect their analog signature to display two breakdown points or “knees”.

Zener diode signatures



Zener Diode



Two zener diodes in series

Note that the signature displayed has two voltage breakdown points. This type of signature is commonly referred to as a “zener pattern” or “zener signature”. Zener signatures are the most common type of signature encountered when testing integrated circuits (ICs). Combining two zener diodes in series essentially combines their voltage ratings.

Review for Diode Signatures

- The signature of a diode will display a forward breakdown point referred to as a “knee”. Zener diodes will have both a forward breakdown point and a reverse breakdown relating to its rated voltage.
- Diodes have polarity with the positive connection being the anode and the negative connection being the cathode. The signature will reverse if the component or test leads are reversed.
- Failures in diodes and other semiconductive components are usually resistive in nature. These faults usually require setting the ASA test instrument resistance range to a higher value such as 10KΩ. In some cases, the failure may appear as a rounding of the “knee”.
- The horizontal graticule can be used to approximate the breakdown voltage of a diode. Divide the instrument voltage setting by 4 to determine the horizontal volts per division.
- The flexibility of variable ranges allows for enhancing or disregarding parts of a composite signature for components being tested in-circuit.

Section 6 Testing Transistors

Introduction

A bipolar junction transistor is a three layer device of which there are two types. A PNP transistor has a layer of N type material inserted between two layers of P type material. A NPN transistor has a layer of P type material inserted between two layers of N type material. Figure 6-1 below illustrates their construction and also shows the schematic symbol used to represent both PNP and NPN transistors.

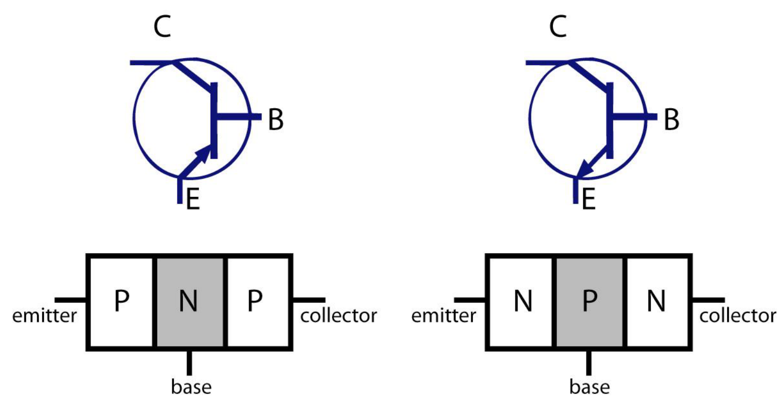


Figure 6-1 Transistor construction

In order to better understand the nature of transistor signatures we can model these devices in the terms of equivalent diode circuits shown in figure 6-2. This diagram shows the collector to base junction appears as a simple diode signature and the base to emitter junction appears as a zener diode signature. These signatures should be familiar to you from the previous section on diodes.

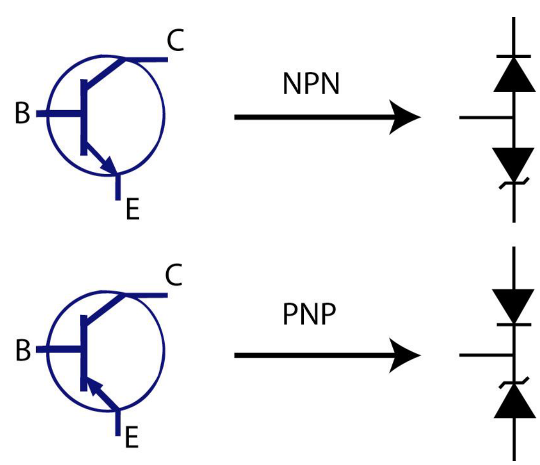
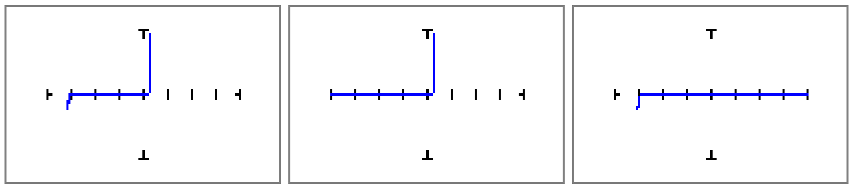


Figure 6-2 Transistor equivalent circuits

PNP and NPN Transistor Signatures

The following examples illustrate how NPN and PNP transistor signatures are displayed.

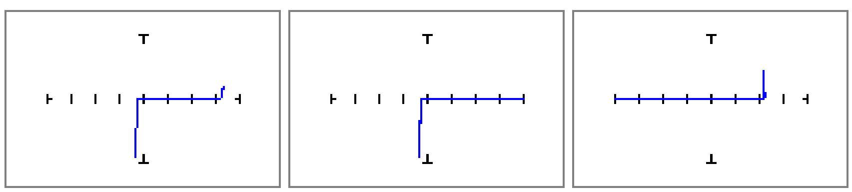
Typical transistor signatures – PNP



Base to Emitter   Base to Collector   Emitter to Collector

Note that the signatures displayed reflect the equivalent PNP circuit shown in figure 6-2. Also note that the reverse breakdown point shown on the emitter to collector signature is the close to the reverse breakdown for the base to emitter signature.

