

How to Perform a Custom Calibration on a ThinkRF WSA5000

1 Introduction

The ThinkRF WSA5000 provides a built-in facility that allows the end-user to load a customized calibration file to the WSA unit. A calibration file is used to map the reference levels against various radio parameter settings and physical parameters, such as frequency, temperature, and insertion loss of the attenuator. A customized calibration file allows the end-user to optimize the unit specifically for the intended user application. It can be used to reduce the effect of unit-to-unit variation and to enhance the parameters that are most important to the end-user application.

This application note is intended to assist the end-user in performing the calibration process over the frequency. A step-by-step calibration procedure is provided below. The procedure assumes that the user is familiar with operating the WSA5000 including how to communicate with and control the unit using SCPI commands (referring to WSA5000's *User Guide* and *Programmer's Guide* as required).

2 Setup Requirements

The following items are required to carry out the calibration:

- A WSA5000 with firmware version 3.2.6 and above, its power adaptor and a CAT-5 Ethernet cable with RJ-45 connectors.
- An RF signal generator that is capable of synthesizing signals over the frequency range of interest.
- An RF coaxial cable with a male SMA connector to connect to the WSA5000 input on one end and the appropriate connector on the opposite end to connect to the RF signal generator. Ensure that the cable is specified for the frequency range of the calibration.
- A software application for determining the power level of the input signal as seen by the WSA5000, for examples - the API, PyRF library or its GUI, all provided by ThinkRF.

Optional:

- A similar cable as above to connect a 10 MHz reference clock source to the WSA5000.
- An RF power meter to accurately measure the signal power that is presented to the WSA5000.

3 Setup Steps

3.1 Setting Up the RF Signal Generator

1. Connect the RF cable to the RF signal generator. **Do not connect the signal source to the WSA5000 yet until the WSA5000 is on and the attenuation state is determined in section 3.2.**
2. Set up your signal generator. Verify the signal source of the signal generator with the use of a power meter prior to connecting the source directly to the WSA5000's RF IN connector. **ThinkRF's receivers can tolerate a maximum input signal of -10 dBm when the front-end attenuator is out of the circuit and +10 dBm when the attenuator is in the circuit.**



Caution: Injecting signal levels that exceed these specifications will result in permanent damage to the receiver.

3.2 Setting Up the WSA5000

3. Connect the WSA5000 to its power adaptor and turn the unit on. Ensure that the status LEDs on the unit indicate that the unit is operating properly.
4. Determine the unit's IP address unit using the procedure described in the WSA5000's *User Guide*.
5. Turn the WSA5000's input attenuator **OFF** using the following SCPI command:

:INPUT:ATTENUATOR OFF

6. Connect the SMA plug to the WSA5000's **RF IN** port.

3.3 Optional

If the 10 MHz external reference source is used:

7. Ensure the external 10 MHz reference level is between **-10 dBm** and **0 dBm**.



Caution: Exceeding the level of 0 dBm will result in permanent damage to the internal clock circuit. Additionally, the 10 MHz reference must be powered down prior to powering down the WSA5000.

8. Connect a suitable cable from the 10MHz reference source to the **10 MHz IN** port on the WSA5000.
9. Switch the WSA5000 to use the external reference clock:

:SOURCE:REFERENCE:PLL EXT

4 Calibration Steps

1. Ensure that the decimation factor is set to 1 and the frequency shift is set to zero by issuing the following SCPI commands:

:SENSE:DEC 1

:SENSE:FREQ:SHIFT 0

2. Set the WSA5000 to the RFE (Receiver Front End) mode of interest:

:INPut:MODE <mode>

where <mode> is: ZIF, SH, HDR or IQIN

3. Tune WSA5000 to the frequency of interest, for example to tune the receiver to 2450MHz:

:SENSE:FREQ:CENTER 2450 MHz

4. Set the RF signal generator to generate a tone that would be visible within the bandwidth of the RFE mode of interest. Note that in ZIF and IQIN mode, avoid injecting a signal frequency that is the same as the WSA5000's center frequency to avoid creating a DC offset.
5. Record the Reference Level that is reported in the VRT context packet (R_{old}). The context packets are returned along with VRT data packets. See the "Reference Level" section of the *Programmer's Guide* for more details.
6. Record the power level that is observed at the frequency of the injected input signal using the WSA5000 RTSA application or the customer-specific measurement application.
7. Calculate the new reference level using the following formula:

$$R_{new} = R_{old} - (P_{observed} - P_{input})$$

where:

