Abnormalities Ensuing from Back-Tracing and Probe Selection or What Can We Do to Mitigate Diagnostic Problems

Larry V. Kirkland
WesTest Engineering Corp.
810 Shepard Lane
Farmington, Utah 84025
801-451-9191 ext 124

ABSTRACT – Fault localization should always be a top priority with TPS re-host or new development. In fact, diagnostics should be a first step and the most critical step. Fault isolation should be a conscience effort as the main-line program is developed. During main-line program development an engineer could perceive fault isolation problems that might arise and then adjust the main-line to refine the testing such that smaller or more precise sections of a circuit will be tested so that fewer components come into consideration. Current flow problems can arise that don't appear obvious at the time Test Requirements Documents (TRD) are prepared and thus the circuit test can be weak or somewhat incomplete. We need to augment or improve the test requirements through-out all phases of circuit design and testing.

A probe can be any conductor used to establish a connection between the circuit under test and the measuring instrument[1]. Standard probing techniques like the back-trace probe have proven effective. However, there are shortcomings with the standard back-trace probe. At times, the standard back-trace probe can cause diagnostic problems which can be deceiving. These deceiving problems tend to contribute to wrong callouts and mis-information. If the probing is defective then the diagnostics is defective.

A "perfect" probe is nice to dream about. But in reality, no probe is perfect. Even a simple length of wire is still potentially a very complex circuit. For dc signals, a probe appears as a simple conductor pair with some series resistance and a terminating resistance. However, for ac signals, the picture changes dramatically as signal frequencies increase.

Any length of wire has distributed inductance (L), and any wire pair has distributed capacitance (C). The distributed inductance reacts to ac signals by increasingly impeding ac current flow as signal frequency increases. The distributed capacitance reacts to ac signals with decreasing impedance to ac current flow as signal frequency increases.

The interaction of these reactive elements (L and C), along with resistive elements (R), produces a total probe impedance that varies with signal frequency. Through good probe design, the R, L, and C elements of a probe can be controlled to provide desired degrees of signal fidelity, attenuation, and source loading over specified frequency ranges[4].

There are probing techniques that must be considered under certain diagnostic tests. There are circuit configurations that just don't respond well to the standard back-trace probe. During integration of a Test Program Set (TPS), whether a re-host or a new development, when fault insertion is being performed, problems with the standard back-trace probe might arise. If the engineer becomes aware of probing problems there needs to be a plan of action to resolve the issue. We should never dismiss any issues encountered in TPS development. The worn out comment "it can't be diagnosed" should never be a part of TPS development.

Voltage probes are intended to measure or display voltages on the Unit Under Test (UUT). Ideally, the test instrument and its probe will not affect the voltage being measured. Practically, that translates into the test instrument and its probe presenting a high impedance that will not load the UUT. In many situations, an impedance with a resistive component of a meg ohm is adequate. For AC measurements, the reactive component of impedance may be more important than the resistive.

Because of the high frequencies often involved, oscilloscopes do not normally use simple wires to connect to the UUT. Instead, a specific *scope probe* is used. Scope probes use a coaxial cable to transmit the signal from the tip of the probe to the oscilloscope, preserving high frequencies for more accurate oscilloscope operation. Scope probes fall into two main categories: passive and active. Passive scope probes contain no active electronic parts, such as transistors, so they require no external power.

There is an alternate technique which can be deployed when back-tracing in certain situations that seems to be effective. This technique involves the use of a little known EME probing technology. Properly configured EME equipment can detect and analyze signals without all of the short-comings associated with standard back-tracing. It is imperative the user have an understanding of problems that could arise from back-tracing and what action they can take to derive a proper diagnostic analysis.

This paper will discuss probing problems and fault isolation techniques. Also, this paper will discuss ways to mitigate probing problems and address various diagnostic techniques the TPS developer or the test technician can use to diagnose a fault. Diagnostics and probing techniques can be adjusted to produce the best possible result. The EME technique will be explained with its' various requirements.