Typical transistor signatures - NPN



Base to Emitter   Base to Collector   Emitter to Collector

Note that the signatures displayed reflect the equivalent NPN circuit shown in figure 6-2 and are opposite in polarity when compared to the PNP signatures. Also note that the reverse breakdown point shown on the emitter to collector signature is close to the reverse breakdown for the base to emitter signature.

Using the Pulse Generator or DC Voltage Source to Test Transistor Operation

ASA test instruments with a DC Voltage Source or Pulse Generator can be used to assist in testing transistor operation. An external power supply could also be utilized. Functioning as a basic curve tracer, voltage is applied to the base of the device while monitoring the collector-emitter signature shown on the instrument display. The constant current signature produced is similar to those produced by a transistor curve tracer except that only one curve is shown instead of a family of curves. This technique can be useful in for testing function and matching transistor gain. Figure 6-3 shows the test circuit for a NPN transistor using the DC voltage source to drive the base.

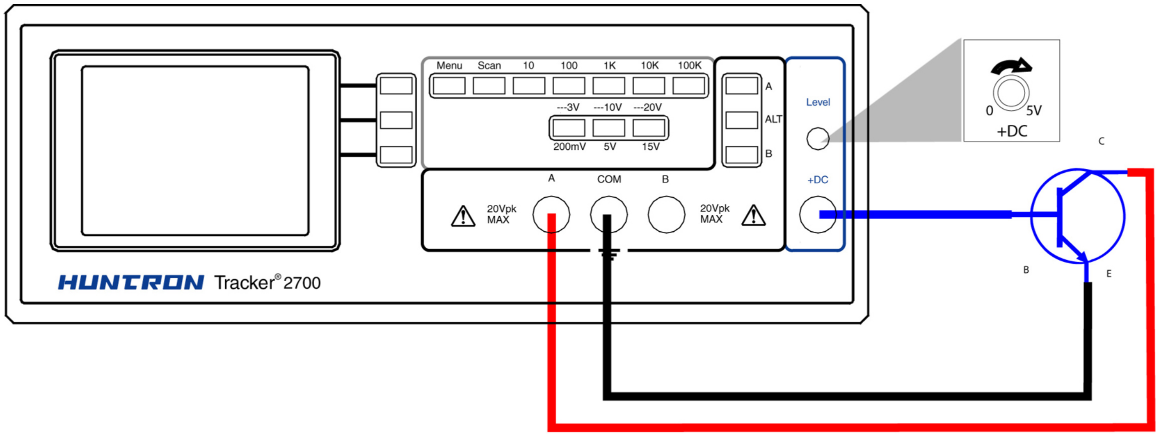
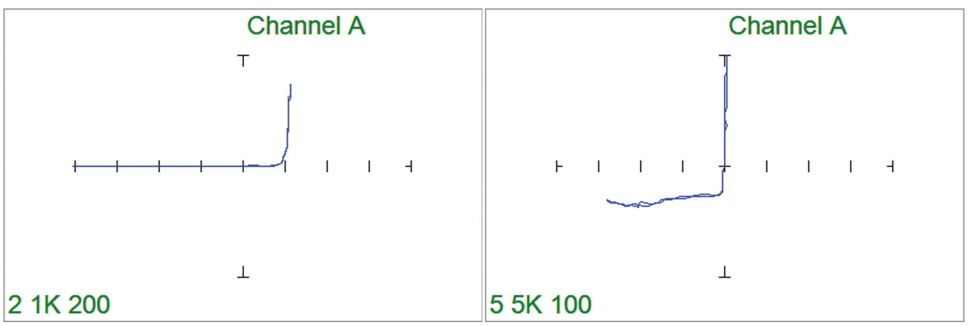


Figure 6-3 Testing a transistor with a DC Voltage Source

Displaying transistor gain



Signatures of PNP transistor with 0V on the base (left) and 0.5V on the base (right)

Observe the signature reaction on the display. It is possible to figure transistor gain by noting the signature at different voltage levels. Note that as the voltage to the base increases the impedance of the emitter-collector connection decreases.

Review for Transistor Signatures

- The signatures of a transistor will display a forward breakdown point and a reverse breakdown point.
- Transistors have polarity and the signatures will reverse if the component or test leads are reversed. NPN and PNP transistors will display signatures that exhibit reversed polarity when compared to each other.
- Failures in transistors and other semiconductive components are usually resistive in nature. These faults usually require setting the ASA test instrument resistance range to a higher value such as 10KΩ. In some cases, the failure may appear as a rounding of the “knee”.

- ASA test instruments can be used to determine transistor type (bipolar, Darlington, etc.), polarity (PNP or NPN), or pin configuration (base, emitter, collector) and also be used as a basic curve tracer for matching transistor pairs.
- The flexibility of the ASA test instrument ranges allows for enhancing and disregarding parts of a composite signature for components being tested in-circuit.

Section 7 Testing the Operation of Switching Devices

Introduction

Switches are electrical devices that either stop or allow current flow within a circuit. In the world of electronics, “switching” is often referred to as a basic function that can be performed by a variety of devices. All of these devices are similar in that they are either on or off. They are different because of the way they are turned on or off.

Switching devices come in many different configurations from simple mechanical switches such as relays to semiconductive devices such as optocouplers or SCRs. Because of this variety of switching devices, each type is tested in a unique way. Using ASA to test switching devices allows us to ignore the differences and concentrate more on the switching function itself. This section will explore how different switching devices are tested and also how the DC voltage source or Pulse Generator can be used to gate these devices.