R_{new} = the new reference level in dBm

R_{old} = the current reference level from the VRT context packet in dBm

$P_{observed}$ = the power level observed on the WSA5000 GUI (or your application) in dBm

P_{input} = the RF power level presented to the input connector on the WSA5000 in dBm

8. Repeat steps 2 to 7 for all the frequencies of interest. See the [Interpolation Calculation](#) section for information on how the reference level is interpolated to create a new reference level at a frequency between two calibrated points.
9. Repeat steps 1 to 8 for any additional RFE modes of interest.
10. Once all the data has been collected, create the custom calibration file as described below in [Appendix A: Creating a Custom Calibration File](#). An example of a custom calibration file is provided in [Appendix B: Example XML Calibration File](#).
11. See the “Customizing the WSA5000's Calibration” section of the *User's Guide* for instruction on how to upload your custom calibration file to the WSA5000 using the web administrative console.

4.1 Interpolation Calculation

When the WSA5000 is set to a frequency that has not been directly calibrated, the required calibration value is derived by interpolating between the two adjacent calibration points. The interpolation is performed using the following formula:

$$R_{new} = \frac{|R_{above} - R_{below}| * (F_{current} - F_{below})}{F_{above} - F_{below}} + R_{below}$$

where:

R_{new} = the reference level interpolated in dBm

R_{above} = the calibrated reference level at the calibrated frequency immediately *above* the current center frequency in dBm

R_{below} = the calibrated reference level at the calibrated frequency immediately *below* the current center frequency, dBm

$F_{current}$ = the current WSA5000's center frequency in Hz

F_{above} = the calibrated frequency immediately *above* the current center frequency in Hz

F_{below} = the calibrated frequency immediately *below* the current center frequency in Hz



Notes: If a large number of calibration points are loaded:

- It will take longer on the first boot up of the WSA5000 after the custom calibration file is uploaded.

- The sweep rate may be affected as a longer look-up time is required by the embedded software. The worst case look-up time is determined by the big-O algorithm $O(\log(N))$ where N is the number of points to be look-up.

5 Additional Information

1. During normal operation of the WSA5000, when the attenuator is turned on, the attenuation value of -20 dBm is automatically added in the reference level reported by the VRT context packet
2. Each WSA5000 unit should be calibrated individually as the unit-to-unit variation of gain in the

signal path due to component tolerances can be significant.

3. When a factory reset is applied to the WSA5000, the calibrated values would be reset to the system default values effectively deleting the user calibration file.
4. In order to better understand how the WSA5000 overrides the factory/system reference values with user calibration values and how the calibration source is selected when there are more than one source available, see the “Calibration File Source Selection” section of the WSA5000 *User’s Guide*.

Appendix A: Creating a Custom Calibration File

The calibration settings for the WSA5000 are stored in an XML file. The XML file name must have a .xml extension. You can create your own calibration file consistent with the structure and format described below (descriptions of the XML tags follow). **Replace the *italicized texts* with the appropriate values.**

```

<cal>
  <created>YYYY/MM/DD HH:MM:SS</created>
  <model>WSAXXXX-XXX</model>
  <prodrev>X</prodrev>
  <firmware>X.Y.Z</firmware>
  <version>2</version>
  <inputmode>
    <rfe_mode>
      <freqrange start="start_value" stop="stop_value">
        <freq value="freq_value_1">ref_level_1</freq>
        <freq value="freq_value_2">ref_level_2</freq>
        ... so on for more frequency steps ...
      </freqrange>
      ... so on for more frequency ranges ...
      <temprange start="start_value" stop="stop_value">
        <temp value="temp_value_1">ref_level_1</temp>
        <temp value="temp_value_2">ref_level_2</temp>
        ... so on for more temperature steps ...
      </temprange>
      ... so on for more temperature ranges ...
    </rfe_mode>
    ... so on for more RFE modes ...
  </inputmode>

  <vga_path>
    <gainrange start="start_value" stop="stop_value">
      <gain value="gain_value_1">ref_level_1</gain>
      <gain value="gain_value_2">ref_level_2</gain>
      ... so on for more gain steps ...
    </gainrange>
    ... so on for more gain ranges ...
    <temprange start="start_value" stop="stop_value">
      <temp value="temp_value_1">ref_level_1</temp>
      <temp value="temp_value_2">ref_level_2</temp>
      ... so on for more temperature steps ...
    </temprange>
    ... so on for more temperature ranges ...
  </vga_path>

  <attenuator>
    <freqrange start="start_value" stop="stop_value">
      <freq value="freq_value_1">ref_level_1</freq>
      <freq value="freq_value_2">ref_level_2</freq>
      ... so on for more frequency steps ...
    </freqrange>
    ... so on for more frequency ranges ...
    <temprange start="start_value" stop="stop_value">
      <temp value="temp_value_1">ref_level_1</temp>
      <temp value="temp_value_2">ref_level_2</temp>
      ... so on for more temperature steps ...
    </temprange>
    ... so on for more temperature ranges ...
  </attenuator>
</cal>