I. INTRODUCTION

There are inherent problems that occur with circuit diagnostics. Accessibility and the thru-put problem arises from circuit accessibility, complicated state transition sequences when trying to control the circuit (very high rate, edge changes) and observance of what's really happening at some internal circuit element. Some of the Back Trace Probing[2] problems (see figure 1) that could arise are:

1. Encountering a package that cannot be probed during the back trace
2. Test leads and fixtures are susceptible to leakage due to moisture absorption in insulating materials and "dirty" surface films[3].
3. Convergence or fan-out of back trace paths
4. Effect that feedback in the circuit under test has on backtrack probing
5. Test results are inconsistent
6. Tester problems (especially noise) - Legacy systems or even new systems can have this problem - this is a critical part of new Automatic Test Equipment (ATE) fabrication
7. Marginal voltage levels or timing on the board - Variations occur quite often and are difficult to set
8. Capacitive loading introduced by the probe can affect signal rise/fall times
9. Fault in an asynchronous loop will cause all packages in the loop to exhibit both failed inputs and outputs. Thus, a 'ring' of failed segments is formed, and the actual fault site cannot be explicitly located.
10. Intermittent component failures - Back trace may be hopelessly confused by the inconsistent results
11. Others or commons:
    a. Many back trace probes are prone to mis-probe problems when 8 or more probes are required
    b. Package layout
    c. Package location
    d. Probe tip/type
    e. Sequence
    f. Loops
    g. Fan-out
    h. Various loading problems
    i. Capacitance and/or Inductance
    j. Random noise
    k. Ground wire length
    l. Ground Point
    m. Circuit configuration
    n. Loops
    o. Improper grounding
    p. Mis-probes
    q. Test lead quality

If anyone needs convincing about the effects that scope probes can have on a signal, consider this example of a logic gate shown in Figure 2. The measurement at the gate's output (V_{Out}) would be a square wave, of course. Adding a second probe to the input would increase the capacitance at C1.

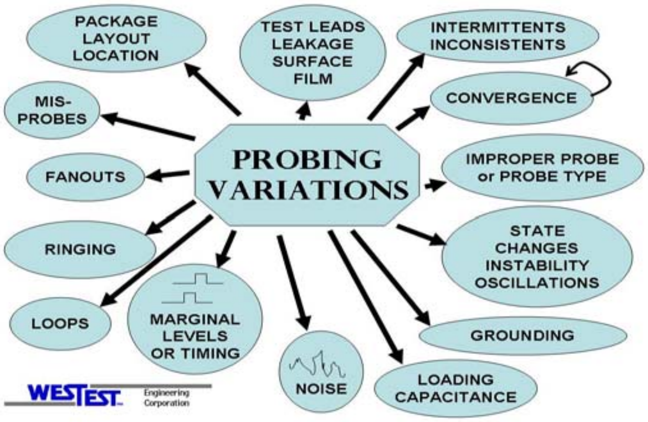

Figure 1. Probing Variations

If that second probe is a low-capacitance probe, the added loading brings the gate's switching speed from about 77 MHz down to 58 MHz. A standard probe degrades the situation further, dropping the switching rate to 33 MHz. Given that a Schmitt trigger inverter gate like this is a basic building block of digital design, one can see how much probe loading can adversely affect circuit behavior[4].

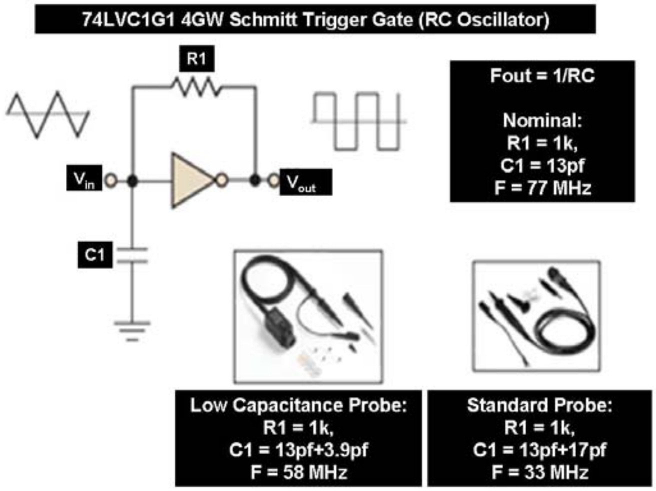

Figure 2. *This diagram illustrates the effect that scope probes can have on a signal. A low-C probe at C1 brings the gate's switching speed from about 77 MHz down to 58 MHz. A standard probe drops the switching rate to 33 MHz. (courtesy of Tektronix)*