Testing Switch Devices with the DC Voltage Source or Pulse Generator

Many switching devices are voltage controlled. Devices such as relays respond to a changing voltage to turn the switch on and off. Semiconductive switches such as SCRs and TRIACs respond to voltages above a certain level to activate the switching function. All of these types of devices can be tested dynamically using the DC Voltage Source, Pulse Generator or an external power supply to apply a controlled voltage that will activate the switching function.

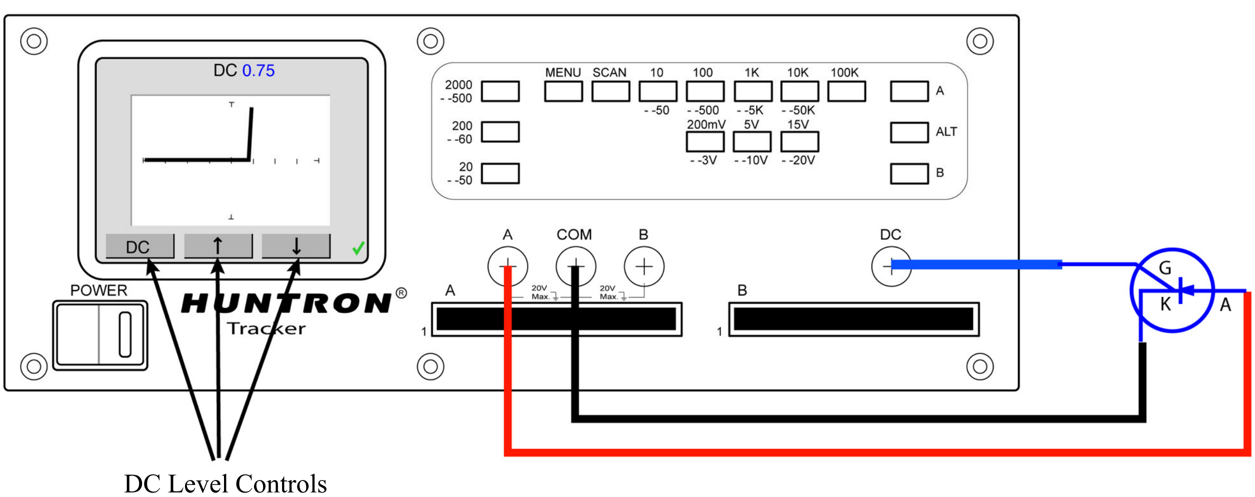
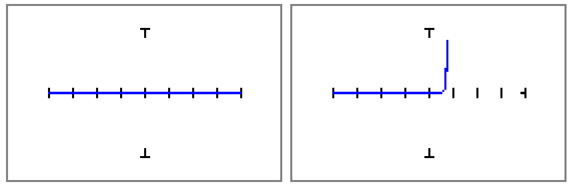


Figure 7-1 Testing a SCR with a Huntron Tracker

Testing a Silicon Controlled Rectifier (SCR)



SCR - No voltage SCR - Voltage applied

Silicon controlled rectifiers are essentially a voltage controlled diode. If the gate is at the same voltage level as the cathode then the SCR acts as an open. When the voltage level applied to gate is more positive than the cathode (typically at 0.6V), current flows between the anode and cathode.

Testing a TRIAC is very similar to the SCR test with the exception that you see the cathode to anode signature bias in two directions (similar to a zener diode). This because a TRIAC is a bidirectional switched device.

