Case Study of Near Field Signature Analysis (NFSA)

as presented by Tom Farkas of Test Evolution Corp. (TEV) at AUTOTESTCON 2008, Salt Lake City, Utah

Huntron Access 2 Prober with TEV NFSA Probe used for RF Diagnostics
Case study of Near Field Signature Analysis (NFSA) as a diagnostic tool for high frequency circuits

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Abstract – A presentation of the method of Near Field Signature Analysis as a tool for diagnostic failure localization in high frequency circuit assemblies will be given. Traditional techniques of localizing faults in RF circuits rely heavily on manual methods and ATE approaches have limitations based on how much intelligence can be embedded into the software. Following the trends of robotic application, this method combines precise mechanical positioning and non-contact probing with local synthetic measurement technology. The technique can shorten the time to diagnosis by augmenting the ATE with more positional information and save manual labor by creating an automated parallel operation for failed RF assemblies. It also may generate data of a prognostic value. A case study will be used to demonstrate quantitatively the possibilities and limitations of the technology. Multiple units of a typical microwave circuit assembly will be examined with this method at several measurement points. A following set of measurements on failing assemblies will be then be presented and compared with the reference measurements and their respective known-good measurements.

Keywords – Automated Test, ATE, NCT, Diagnostic Techniques, Near Field Probes

I. INTRODUCTION

High frequency circuits, RF and Microwave circuits in particular, present a unique problem. Failures are often difficult to diagnose due to several factors including an “unobserveability” problem associated with any direct in vivo measurements contacting the circuits under test. As is well known, unlike digital and analog circuits, high frequency signal paths are sensitive to loading. High contact measurement impedances are difficult to achieve at signal frequencies beyond a few hundred Megahertz. Further, signal levels in RF and microwave circuits are often very low comparatively. The environment is hostile in that there are many possibilities for interference. The time honored means of signal tracing to identify faulty components is at best an art performed by a skilled and experienced practitioner. The advantages of non-contact testing (NCT) of complex and potentially conformal coated assemblies are apparent in the work of Umstadter et al[1].

In recent decades, manufacturing consistency has reached a point where performance variance for a given assembly is minimized. Surface mount devices coupled with microstrip techniques maximize performance and repeatability in designs. As such it can be reasoned that the signal levels within a given design are consistent as well. High frequency currents, voltages and impedances thus yield electromagnetic fields [2]. These fields are typically a nuisance or by product in the design process (unless one is intending to design an antenna) are as repeatable as the circuits and the currents flowing within them as according to Maxwell’s equations.

The classical definition of these fields being “near” versus “far” is related to wavelength but mostly relevant in the literature to antennas [3]. In actuality the EM fields originating from any circuit at close range, always within a wavelength will be considered “near” for our purposes. The distance, r, below which is referred to as the reactive or evanescent near field [4] is commonly defined as:

\[ r < \frac{\lambda}{2\pi} \]  

At 20GHz this would roughly be 2.4mm; at 2GHz this would be 2.4cm. Reactive near fields comprise a volume wherein energy storage is freely exchanged between the circuit and the field. The magnitude of a particular field can be expected to fall off in a complex manner exponentially with distance [5].

If one examines multiple units of the same type, one would expect reactive near fields measured at some location above the unit to be correlated to the respective currents and voltages under common test conditions to be consistent, or at least within all of the respective test set-up and component tolerances, from assembly to assembly. If a known good unit or set of units can be measured and compared under identical test conditions to an unknown unit, then a determination may be made indicating potential fault locations. The magnitude of the measurements in absolute units is unimportant.

The key factors in making this determination, which pull this technique away from a qualitative approach, are the basic unit to unit consistency of performance, field measurement repeatability and mechanical positioning repeatability. If the sum of these errors is much less than the error created by a particular fault within the RF signal chain, then near field measurements can be used to discover and locate the aforementioned faults.

A. Near Field Measurements

For as long as RF circuits have been troubleshooted, technicians have improvised devices to non-invasively measure signal levels internal to circuits. These are colloquially known as “sniffers”. Manually placed above a
circuit and connected to a spectrum analyzer, one can measure low levels at high frequency and, with experience, make a qualitative judgment as to whether the signals look right or not.

Our work has been to take the functionality and sensitivity of a spectrum analyzer and put it mechanically into the reactive near field of an operating circuit. We then make field measurements in an automated manner relative to a known standard and use software to collate anomalies indicating substandard behavior to an operator.

The need to distinguish between good and not good assemblies does not require knowledge of the absolute vector magnitude within the reactive near field of a given circuit. It merely requires the consistent placement of a probe within that space and comparative measurements.