Does current always flow as planned? In a series circuit (on a good board), the current through each of the components is the same, and the voltage across the components is the sum of the voltages across each component. In a series circuit (on a bad board), the current through each of the components is different, depending on the fault, and the voltage across the components is different, depending on the fault, across each component[7]. In a parallel circuit(on a good board), the voltage across each of the components is the same, and the total current is the sum of the currents through each component. In a parallel circuit(on a bad board), the voltage across each of the components varies, and the total current is the sum of the currents through each component. Another issue is that current always returns to its source and that the flow of current will follow the path of least impedance. If another signal line provides the lowest impedance path, much of the return current will be within that other signal line, leading to crosstalk between the two lines producing a signal integrity issue. The loss of signal integrity can lead to a number of problems, including but not limited to, jitter or phase noise, crosstalk, improper triggering (including multiple triggering and lack of triggering), and even a complete breakdown in a signal.

II. Probing situations

Issues with probing or diagnostics generally occur during the integration phase. During fault insertion you may experience inconsistent results, callout problems, or path inconsistencies. Sometimes an engineer will merely add a chip to the callout; this can be effective under specific circumstances but can produce further problems if the diagnostics path is large with a potential for several probes. In all cases the engineer should evaluate the diagnostic path and determine what exactly is happening. If it is evident the diagnostics is not functioning as theorized then the engineer should determine where the problem arises. There are many reasons why the diagnostics is not performing properly, so the engineer must find the root cause for any given situation and take the appropriate action to correct the diagnostic anomaly.

There can be probing problems introduced by the engineer or the simulator requiring excessive probing to determine a fault. As shown in figure 3, the possibility of a mis-probe tends to increase exponentially after 8 to 10 probes. It is a fact that following a board layout and finding the component and pin for each probe can become tedious and prone to problems as the number of probes increases. Even with circuits that tend to fail in the same area for most of the units repaired, the diagnostic paths are not always memorized.

Probing the various nodes of the components of UUTs is crucial for understanding the circuits and there reaction to testing. Probes can be thought of as little spears that are aimed at targets on a board[5]. Trace dimensions continue to shrink along with device and pin sizes, the targets we want to probe become smaller to the point where they cannot be hit reliably. Consider that PC trace widths used for controlled impedance boards have very strict line width and space requirements.

Robust software compensates for EME probe proximity errors. Also, EME probing is non-contact so the shortcomings with standard probing are not relevant. EME probing can be incorporated into ATE systems.

In modern high-speed designs, trace widths and spaces as small as 3 mils (0.076 mm) may be used. At gigabit data transmission rates, there is little tolerance for deviations in these specifications. Thus, asking a designer to add a 35-mil target to a 3 mil wide trace is not likely to be met with friendly acquiescence.

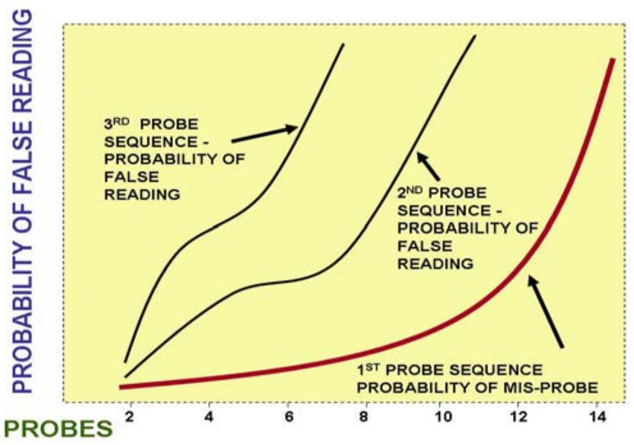

Figure 3. # of probes

Detailed or prolonged probing sequences can produce inconsistent results. Should the user have a mis-probe and back-up with probing there is a tendency of capacitance that can be produced. What can happen is a slight amount of capacitance might produce a voltage change significant enough to cause an erroneous failure. The problem worsens as erroneous failures propagate and further erroneous failures occur.