Testing a Relay

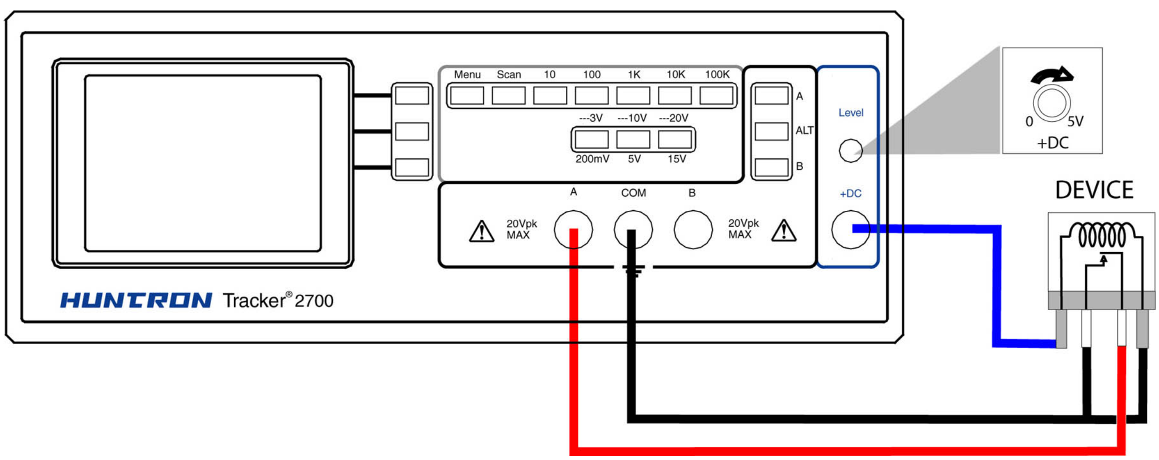


Figure 7-2 Testing a Relay with the Huntron Tracker voltage source

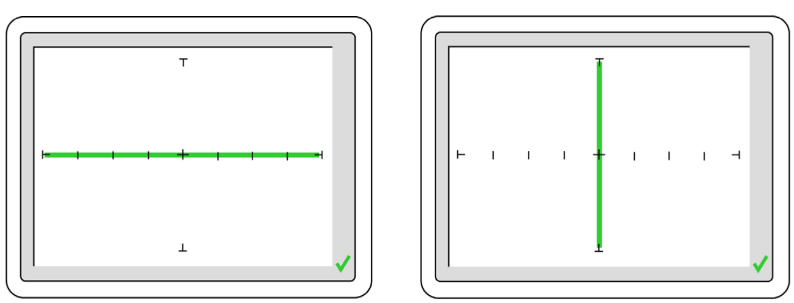


Figure 7-3 Signatures from relay test – OFF (left); ON (right)

Note that the signature becomes a short circuit when the voltage is increased enough to activate the mechanical switch. The voltage level that activates the relay can vary depending on component design. This relay is "normally open" meaning that the switch contacts are in an open position when the device is in a non-powered state. "Normally closed" relays will show a short circuit signature across the switch contacts when in a non-powered state. The voltage level necessary to activate a relay will vary depending on the construction of the device.

Testing an Optocoupler (optical switch)

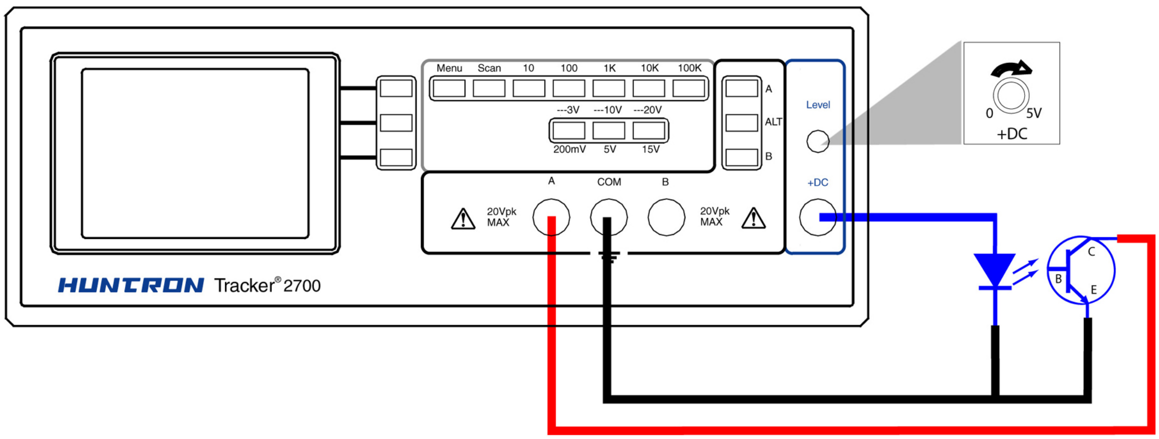
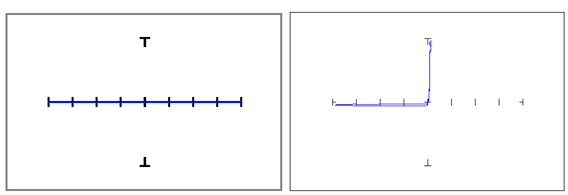


Figure 7-3 Testing an optocoupler with a DC Voltage source



No voltage Voltage applied

When the voltage applied by the DC Voltage source reaches a certain level the optocoupler will bias and the signature will change. Also note that the optocoupler reacts in a similar way to a common transistor in the Testing Transistors (Section 6) section.

Review for Switching Devices

- ASA test instruments will test switches in real time. This makes it an excellent method for detecting noise, contact bounce, resistance and intermittent contact. Test for these types of problems in a low resistance setting such as 10Ω.
- Testing SCRs and TRIACs can sometimes be problematic. Utilizing the DC voltage source or pulse generator to bias these devices allows you to actively view their operation. Their typical

application (high current switching) makes these devices high fatality components and susceptible to degradation and eventual failure.

- Relays are an electrically controlled switch that can be easily tested by using the DC voltage source or pulse generator to activate the device while monitoring the signature of the switch contacts.
- Operation of an optocoupler can be tested using a ASA test instrument and the built-in DC voltage source or pulse generator. Optocouplers are commonly used to isolate parts of a circuit board and come in a wide variety of configurations.

Section 8 Testing Integrated Circuits

Introduction

One of the strongest ongoing trends in electronics today is the push towards making everything smaller. Where digital circuits were once made from discrete transistors, hundreds of these same digital circuits can be embedded on a small chip. This trend will only intensify so it is important to understand how analog signature analysis can be used with this type of circuitry.

Why an Integrated Circuit (IC) Fails

Nothing mysterious happens to a working semiconductor when it fails or suffers degradation. All failures affect the basic nature of these devices to conduct current. The most common causes of IC failures are:

EOS: Electrical Over Stress. The ICs electrical specifications have been exceeded. This can cause opens and shorts.

ESD: Electrostatic Discharge. Repeated exposure causes resistance to build in the device junctions. The range of resistance varies from 5KΩ to 25KΩ with a typical value of 20KΩ. ESD will cause resistance, opens and shorts.