B. Measurement System Description

Several constraints are placed upon the system. The means to sample the near field at precise locations requires a system that is compact enough to be integrated into the robotics. The ranges of field signal frequencies we desire to measure are very broadband in nature. This particular system spans 200MHz to 3GHz. The measurement system is frequency dependent. It also must have very good dynamic range in that fields may be very small or quite large depending on the unit under test.

![Figure 1 NFSA Electrical Block Diagram](image)

The measurement system block diagram is shown in Figure 1. A short monopole antenna (7mm) acts as the field transducer (shown at bottom of the block diagram). The antenna coupled to a front end filter, programmable attenuator (0-60dB) and low noise amplifier. The signal is then presented to a mixer down-converter representing a single conversion receiver architecture. The mixer-down converter comprises a broad span local oscillator controlled by the host computer. The intermediate frequency is low relative to the signals measured but not zero. A fast, reasonably high resolution analog to digital converter captures the filtered IF signals

The driver software performs an FFT and scaling functions on the signal to return a magnitude at the desired input frequency. This architectural approach is inherently synthetic and can be extended to many other types of measurements [6].

The integrated approach avoids the issues associated with separating the antenna and the receiver by a distance that, with the use of cabling, encourages interference and coupling to the UUT. The latter method is described by Salamiti and Stranneby [7]. Their method works for H-field measurements in a plane at lower frequencies but lacks in spatial resolution. Other methods and sensing systems such as Scanning Probe Microscopy are available and have the requisite spatial resolution but are more complicated in implementation requiring special physical probes [8,9]. Yet more complicated approaches involve electro-optic sensors based on changes in birefringence as a function of applied electric field or modulated scattering are more suited to internal MMIC level testing [10,11].

Central to the ability to measure the near field is the ability to place the probe at a repeatable distance from a circuit feature. The system described herein relies on a Huntron Access Prober [12] for this. The Access series prober has positioning resolution of 10um with an accuracy of +/-20um in the XY plane and positioning resolution of 200um in the z direction. An overall view of the complete system is shown in figure 2.

![Figure 2 Overall Pictorial Diagram](image)

II. CASE STUDY OBJECTIVE

Previous proof of concept efforts performed on simple microstrip circuits confirmed early work [13] and showed that measurement resolution was adequate for diagnostic purposes. Figures 3, 4 and 5 show an example of that work.

This case study looks specifically at a real world RF assembly. The desire is to determine if the repeatability of the measurements inclusive of positioning error, measurement error and unit-to-unit variability is at a low enough level
relative to the differentiation between a priori known-good field measurements and field measurements of faulty or unknown Unit’s Under Test (UUT) such that diagnostic determination of errors is possible.

III. CASE STUDY UNIT UNDER TEST

The PCB assembly chosen for this study is a broad band phase-locked synthesizer. A main Phase Lock Loop in the unit spans a bandwidth of 1900-4100MHz. This signal is then branched along various filter and divider paths providing a range of frequencies. The output frequencies are presented to a 1:4 RF multiplexer with individual attenuation and isolation switching.

The unit works well for this work since it has multiple ranges of frequencies resident and many active circuits with potential for faults. For simplification, our data will be taken at the following frequencies 250MHz, 500MHz, 1GHz and 2GHz.

The shielding design is removable thus allowing unimpeded access to the module circuitry. Other types of modules may have integrated housings with channelized designs optimized for isolation. In those cases, the narrow sensor antenna of the system would be guided into cavities to measure the desired fields.

We will define a Virtual Test Point (VTP) as a unique point in Cartesian space above an assembly whose parameters are defined by x, y and z coordinates and frequency. Each VTP has a unique number which is common for all assemblies of this type (ie VTP 1 for one board is at the exact same spot and frequency as VTP 1 for another board). Figure 6 shows this particular assembly with the VTP’s called out graphically as light colored circles.
Since the unit is a PXI based instrument, fixturing and control are straightforward. A program running National Instruments LabWindows CVI controls the UUT while a separate program controls the Huntron prober and NFSA sensor. Ultimately, a combined program could control both UUT along with ATE and the fully integrated NFSA system under one test executive like National Instruments TestStand for instance. A view of the fixturing is shown in figures 7 and 8.

IV. NEAR FIELD SIGNATURE MEASUREMENT RESULTS

Maximum RF signal power levels in the UUT are below 8-9dBm. In general, levels are between 0 and -15dBm – the only exception being the final output which is specified as +6dBm. These levels are typical for an assembly of this type.