III. Strategies

If you encounter a package that cannot be probed realistically by a single back trace probe, consider using a DIP-CLIP. Also, you can skip over a package with the proper setup of stimulus. Evaluating specific inputs of a hard-to-probe chip can be an efficient way to perform diagnostics. It is important to note that there are thousands of circuit designs so individual evaluation is critical.

Convergence or fan-out of back trace paths consists of a path between two or more points that seems like a fixed physical path, but actually is one path out of many possible physical paths is possible. The merging or joining of parallel paths into the same node in a circuit diagram occurs quite often. Problems come in all shapes, sizes, and disguises, but convergence problems do exist. Fan out describes how many logic inputs can be controlled by a single logic output without exceeding the current ratings of the gate. The minimum practical fan out is about five. Modern electronic logic using CMOS transistors for switches have fan outs near fifty, and can sometimes go much higher. The optimal approach to handling large fan out probing is circuit dependent however, there can be useful algorithms and specific engineering test techniques to control the circuit during testing.

Capacitive loading introduced by the probe can affect signal rise/fall times. When the load capacitance of the probe you are using is significant compared to the capacitive load the UUT is designed to drive, your chance of making an accurate measurement is substantially reduced. Remember that the total capacitive loading for a UUT is a combination of the designed-for capacitive fan out, environmental capacitance, and the probe input capacitance. The ratio of the probe capacitance to the UUT capacitance alters the original waveform geometry in both the vertical axis as well as the horizontal axis by that ratio[6]. The effect of incremental probe input capacitance on typical high-performance logic family gate-to-gate signal delay and rise-time is to increase the propagation delay and slow down the signal rise-time. To obtain the least measurement error and lowest propagation delay as a function of probe loading, the lowest characteristic probe input capacitance should be used.

There is an effect that feedback in the circuit under test has on back track probing. Probing a feedback path can affect the phase margin of a feedback circuit causing state changes, instability, and / or oscillations. Feedback paths are common and should be considered during TPS development and re-host. Feedback is when some of the output signal from a circuit is fed back to the input and combined with the input signal. Solutions include breaking the feedback loop, either by properly engineering your stimulus patterns or by physically forcing pin state with a clip on a chip (you sometimes have to do this anyway, just to initialize such circuits, but engineers don't always use this for improved probing resolution).

Test results can be inconsistent. Unlike intermittent fails, which appear in weakened components under changes due to operating environments, inconsistent fails can appear when tested using Automatic Test Equipment (ATE) and they appear in both good chips and bad components. Setting up circuit timing can be critical, each individual timing characteristic must be evaluated, see figure 4. It is very important to note that noisy test equipment or weak instrumentation can contribute to the inconsistent test problem significantly.

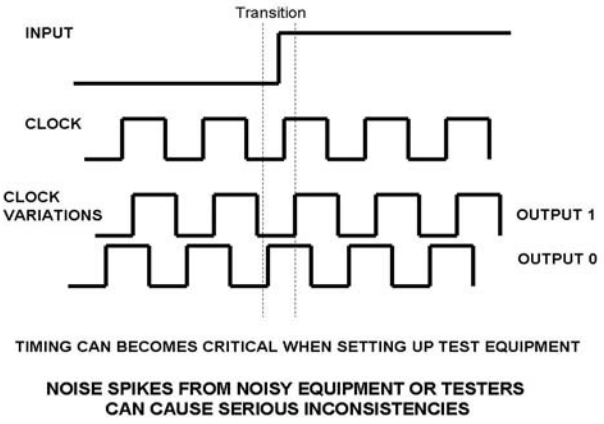

Figure 4. Inconsistent Timing Characteristics

There are useful articles on the internet about probe tips and types for testing various circuits, timing sequences and capacitance loading. Capacitance loading is something often overlooked but there are many things that contribute to capacitance loading when selecting a probe. 1:1 probes create more loading effect than a 10:1 probe. While 1:1 probe may not load most test points, it can load high-impedance test points. In fact, a 1:1 probe design, can, due to resistive loading, have a nearly 35% error on a 500 kΩ test point! However, on that same test point, a 10:1 probe would exhibit only a 5% error due to loading effect. This is error measurement error due to loading effect. Probing with a 1:1 probe can be equivalent to adding a 100 pF capacitor to the UUT while probing with a 10:1 probe is more similar to adding a 10 pF to the UUT or test point – the 1:1 probe is much more likely to affect the feedback circuit than is the 10:1 probe[8].