Dendrites: Hair-like particles that grow between conductors on a substrate causing shorts.

Ionic Contamination: Contamination introduced at the time of manufacturing that develops into leakage between substrate channels. This can cause 5KΩ to 25KΩ of resistance.

Purple Plague: Interaction between gold and aluminum will cause junctions to become very brittle causing opens.

Corrosion or Metallization: Aluminum metallization can cause electromigration, pinholes, corrosion and resistance. This will cause opens and resistance.

Digital Integrated Circuit Signatures

Digital integrated circuits chips are made from semiconductor transistors on a common substrate. Since they are semiconductors, their signatures are variations on the basic diode and transistor signatures observed in earlier parts of this document. Most logic ICs contain multiple circuits of the same type on one chip. These chips often only have a few different signatures despite the fact that they may have many pins. This can make troubleshooting easier by providing easy to find signatures to use for comparison. For example, the integrated circuit schematic shown in figure 8-1 is a 74LS245 Octal transceiver or bi-directional bus buffer.

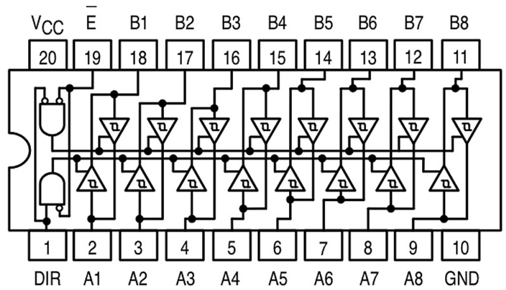


Figure 8-1 74LS245 Octal Transceiver

By examining the circuit drawing closely, four different pin types can be identified. Pins 2 through 9 and 11 through 18 are all connected to both an input and output of a buffer. Pins 1 and 19 are both enable lines and inputs to AND gates (although their names are different). Pin 10 is ground and pin 20 in Vcc. Each pin type will display a signature typical for that circuit and can be used for comparison when testing the other similar pins. For example, the signatures of the address lines A1 through A8 should all have similar signatures.

This same thought process can be used when examining these 74LS14 and 74HC14 IC diagrams.

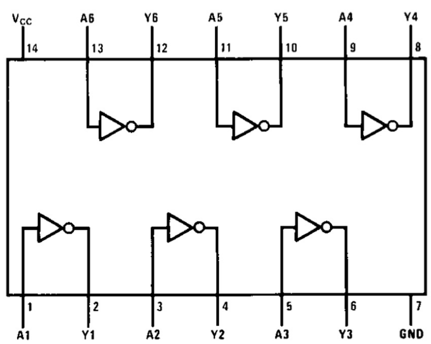
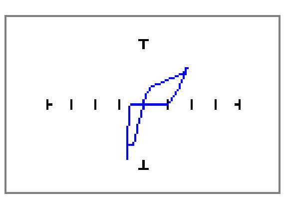
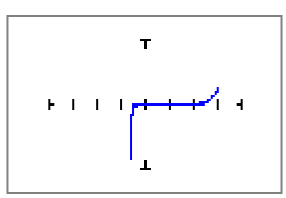
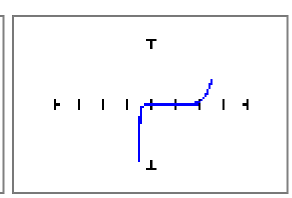


Figure 8-2 74XX14 Hex Inverter IC Pin-out

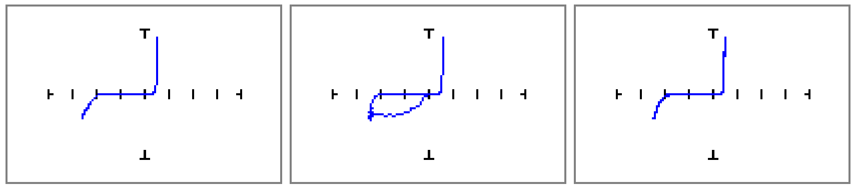
Examining signatures of a logic IC

74HC14 Output pins 74HC14 Input pins 74HC14 Power pin

Note that the signature patterns displayed match the circuit type shown in Figure 8-2. When troubleshooting this device, similar pins could be compared against each other.

Testing TTL circuits with reference to Vcc



74HC14 Output pins   74HC14 Input pins   74HC14 Ground pin

Testing ICs with reference to Vcc may show fault differences not shown when testing with a GND reference. Though this is not common, it is possible. A good practice may to start testing with GND as the common reference and using Vcc as a secondary alternative.

Signatures of Different IC Families

TLL is considered to be one of the primary logic IC families. However, there are other types of ICs that are not TTL but perform very similar functions. Although the logic is the same, there are several differences in the circuitry of each type and these differences are reflected in the ASA signatures.

To examine these signature differences in logic IC circuit types, the signatures of two different hex inverters will be investigated. The 74HC14, and 74LS14, are both hex inverters and have identical truth tables. Figure 8-3 shows that pin arrangement and logic functions are the same but the 74LS14 uses Schottkey transistors and has higher power consumption whereas the 74HC14 use CMOS (complementary metal-oxide-semiconductor) technology for faster switching speed and reduced power consumption.