A. Radial Sensitivity

A first measurement undertaken consists of a field magnitude versus various heights. The probe is positioned at nominal VTP’s (typically 1mm above the UUT circuit). The probe is stepped up by z increments of 200um. A measurement is made for each increment. A plot of four frequencies’ magnitude taken at different VTP’s versus height is shown in figure 9.

Clearly, relative field strength varies with height almost logarithmically (linear in dB). This shows that the radial distance from a circuit feature of interest can be modulated to
enhance or attenuate signal strengths in a relatively predictable manner. The slope or scaling of this, however, would be dependent on the local geometries and the relative x-y positioning of the probe.

Importantly, measurements are sensitive to height in an easily discernable way. Positioning of the Near Field sensor must be exact and repeatable.

B. Measurement Repeatability of a single UUT at multiple VTP’s

A single UUT was fixtured, aligned optically, powered up and stabilized (2-3 minutes estimated time to do this). A series of VTP’s were run in sequence. Over 12 runs the following statistics were gathered.

<table>
<thead>
<tr>
<th></th>
<th>2GHz</th>
<th>1GHz</th>
<th>500MHz</th>
<th>250MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RANGE</td>
<td>0.841514</td>
<td>0.734657</td>
<td>0.682241</td>
<td>0.514017</td>
</tr>
<tr>
<td>STD DEV</td>
<td>0.242357</td>
<td>0.240159</td>
<td>0.260138</td>
<td>0.178861</td>
</tr>
</tbody>
</table>

All measurements are in dB relative to 0dBm sensed at the probe under controlled conditions. Note that the measured values are in dB not dBm; they are not absolute readings.

Distributions were roughly normal with no anomalous outliers. Average levels were set to be within the linear range of the receiver by adjusting the input attenuator accordingly. These should be considered typical results.

C. Measurement Repeatability of multiple UUT’s at multiple VTP’s

Four different known-good UUT assemblies (SN101, 102, 108, 109) were then sequentially measured. Each unit was fixtured, aligned optically for x-y, manually aligned for z height, powered up and stabilized as before. Each UUT was measured 5 times before being powered down and deinserted from the fixture. Of the 13 different VTP’s measured in each run, 4 were selected for worst case spreads (i.e. least favorable statistics). The following table shows these results.

<table>
<thead>
<tr>
<th></th>
<th>2GHz</th>
<th>1GHz</th>
<th>500MHz</th>
<th>250MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN</td>
<td>-20.9348</td>
<td>-23.078</td>
<td>-20.4044</td>
<td>-26.6887</td>
</tr>
<tr>
<td>MAX</td>
<td>-18.2167</td>
<td>-20.9251</td>
<td>-17.3105</td>
<td>-21.998</td>
</tr>
<tr>
<td>RANGE</td>
<td>2.718094</td>
<td>2.152807</td>
<td>3.093948</td>
<td>4.690655</td>
</tr>
<tr>
<td>STD DEV</td>
<td>0.836267</td>
<td>0.516454</td>
<td>0.803807</td>
<td>1.197334</td>
</tr>
</tbody>
</table>

This shows that the agglomeration of errors consisting of straight up measurement error, robotic positioning error, internal signal level variation, and board to board variability due to normal tolerances, is reasonably narrow. As a note of interest, the time it took to run through one cycle of 13 VTP’s is less than a minute including all positioning movement and measurement signal processing. No special averaging was used during the RF measurements and the UUT was not coherent to the measurement system. The unit test period for all measurements was approximately 260uS with 4096 samples captured.

D. Limit Setting Methodologies

These measurements would, under normal operating conditions, make up the basis for a set of test limits. The test limits could be calculated based on both the statistics of measured known-good boards. In practice, some allowance for experience would be made based on the individual design and its respective constraints. A starting point for limits calculation could be 3 to 5 times the standard deviation. If, as above, the worst case standard deviation is on the order of 1dB then this would figure to +/-3 to 5dB limits.