Items to remember when selecting, evaluating and connecting each of your probes include:

1. Use the manufacturer's probe recommended for your instrument.
2. At times, you may need to use more than one ground point on the Unit Under Test (UUT). Do not assume you can tie all of your grounds to one point and then connect one ground lead to your UUT. Insert additional faults if you feel it is required to verify the diagnostics.
3. Do not extend your ground leads or probe leads in any way. If you see ringing, it is safe to assume that your ground lead is too long. Make sure your ground lead is as short as possible.
4. Avoid a loading effect and its effect on your UUT: When probing high-impedance or feedback circuits, avoid using a 1:1 probe. Very often, the1:1 probe is fine, but the 10:1 probe may be a better choice[7].
5. Avoid sudden changes with your sensitive circuits: Avoid switching your probe's attenuation switch (1X, 10X) while connected to your test point. Also, if you must use a 1:1 probe, avoid range-switching your test instrument while connected to any sensitive test point or UUT.
6. Generally, a x10 scope probe is useful in several applications:
    - To reduce loading effect on the circuit under test
    - To compensate for the effect of test cable capacitance
    - To permit the measurement of large voltages

Proper grounding is always critical is every testing application. Induced noise, instability and spiking are key factors associated with improper grounding. A probe left floating without a ground lead because of the assumption the circuit common is somehow connected to the power-line ground and the probe instrument is also connected to the power-line ground, and that completes the measurement circuit is never a good assumption. Although this is probably correct, close point grounding stabilizes the measurement and can prevent:

(a) The measurement circuit from becoming a large loop (sometimes referred to as a ground loop) and this will tend to act as an inductive pickup for noise[9]

(b) The large measurement loop and its inductance result in a terrible transient response so square waves can be badly distorted, showing spurious overshoot and ringing.

(c) Power-line currents, in the power ground connection in the length of wire between the power supply ground and the instrument ground, creating a noise voltage that is superimposed on the measurement.

The probe ground clip as a short wire with an alligator clip at the end. In this ground arrangement, the clip is attached to a ground point in the vicinity of the measurement point. Now the measurement circuit loop is reduced to a small area which includes the probe and the ground clip wire. This measurement setup is adequate for many applications. However, if you notice that moving the ground clip wire changes the shape of a waveform or signal measurement or has some effect on the amount of noise pickup, then the measurement loop is having an effect. You could move the probe or change the probe point on the UUT.

There is a probe capacitance compensation adjustment feature associated with some probes and instruments. This can be useful to compensate for capacitance effects.

To find the EMI emission source you should make the measurement closer to the circuit. Near-field magnetic (H-field) and electric (E-field) probes let you "sniff" around the components, circuits, cables, and enclosures to find the source, see figure 5. Near-field probes allow the measurement of an electromagnetic field. They are commonly used to measure electrical noise and other undesirable electromagnetic radiation from the UUT without introducing much loading into the circuitry. They are commonly connected to spectrum analyzers or oscilloscopes.

A Near Field Probe Set might consists of three to four loop probes, one stub and one ball probe, an extension handle, an optional battery-powered preamplifier, and a foam-lined carrying case with a manual and application note. The handle of each probe terminates in a BNC connector. Probes are designed to be used with a signal analyzing device such as an oscilloscope or spectrum analyzer. The optional preamplifier is useful when signal amplification is necessary for the analyzing device.

A spectrum analyzer measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. The display of a spectrum analyzer has frequency on the horizontal axis and the amplitude displayed on the vertical axis. To the casual observer, a spectrum analyzer looks like an oscilloscope and, in fact, some lab instruments can function either as an oscilloscope or a spectrum analyzer. A skilled technician can use a spectrum analyzer. The technician can use a good board/bad board method to determine diagnostic differences at a given point in a circuit.

Figure 5. Near field EME probe set[10]

A major factor is the profound power and features of the Test Executive. In reality, the Test Executive is the strength of testing and diagnosis. Figure 6 shows the Test Executive debug tools.