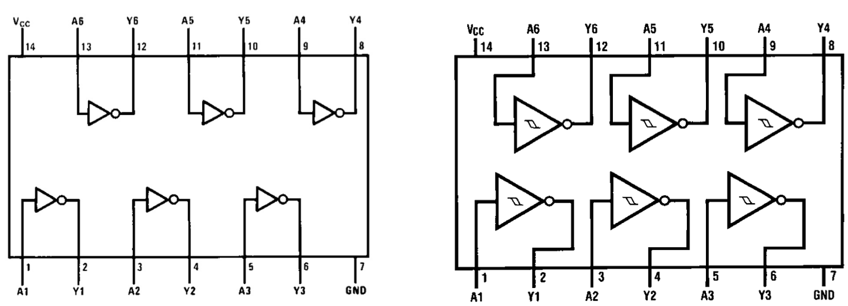
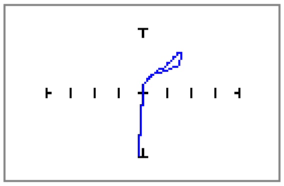


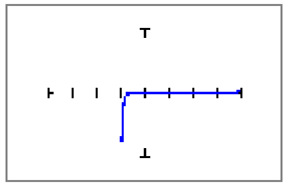
Figure 8-3 74XX14 Pin out configurations (LS on left, HC on right)

Note that there are only four types of circuit connections; input, output, power (Vcc) and ground. This means that there will only four types of signatures displayed when testing the individual component pins.

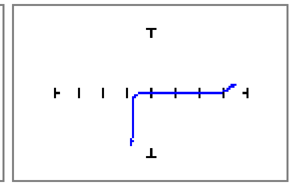
Comparing Two Hex Inverter ICs



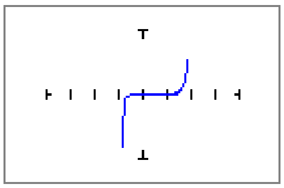
74HC14 Input pins



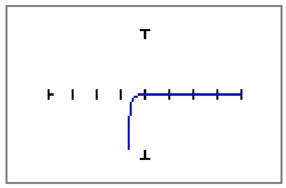
74HC14 Output pins



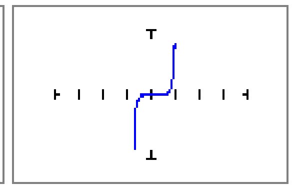
74HC14 Power pin



74LS14 Input pins



74LS14 Output pins



74LS14 Power pin

Because of the differences in the internal construction of the two inverter ICs, the similar pins have different signatures. To test one of these ICs without a comparison IC, one only needs to compare each input against the other input pins and each output pin against the other five output pins. The basic idea is to identify the patterns displayed in the signatures of similar pins.

Testing Analog ICs

Of all of the analog ICs in use today, operational amplifiers, commonly called “op amps” are probably the most common and present another troubleshooting challenge. Each pin can display a different analog signature. These signatures are a result of the internal architecture of the IC and the connected circuit elements.

Op amps are best tested by comparing component signatures on a bad board with those on a known good board.

In this example, a known good LF412 component will be used for signature comparison when looking for a fault on the suspect IC. The circuit diagram for the LF412 op amp is shown in figure 8-4.

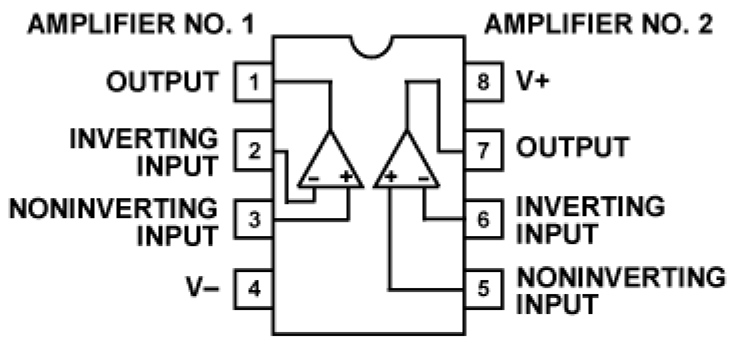
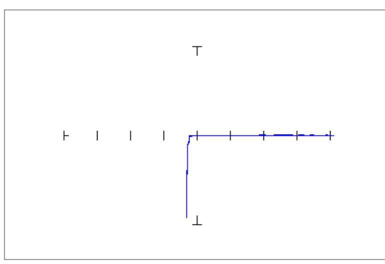
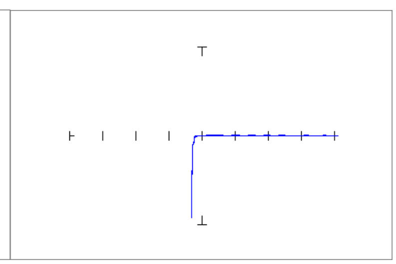


Figure 8-4 LF412 Operation Amplifier Pin configuration

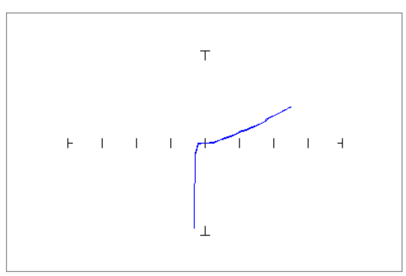
Op Amp signatures

Note that similar pins have similar signatures when compared against each other.

Non Inverting Inputs Pin 3 Pin 5

The fault on pin 5 of a faulty component shown in the signature below is caused by a resistive short to Vcc. This type of fault is indicative of the types experienced in the real world.