```

The following table describes the XML tags used in the calibration settings XML document. The tags are grouped by levels with the higher level tags are sub-elements of the lower level tags (e.g. <temp> is a sub-element of <temprange> which is a sub-element of <attenuator>).

XML Tag	Description
Root Level Tag:	
<cal>	The calibration information, the root element.
Level One Tags:	
<created>	The date and time the file was created using the format YYYY/MM/DD HH:MM:SS (e.g., 2014/06/07 13:25:50).
<model>	The model number of the WSA unit, expressed as WSAXXXX-XXX (e.g., WSA5000-220). This information is available on the “Device Status” page of the WSA administration console.
<prodrev>	The product revision of the WSA unit in the format listed on the “Device Status” page of the WSA administration console (e.g., 1.2).
<firmware>	This tag is to be used with products with firmware v3.2.7 or higher. If you have older firmware image, it is recommended that to upgrade your unit to the latest version. If upgrade is not possible, use <hwrev> instead. The firmware version installed on the WSA unit in the format listed on the “Device Status” page of the WSA administration console (e.g., 3.2.6 or 4.1.0).
<version>	The version of the XML file format, expressed as an integer. For units with firmware v3.2.7 and higher, use version 2; otherwise, use version 1.
<inputmode>	The input modes starting point. This section contains the sub-elements for each supported RFE mode.
<rfe_mode>	The RFE mode to be calibrated. Replace rfe_mode with the appropriate RFE tag name <zif>, <sh>, <hdr>, or <iqin>.
<vga_path>	This section contains - at least one frequency range <freqrange> element and one or more frequency <freq> sub-elements per range; and - at least one temperature range <temprange> element and one or more temperature <temp> sub-elements per range. The VGA (variable-gain amplifier) path to be calibrated. Replace vga_path with tag name <vgai> or <vgaq> for the I or Q path, respectively.
<attenuator>	This section contains - at least one gain range <gainrange> element and one or more gain <gain> sub-elements per range; and - at least one a temperature range <temprange> element and one or more temperature <temp> sub-elements per range. The attenuation path to be calibrated. This section contains - at least one frequency range <freqrange> element and one or more frequency <freq> sub-elements per range; and - at least one temperature range <temprange> element and one or more temperature <temp> sub-elements per range.

XML Tag	Description
Level Two Tags:	
<freqrange>	<p>The frequency range to be calibrated. You must specify values for the “start” (lower bound) and “stop” (upper bound) attributes in Hz.</p> <p>To be used with <inputmode> and <attenuator> sections only.</p>
<gainrange>	<p>The VGA's gain range to be calibrated. You must specify values for the “start” (lower bound) and “stop” (upper bound) attributes in dB.</p> <p>To be used with <vga_path> section only.</p>
<temprange>	<p>The temperature range to be calibrated. You must specify values for the “start” (lower bound) and “stop” (upper bound) attributes in Celcius.</p>
Level Three Tags:	
<freq>	<p>Specify a frequency value (in Hz) and a reference level (in dBm, expressed as a float value). The reference value for any frequencies between two specified frequency intervals will be linearly extrapolated.</p> <p>To be used with <freqrange> section only.</p>
<gain>	<p>Specify a gain value (in dB) and a reference level (in dBm, expressed as a float value). The reference value for any gains between two specified gain intervals will be linearly extrapolated.</p> <p>To be used with <gainrange> section only.</p>
<temp>	<p>Specify a temperature value (in Celcius) and a reference level (in dBm, expressed as a float value). The reference value for any temperatures between two specified temperature intervals will be linearly extrapolated.</p> <p>To be used with <temprange> section only.</p>



Note: You do not need to specify values for all RFE modes, VGA or attenuator and ranges in the calibration file. Only the calibration settings of the RFE mode(s) specified in the custom calibration file will be overwritten by the customized settings. The remaining settings will remain at their previous calibration values.