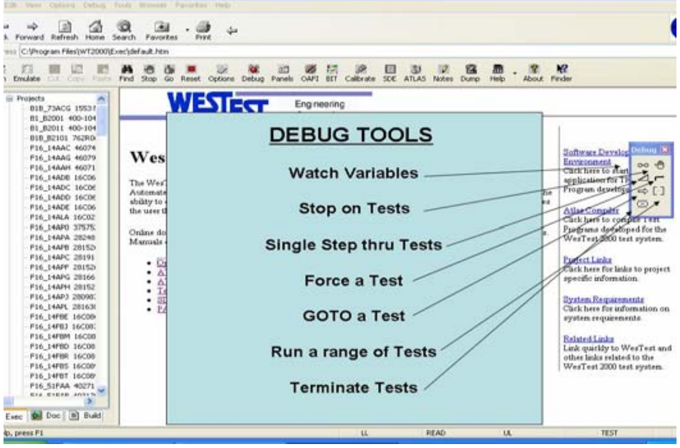

Figure 6. Test Executive Debug Tools

You can use the debug tools to aid in using Near Field EME measurements. Debug "STOP" conditions: CAN STOP ON SPECIFIC TEST or CAN ENTER MULTIPLE TESTS TO STOP ON or CAN STOP WHEN A VARIABLE IS AT A CERTAIN VALUE or CAN STOP ON MULTIPLE VARIABLES or CAN STOP WHEN A TEST FAILS. The single step selections cover many possible scenarios which can be utilized. The FORCE GO issued by the TPS developer can be used to FORCE MAINLINE TESTING TO CONTINUE AFTER A FAILURE; the FORCE NOGO used by the TPS Developer can be used to verify diagnostics.

The debug "GO TO A SPECIFIC TEST" is USED TO BYPASS PREVIOUS TESTING this is ESPECIALLY USEFUL FOR STAND ALONE TESTS to DEBUG. The debug "RUN A RANGE OF TESTS" can be USED TO BYPASS PREVIOUS TESTING this is ESPECIALLY USEFUL TO DEBUG INTERACTIVE TESTS. The stop execution is used to stop the test program and power down.

Using the STOP on test function with a EME application is an excellent way to use the power of the Test Executive. We use Stop on Test to test EME applications. Figure 7 shows using an EME probe near a suspected fault. Although an EME probing approach can be trained and utilized as part of the TPS diagnostics; a skilled technician can utilize the EME probe on-the-fly by comparing a good board with a defective board.

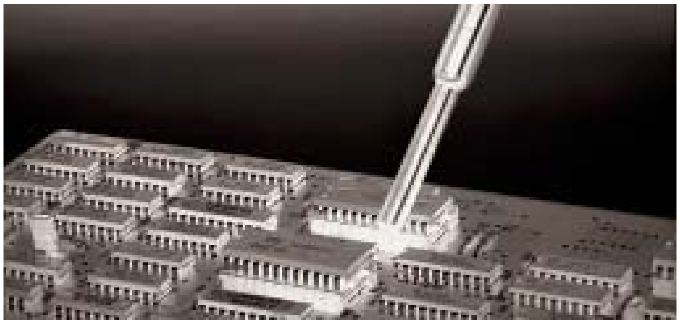

Figure 7. Near Field Probe close to a Suspected Defective Chip

Also, Handheld Spectrum Analyzers as shown in Figure 8 can be useful to:

- Pinpoint EME sources
- Estimate EME field strength
- Identify faulty components

Golden board testing is an excellent way to determine how much confidence one can have with the test results from a low-cost analyzer.

A useful trick is to follow a digital signal (e.g. a clock) from its source to its final load, to see how badly its waveform degenerates. A good circuit board with low emissions will maintain good waveform integrity along the whole length of its PCB tracks. Where waveforms degrade significantly, their ringing frequencies warn you of likely emissions problems.

EMC transducers such as close-field probes, current probes, and antennas have no metallic connection to the UUT so do not suffer from as many problems as clip-on ’scope voltage probes, but on the other hand they don’t measure signal waveforms directly, as a voltage probe does.