Pin 5 resistive fault

Op amps can also be checked using other methods that can be explored independently. One method is to test the op amp using the output pin as the common reference while making a signature comparison between the – and + pins of the device. This method works well when an op amp is isolated from power and ground. When there is more than one op amp in a package (“dual” and “quad” op amps), compare the op amps against each other looking for significant differences. This comparison technique will also work well with comparator ICs.

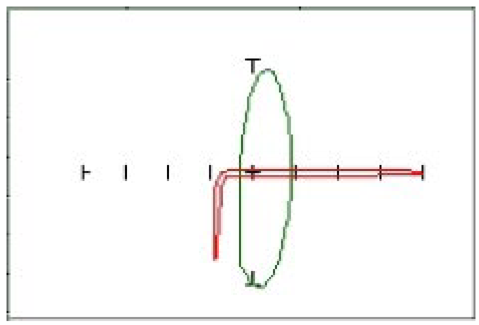
Review of Testing Integrated Circuits

- Digital ICs can fail in several ways but the failures are generally resistive in nature. Using a resistance range setting of 5KΩ to 20KΩ will help find these types of problems.
- Having information about a digital ICs pin-out can help troubleshoot the component. In many cases, a digital IC will have only a few unique signatures such as input, output, voltage and ground pins. It is an easy task to compare similar pins against each other looking for similarities. A difference in signatures may indicate a problem.
- ICs with the same logic table but different design structure (i.e. 74LS14 versus a 74HC14) will typically show different signatures when comparing the same pins. The internal circuit construction causes these differences.
- Using the ALT (alternating) mode makes the comparison of two digital ICs quick and easy. Comparisons can be made at the pin level (i.e. comparing similar pins on the same component) or at the component level (i.e. comparing the same component on a good versus bad circuit board).
- Troubleshooting microprocessor bus circuitry can be difficult and success depends on good troubleshooting skills and ability to isolate problems to the component level. Knowledge of the board under test, a good visual inspection and comparison mode will help deal with detecting problems in bus circuits.
- Comparing similar bus lines against one another can lead to a fault without having to memorize every possible signature. Address lines should exhibit the same signatures as well as data lines. If schematic diagrams are not available, find the pin-out configuration for various ICs to help determine which pins are address lines, data lines and control lines. Use the comparison mode to easily compare one bus line against the other similar lines.
- When comparing bus lines, watch for patterns that indicate whether a signature is good or suspect. Also note that if a bussed component has more than one bad signature besides a faulty bus line then that component is likely to be the actual failure.
- Begin testing complex boards by probing its connectors. In many cases, faults caused by outside influences can be detected and traced back from the connector to a faulty component.
- Treat SMT devices the same as their through-hole equivalents but realize that a lower test voltage will likely be needed to obtain a useful signature. Try testing SMT devices at 3 volts or lower.
- When attempting to isolate the faulty component on a bus, it may be necessary to use a unique pin on an IC as the common reference. Pins such as chip enable, output enable, row address strobe and column address strobe are all unique bus pins.

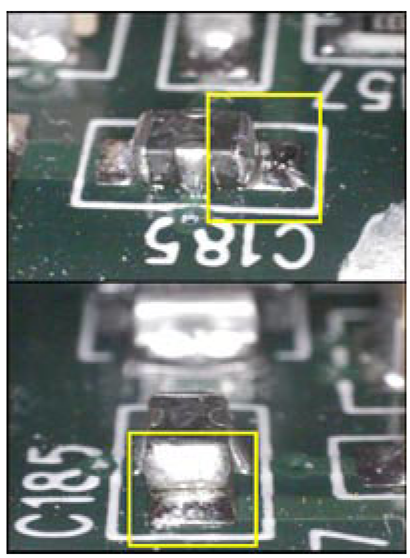
Section 9 Analog Signature Analysis Failure Examples

Example 1

The image below shows signature differences detected on an actual customer PCB. The issue here is that the capacitance shown in the green good signature (the elliptical signature) is no longer shown in the red bad signature which now shows just a diode shape. This means that the capacitance that is normally in parallel with the semiconductor is no longer there. This indicates a possible open connection to the capacitor.

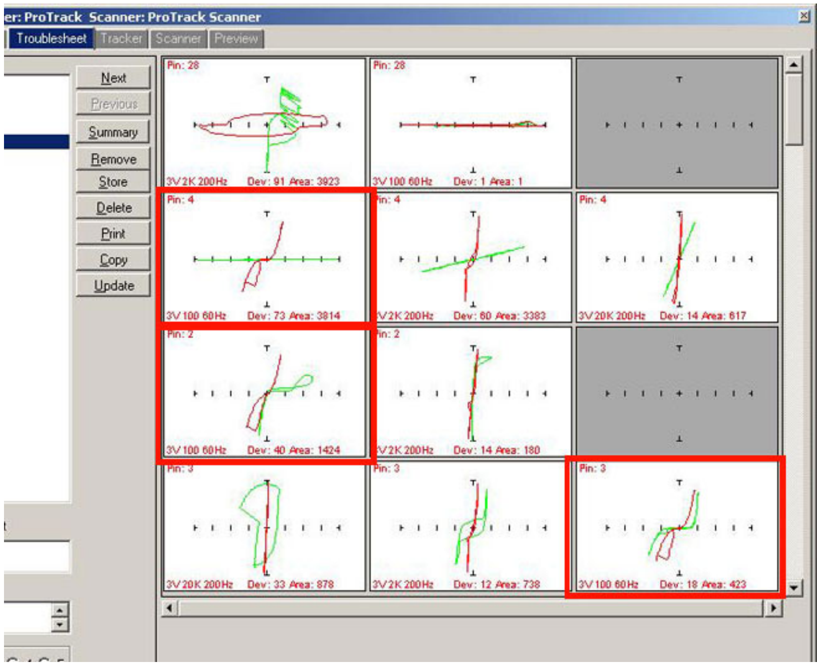


Upon closer inspection of the suspect area in the image below, the true problem is apparent. Note that the solder connection to the capacitor is bad. This is causing the open problem indicated by the signature analysis.