V. FAULT DETECTION AND LOCALIZATION

The approach a test engineer may take in applying what has been presented here might go something like as follows. An assembly which requires diagnosing is identified. The engineer examines the UUT schematic with an eye toward following the RF signal flow. Natural points along that path are selected for Virtual Test Points. A set of known good boards are then run in the prober making Near Field measurements at the approximate VTP’s. The actual positions are adjusted along with the height to obtain repeatable measurements. The VTP’s are then saved. Quantities of good boards small or large are run and data is gathered for each and saved. An average value for each VTP over the boards sampled is combined into a data set. This is the Near Field Signature. Using the limit setting methodology aforementioned, limits are set for each VTP. Unknown UUT’s are run with the same VTP’s against the limits. Any anomalies in internal performance will show in comparison as limits failures. Where the failures in a given signal chain occur or start to occur (depending on circuit dependencies) are indicative of the failure origin. Note that there is no limit on the number or density of VTP’s. At approximately 1 second per VTP, the penalty for over determining the fault map with too many VTP’s is minimal. Further, when integrated into an ATE test program, decision trees and iterative routines can refine the fault radius to the smallest value possible.
A. RF Switch Failure Example

Like almost every RF module or assembly, the UUT chosen for this example has many different signal processing paths that are connected with solid state switches. An simple way for us to demonstrate a failure is to exploit this feature. The following shows in block diagram form a part of the actual assembly to be examined. Called out are the VTP’s and their location on the block diagram.

![Block diagram section of RF Switch Failure](image1)

**Figure 10 Block diagram section of RF Switch Failure**

The entry point to this circuit is a 1GHz signal measured at VTP 2. The signal path can be selected to be divided, amplified and filtered or sent in a different direction. The divider output is at 500MHz as is the remainder of that signal path with accordingly variable levels. The physical layout is shown with the VTP’s called out on it in Figure 11.

![Physical Layout of the UUT with VTP’s](image2)

**Figure 11 Physical Layout of the UUT with VTP’s**

A first set of measurements are taken at VTP 2, 5, 6 and 7 respectively on the four different serial numbered assemblies under normal switch settings. The switch is set to the opposite path and another second set of measurements is taken. The comparison between the two sets of measurements is shown in the following tables for each of the different assemblies. The delta between nominal and failing are clearly delineated in dB relative.

<table>
<thead>
<tr>
<th>SN101</th>
<th>VTP</th>
<th>NOMINAL</th>
<th>SWITCH FAILURE</th>
<th>DELTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-21.825</td>
<td>-22.407</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-18.984</td>
<td>-61.147</td>
<td>42.16</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-16.366</td>
<td>-67.103</td>
<td>50.74</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>-20.503</td>
<td>-63.987</td>
<td>43.48</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3 SN101 Nominal compared to Failure**

<table>
<thead>
<tr>
<th>SN102</th>
<th>VTP</th>
<th>NOMINAL</th>
<th>SWITCH FAILURE</th>
<th>DELTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-21.239</td>
<td>-21.836</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-17.813</td>
<td>-53.568</td>
<td>35.75</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-15.928</td>
<td>-60.644</td>
<td>44.72</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>-19.745</td>
<td>-62.684</td>
<td>42.94</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4 SN102 Nominal compared to Failure**

<table>
<thead>
<tr>
<th>SN108</th>
<th>VTP</th>
<th>NOMINAL</th>
<th>SWITCH FAILURE</th>
<th>DELTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-21.978</td>
<td>-22.082</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-19.172</td>
<td>-58.099</td>
<td>38.93</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-16.304</td>
<td>-63.024</td>
<td>46.72</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>-20.006</td>
<td>-55.824</td>
<td>35.82</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5 SN108 Nominal compared to Failure**

<table>
<thead>
<tr>
<th>SN109</th>
<th>VTP</th>
<th>NOMINAL</th>
<th>SWITCH FAILURE</th>
<th>DELTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-21.194</td>
<td>-21.023</td>
<td>-0.17</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-17.064</td>
<td>-80.207</td>
<td>63.14</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-15.311</td>
<td>-57.455</td>
<td>42.14</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>-19.165</td>
<td>-56.833</td>
<td>37.67</td>
<td></td>
</tr>
</tbody>
</table>

**Table 6 SN109 Nominal compared to Failure**

Following the signal failures backward until a passing VTP is found leads to the general location of the fault (i.e. in this case the switch).

VI. CONCLUSIONS

We have presented a case study and description of a new technique for diagnosing RF circuits. The Near Field Signature Analysis method combines accurate spectral measurements with repeatable robotic positioning. Measurement sensitivity is such that small deviations in position for a given RF measurement can be readily discerned. This allows for detecting very fine or gross changes in circuit behavior due to faults. An opportunity exists to exploit this fact. Further study can be applied in many directions including software reasoning that guides the measurement technology automatically to reduce the fault.
radius or graphical representations that identify faults quickly to unskilled operators. The synthetic nature of the measurements can be brought to bear on other types of faults beyond simple signal level disruptions to issues such as spurious oscillation detection, modulated signals and other non-linearity’s.

VII. ACKNOWLEDGEMENTS

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REFERENCES