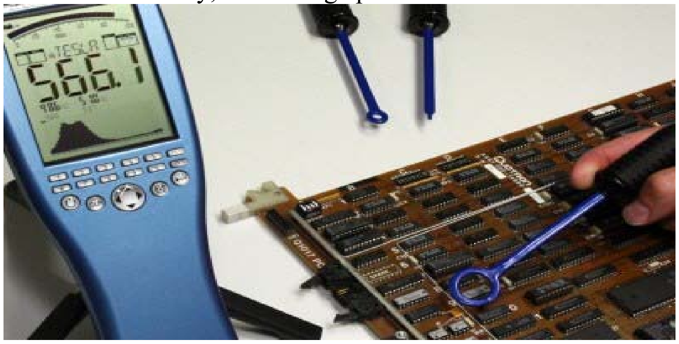

Figure 8. Magnetic field measurement on a group of components using the 25mm H-field probe[11]

IV. CONCLUSION

Probing problems actually do occur and they do arise during TPS integration and in the repair shop. All too often, these probing problems can not be ignored so the engineer must take the appropriate action. Engineering the proper probing sequence on some UUTs can be very intensive, but it is very important to maintain quality and deliver a TPS that is efficient and effective. Remember, grounding probes properly is always a good idea and adding operator instructions about grounding and proper probe use is also a good idea. Standard or default probing techniques work effectively quite often. Probing problem situations will arise and must be addressed. There are techniques the engineer can employ to solve probing problems. It is good to have a strong suspicion of all probe measurements by asking yourself is this waveform or signal a real signal in the circuit or is it an artifact and a result of the measurement setup?

Giving a skilled technician a variety of methods and tools to determine an actual fault can be very important. Using the EME technology on-the-fly requires a robust Test Executive and an understanding of spectrum analyzer measurements. Also, Handheld Spectrum Analyzers can make this technology easily usable. In this age, non-automated testing is not preferred but sometimes useful especially with abstract sciences where good board training for diagnostic routines could involve huge quantities of information.

This paper can’t cover all the various characteristics associated with effective and efficient diagnostic probing because there are so many considerations. However, the test engineer’s skills or the test technician’s skills become relevant when determining the actual fault. Also, there is simply not enough space to discuss all the various probing techniques and the optimal approach to probing in all situations. This paper is provided to offer thoughtful considerations to the technician and engineer when performing probing. Probing considerations are often ignored and the potential problems that might arise are often not considered. It is the author’s hope this paper might provide some insight into all the possibilities associated with probing.

References:

1. http://www.epanorama.net/links/measuring.html, Measuring and testing – ePanorama, 29 September, 2011
2. Kirkland, Larry, AUTOTESTCON 2011, ATS Considerations for New Testing Technologies
3. Forcier, Neil, DMM Resistance Measurement Considerations, Evaluation Engineering Group Members, 28 September, 2011
4. Test Probes Evolve To Keep Up With Embedded, Maliniak, David, 30 *May, 2012,* http://electronicdesign.com/article/test-and-measurement/test-probes-evolve-embedded-73984
5. Kirkland, Larry, AUTOTESTCON 2010, ATS Considerations for New Testing Technologies
6. Jacobsen, Chris,; Wible, Kevin, Applying a New In-Circuit Probing Technique for High-Speed/High Density Printed Circuit Boards to a Real-Life Product , http://cp.literature.agilent.com/litweb/pdf/5989-5748EN.pdf, 28 Sept 2011.
7. Tektronix Technical brief, The Effect of Probe Input Capacitance On Measurement Accuracy, http://www.tek.com/Measurement/App_Notes/Technical_Briefs/ProbeInput/eng/60W_8910_1.pdf
8. Are you probing high-impedance circuitry or otherwise sensitive circuits and systems?, http://tmi.yokogawa.com/products/oscilloscopes/scopecorders-oscillographic-recorders/dl750dl750p-scopecorder/
9. Hiscocks, Peter D., Gaston, James, Oscilloscope Probes:Theory and Practice, p5, 12 July, 2007
10. COM-POWER Corporation http://www.com-power.com/near_field_probes.html
11. Aaronia ag www.aaronia.de http://www.spectran.com/EMC_Probe_Set.htm