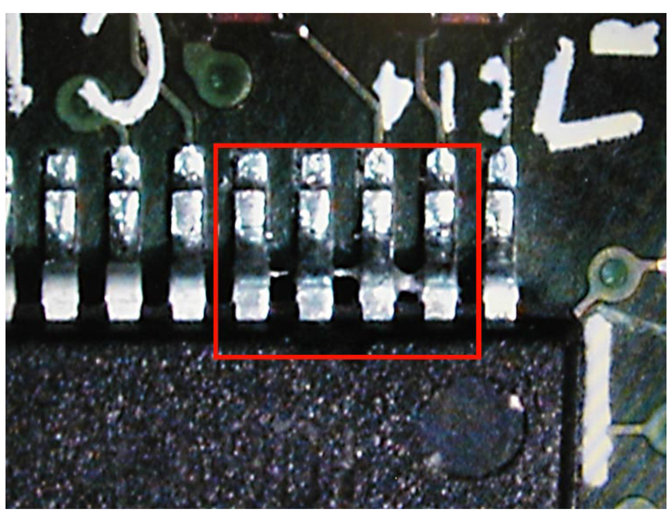
Example 2

The key signatures in this analysis are indicated with red boxes. Note that the red signatures are the same where the green signatures for those same pins are very different from each other.



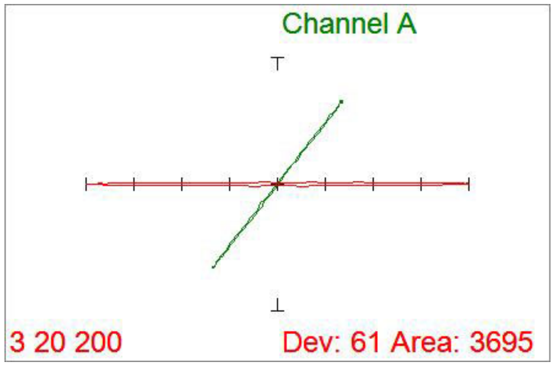
The only way these signature differences are possible is by a very low resistance short circuit connecting the pins together. Note that pin 4 normally indicates a resistive signature (the angled signature in green; very likely caused by a connected pull-down resistor) whereas the red signature indicates that the normally connected resistance is being bypassed. In Signature Analysis troubleshooting, any resistive change is worth investigating.

Further analysis with a high powered video camera of the suspect pins (see image below) verified the actual problem of pins shorted together by solder. This appears to be production process error.

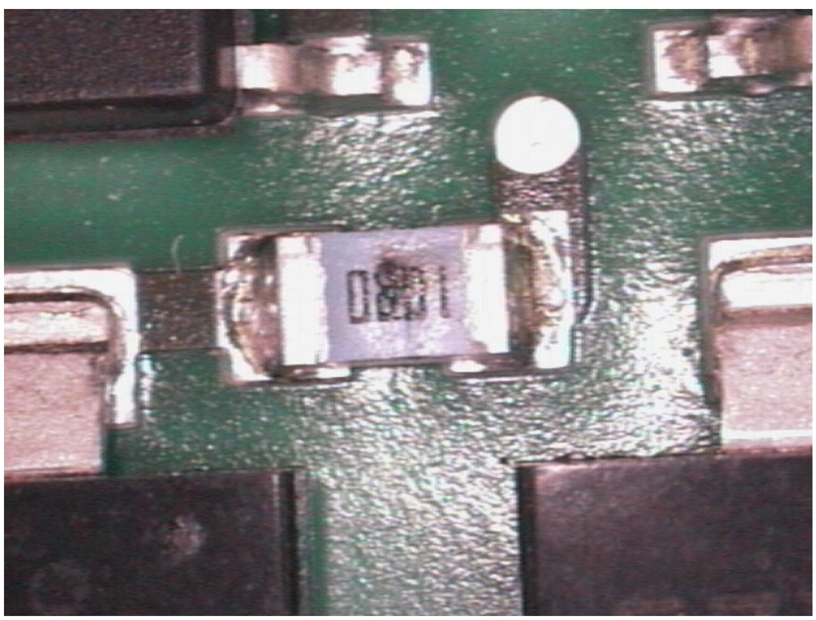


Example 3

In this example, the good (green) signature indicates the presence of a resistive component. Based on the signal ranges setting indicated and the angle of the signature, the value is approximately 10 ohms. The bad (red) signature is indicating a severe increase in resistance which means that the component has become very resistive or has become an open.



Inspection with a video microscope shows a burn mark in the center of the resistor. It is likely that this component was subjected to excessive current which caused to become an open circuit.



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