Appendix B: Example XML Calibration File

This example calibration file specifies the calibration reference level values for various specific frequencies between 0 to 2 GHz, several specific temperatures, and specific VGA's gain ranges between -10 to 30 dB.

You can specify different values for the ranges or the level three tag elements; they do not have to be the same as shown in this example.

```
<cal>
  <created>2014/07/09 12:34:45</created>
  <model>WSA5000-108</model>
  <prodrev>1.2</prodrev>
  <firmware>4.1.0</firmware>
  <version>2</version>

  <inputmode>
    <sh>
      <temprange start="-40" stop="85">
        <temp value='-10'>-1</temp>
        <temp value='0'>3</temp>
        <temp value='15'>6</temp>
        <temp value='33'>8</temp>
      </temprange>
      <freqrange start="0" stop="20e9">
        <freq value='100e6'>5</freq>
        <freq value='500e6'>7.1</freq>
        <freq value='10e9'>18.2</freq>
        <freq value='20e9'>8.2</freq>
      </freqrange>
    </sh>

    <zif>
      <freqrange start="0" stop="20e9">
        <freq value='100e6'>6</freq>
        <freq value='500e6'>8.1</freq>
        <freq value='10e9'>14.5</freq>
        <freq value='20e9'>9.5</freq>
      </freqrange>
      <temprange start="-40" stop="85">
        <temp value='-40'>-4</temp>
        <temp value='0'>1</temp>
        <temp value='35'>4</temp>
        <temp value='85'>7</temp>
      </temprange>
    </zif>

    <hdr>
      <freqrange start="0" stop="20e9">
        <freq value='100e6'>14</freq>
        <freq value='500e6'>28.1</freq>
        <freq value='10e9'>23.1</freq>
        <freq value='20e9'>29.5</freq>
      </freqrange>
      <temprange start="-30" stop="40">
        <temp value='-11'>-2</temp>
        <temp value='0'>2</temp>
        <temp value='13'>4</temp>
        <temp value='32'>5</temp>
      </temprange>
    </hdr>
  </inputmode>
</cal>
```

```

    </temprange>
</hdr>

<iqin>
  <freqrange start="0" stop="0">
    <freq value="0">17</freq>
  </freqrange>
  <temprange start="-40" stop="85">
    <temp value='25'>1</temp>
  </temprange>
</iqin>
</inputmode>

<vgai>
  <gainrange start="-10" stop="30">
    <gain value='-10'>0.9</gain>
    <gain value='0'>0.5</gain>
    <gain value='10'>-0.7</gain>
    <gain value='20'>-1.3</gain>
  </gainrange>
  <temprange start="-40" stop="85">
    <temp value='-40'>-4</temp>
    <temp value='0'>1</temp>
    <temp value='35'>4</temp>
    <temp value='85'>7</temp>
  </temprange>
</vgai>
<vgaq>
  <gainrange start="-10" stop="30">
    <gain value='-10'>1.2</gain>
    <gain value='0'>0.8</gain>
    <gain value='10'>-0.6</gain>
    <gain value='20'>-1.2</gain>
  </gainrange>
  <temprange start="-40" stop="85">
    <temp value='-40'>-3</temp>
    <temp value='0'>1</temp>
    <temp value='35'>3</temp>
    <temp value='85'>6</temp>
  </temprange>
</vgaq>

<attenuator>
  <freqrange start="0" stop="20e9">
    <freq value='100e6'>19.4</freq>
    <freq value='500e6'>20.1</freq>
    <freq value='2e9'>20.3</freq>
  </freqrange>
  <temprange start="-40" stop="85">
    <temp value="-40">-10</temp>
    <temp value="25">0</temp>
    <temp value="75">10</temp>
  </temprange>
</attenuator>
</cal>

```