High Frequency Spectrum Analyzer Calibration

An overview of spectrum analyzer calibration and how the 9640 can simplify and improve the efficiency of all spectrum analyzer calibrations
How to use this material

• The following pages are intended as self-learning materials

• They may also be used as a presentation for others who need to become familiar with the basics of spectrum analyzer calibration
  – Including customers and other calibration practitioners
Outline

• What is a spectrum analyzer and why are they calibrated?
• Typical calibration systems and calibrated parameters
• Reducing complexity and improving efficiency
• Conclusions
What is a Spectrum Analyzer?

- Spectrum analyzers are used in numerous applications to display and measure the frequency domain characteristics of a signal.
- In the simple form shown here, their architecture resembles an AM superheterodyne receiver. Tuning is swept to display the required frequency range. A mixer is used to down-convert the input signal to a lower, intermediate frequency (IF) for processing.
- Most modern spectrum analyzers use two or three stages of down-conversion, and also digitize the signal. Some of the IF filtering and logarithmic conversion is usually implemented in digital signal processing.
- More information about spectrum analyzer principles, capabilities and applications can be found on their manufacturer’s websites.
Spectrum are analyzers one of the top 3 RF cal lab workload items
- Spectrum analyzers, Signal Generators, Power Meters/Sensors

- Typical calibration workload includes high frequency analyzer UUTs
  - 18 GHz, 26 GHz & 40 GHz
  - The bulk of the workload is generally at lower frequencies
  - Increasing numbers of higher frequency units are appearing in the cal lab workload

(~60% of the workload)
Why are they calibrated?

- Spectrum analyzers are sophisticated measuring instruments
  - High performance, tight specifications
  - Plethora of measurement features
  - Applications require numeric data
  - No longer ‘indication only’
- And all the usual ‘quality assurance’ (ISO9000 etc) reasons…
How are they calibrated?

- Using either dedicated systems, or a collection of the required items assembled for the specific job at hand

- Generally a slow time consuming process employing several instruments including signal generators and power meters, attenuators, filters and other items
  - Power meter is used as level calibration standard
  - Frequency reference often used to enhance signal generator frequency accuracy
  - Low phase noise signal generator(s) also required

- Automated systems need frequent user intervention to change the interconnections. Consequently there are many opportunities for mistakes and highly trained staff are needed. Operator time is often wasted waiting for the next setup change.
The application note “A Guide to Calibrating Your Spectrum Analyzer” describes how spectrum analyzers are calibrated using traditional equipment & methods

- More about how a spectrum analyzer operates
- More about the characteristics and parameters are calibrated
- More about existing calibration methods, used before the 9640 became available
Calibrated parameters

• We analyzed the published cal procedures for 15 spectrum analyzer models from 5 manufacturers and found 80 different tests described.

• 20 tests are performed on the majority of all the models in the study.
  – Often the same test is simply called by another name.

• In general, the common tests are:
  – Frequency Accuracy
  – Level Accuracy
  – Frequency Response
  – Attenuator Response
  – Display Linearity
  – Displayed Average Noise Level
  – Resolution Bandwidth Accuracy
  – Resolution Bandwidth Selectivity
  – Resolution Bandwidth Switching Accuracy
  – Sweep Time Accuracy
  – IF Image Response
  – Noise Sidebands
  – Residual FM
  – Residual & Spurious Responses
  – Harmonic Distortion
  – 3rd order Intercept (TOI)
  – Tracking generator tests

So, are all of these tests performed throughout the analyzer’s frequency range?
Majority of test points are at LF

Analysis of published calibration procedure for a 26GHz analyzer: 80% of testpoints <3GHz

Example: The calibration guide published by Agilent Technologies for its ESA series spectrum analyzer product range is 640 pages long!

This table summarizes tests and test point frequencies for the E4407B model, totalling over 400 individual test points.

<table>
<thead>
<tr>
<th>Calibration Test</th>
<th>Test Signal Frequency/Range</th>
<th>Tested at LF Only</th>
<th>Tests include HF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Span Accuracy</td>
<td>300MHz - 1.5GHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Frequency Readout Accuracy</td>
<td>1.5GHz - 21GHz</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Level Accuracy</td>
<td>50MHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Frequency Response</td>
<td>9kHz - 26.5GHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Attenuator Switching Accuracy</td>
<td>50MHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Display Linearity</td>
<td>50MHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Displayed Average Noise level</td>
<td>10MHz - 26.5GHz</td>
<td>No input required</td>
<td></td>
</tr>
<tr>
<td>Resolution Bandwidth Accuracy</td>
<td>50MHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Resolution Bandwidth Selectivity</td>
<td>50MHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Resolution Bandwidth Switching Accuracy</td>
<td>50MHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Sweep Time Accuracy</td>
<td>500MHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Spurious Responses</td>
<td>2GHz - 21.6GHz</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Noise Sidebands</td>
<td>1GHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Residual FM</td>
<td>1GHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Harmonic Distortion</td>
<td>300MHz - 3.1GHz</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>3rd Order Intercept (TOI) &amp; Gain Compression</td>
<td>50MHz - 14GHz</td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>
Test point frequencies

For high frequency UUTs, >70% of the test points are at frequencies less than 4 GHz

- On Multi GHz Analyzers most tests are performed well below their maximum frequency

- On a typical 26 GHz Spectrum Analyzer, over 80% of the test points are at 4 GHz and below
  - Directly related to spectrum analyser architecture & design
Equipment & setup complexity

- These setup diagrams are just a few examples taken from the E4407B calibration procedure.

- The E4407B is a typical 26GHz analyzer.

- Its calibration procedure requires 27 different equipment setups:
  - Employing 6 individual signal sources
  - Many are obsolete or presenting maintenance & support difficulties, usually the lower frequency sources.

- The majority of the complexity is for the lower frequency test points.

- Other analyzer models from the other manufacturers require a similar number of equipment items and setups.
Cost effective alternative

• Deploying a 9640 as the core of the spectrum analyzer calibration system
• The 9640 addresses all of the low frequency test points
  – The 9640 replaces multiple generators and a variety of ancillary RF components
  – 27 setups reduced to 9 for a 26GHz analyzer
• Majority of the testing is now addressed by a single source
  – Fewer setups and faster test times. Connect once, test lots.
  – When automated, operator is intervention significantly reduced
  – Operator efficiency is greatly improved
What about the higher frequency points?

- Continue to use the existing high frequency generators for the remaining tests requiring frequencies above 4GHz

- Labs already own 26GHz or 50GHz generators
  - HP836xx, Agilent 8257 series, etc. These are either quite new or reliable.

- The 9640 and MET/CAL solutions are defined and designed to work with the above generators as a cost effective replacement solution
  - The 9640 replaces multiple generators and a variety of ancillary RF components
  - ROI is less favourable if the high frequency generators are also replaced

- ‘Walk-away’ automation with the 9640 and MET/CAL means fewer lead changes, faster calibration times, less operator time wasted and results in significant time and efficiency savings
**Example: ESA series**  
**Summary of verification tests**

<table>
<thead>
<tr>
<th>UUT Verification/Functions</th>
<th>UUT Bandwidth</th>
<th>1.5 GHz</th>
<th>1.5 GHz</th>
<th>3 GHz</th>
<th>3 GHz</th>
<th>6.7 GHz</th>
<th>13.2 GHz</th>
<th>26 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements</td>
<td>E4401B</td>
<td>E4411B</td>
<td>E4402B</td>
<td>E4403B</td>
<td>E4404B</td>
<td>E4405B</td>
<td>E4407B</td>
<td></td>
</tr>
<tr>
<td>UUT Model &amp; Freq Range</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Tests below 3 GHz frequency</td>
<td></td>
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</tr>
</tbody>
</table>

- **10 MHz Reference Output Accuracy**:  
  - Universal Counter & Freq  
  - 10 MHz  
  - Requirement: E4401B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **10 MHz High-Stability Frequency Reference Output**:  
  - Universal Counter & Freq  
  - 10 MHz  
  - Requirement: E4411B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **Frequency Readout and Marker Frequency Count Accuracy**:  
  - 9640A  
  - 1.8 GHz  
  - Requirement: E4403B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **10 MHz Reference Output Accuracy**:  
  - Synthesizer to 9 GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **Frequency Span Accuracy**:  
  - 9640A  
  - 1.5 GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **Noise Sidebands**:  
  - 9640A  
  - 1 GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **System-Related Sidebands**:  
  - 9640A  
  - 1 GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **Residual FM**:  
  - 9640A  
  - 1 GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **Input Attenuation Switching Uncertainty**:  
  - 9640A  
  - 10 MHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **Resolution Bandwidth Switching Uncertainty**:  
  - 9640A  
  - 10 MHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **Absolute Amplitude Accuracy (Reference Settings)**:  
  - 9640A  
  - 50 MHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 50 MHz

- **Amplitude Readout and Marker Frequency Count Accuracy**:  
  - 9640A  
  - 1 GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Accuracy: 10 MHz

- **Frequency Response**:  
  - 9640A plus synthesizer and powermeter/sensor for tests >4GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Frequency: 1.5 GHz

- **Frequency Response (Preamp On)**:  
  - 9640A plus synthesizer and powermeter/sensor for tests >4GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Frequency: 1.5 GHz

- **Other Input-Related Spurious Responses**:  
  - 9640A plus synthesizer and powermeter/sensor for tests >4GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Frequency: 1.31 GHz

- **Spurious Responses**:  
  - 9640A plus synthesizer and powermeter/sensor for tests >4GHz  
  - Requirement: E4407B  
  - UUT Bandwidth: 1.5 GHz  
  - Frequency: 0.05 MHz

**Tests requiring Signal sources to maximum frequency**

The 9640 addresses the majority of the tests and test points. Used together with existing HF generators, etc for the high frequency tests.
Conclusions

• Majority of time & complexity involves low frequency test points

• Low frequency test points place the most demanding signal requirements
  – Level accuracy, attenuation, spectral purity

• Low frequency test points require many equipment items
  – Signal sources, attenuators, filters, power sensors, splitters, etc

• Low frequency test points offer greatest opportunity for cost effective efficiency improvements
  – By using the 9640, purpose designed to be the core of a high frequency spectrum analyser calibration system