

## Application Note

74-0059-180604

# How to Perform a Custom Calibration on a ThinkRF R5500

The ThinkRF R5500 Real-Time Spectrum Analyzer allows the end-users to load a customized calibration file to the unit in order to optimize the unit, to reduce unit-to-unit variation or to enhance parameters that are most important to the end-users' application. A calibration file is for mapping the reference levels against various radio settings and physical parameters, such as frequency, temperature, and insertion loss of the attenuator.

This application note provides a step-by-step calibration procedure for the end-users to do such calibration.

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# 1 Introduction

The ThinkRF R5500 provides a built-in facility that allows the end-user to load a customized calibration file to the RTSA 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 R5500 including how to communicate with and control the unit using SCPI commands (referring to *R5500 User Guide* and *Programmer's Guide* as required).

## 2 Setup Requirements

The following items are required to carry out the calibration:

- A R5500, 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 R5500 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 R5500, 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 R5500.
- An RF power meter to accurately measure the signal power that is presented to the R5500.

## 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 R5500 yet until the R5500 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 R5500's RF IN connector.



**Caution:** ThinkRF's receivers tolerate a maximum input signal of **+10 dBm** at the RF IN port. Injecting signal levels that exceed the specification will result in permanent damage to the receiver.

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## 3.2 Setting Up the R5500

3. Connect the R5500 to its power adaptor and turn the unit on. Ensure that the status LEDs on the unit indicate that the unit is operating properly. See R5500's *User Guide*.
4. Determine the unit's IP address unit using the procedure described in the R5500's *User Guide*.
5. Turn the R5500's input attenuator off by using the following SCPI command:  

```
:INPUT:ATTENUATOR 0           # for -408 model only  
:INPUT:ATTENUATOR:VARIABLE 0 # for -418 and -427 models
```
6. Connect the SMA plug to the R5500'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.**



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**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 R5500.**

---

8. Connect a suitable cable from the 10MHz reference source to the **10 MHz IN** port on the R5500.
9. Switch the R5500 to use the external reference clock:

```
:SOURCE:REFERENCE:PLL EXT
```

## 4 Calibration Steps

1. Ensure that the decimation factor is set to 1 (no decimation) and the frequency shift is set to zero by issuing the following SCPI commands or a \*RST command:

```
:SENSE:DEC 1
```

```
:SENSE:FREQ:SHIFT 0
```

2. Set the R5500 to the RFE (Receiver Front End) mode of interest:

```
:INPut:MODE <mode>
```

See *R5500 Programmer's Guide* for the modes available.

3. Tune R5500 to the frequency of interest, for example 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 mode, avoid injecting a signal frequency that is the same as the R5500'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 R5500 S240 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 R5500 GUI (or your application) in dBm

$P_{input}$  = the RF power level presented to the input connector on the R5500 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 Files](#).
11. See the "Customizing the R5500's Calibration" section of the *User's Guide* for instruction on how to upload your custom calibration file to the R5500 using the web administrative console.

## 4.1 Interpolation Calculation

When the R5500 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 R5500'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 R5500 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 R5500, when the attenuator is set to non-zero, that attenuation value is automatically added in the reference level reported by the VRT context packet
2. Each R5500 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 R5500, 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 R5500 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 R5500's *User's Guide*.

## Appendix A: Creating a Custom Calibration File

The calibration settings for the R5500 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>
  <tpn>YY-XXXX</tpn>
  <cl>X</cl>
  <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>

  <attenuator>
    <att_value>
      <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 ...
    </att_value>
    ... so on for other att_value
    <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>

  <psfm>
    <psfm_mode>
      <lina_stage>
        <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 ...
  ... so on for more temperature ranges ...
</lna_stage>
</psfm_mode>
... so on for more PSFM modes ...
</psfm>
</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								
<b>Root Level Tag:</b>									
<cal>	The calibration information, the root element.								
<b>Level One Tags:</b>									
<created>	The date and time the file was created using the format <b>YYYY/MM/DD HH:MM:SS</b> (e.g., 2017/06/07 13:25:50).								
<tpn>	The ThinkRF part number (TPN) of the RTSA unit, expressed as XX-XXXX. The following is a list of the TPN corresponding to the ThinkRF product model: <table border="1" data-bbox="730 1113 1185 1291"> <thead> <tr> <th>Product Model</th> <th>TPN</th> </tr> </thead> <tbody> <tr> <td>R5500-408</td> <td>32-0045</td> </tr> <tr> <td>R5500-418</td> <td>32-0047</td> </tr> <tr> <td>R5500-427</td> <td>32-0046</td> </tr> </tbody> </table>	Product Model	TPN	R5500-408	32-0045	R5500-418	32-0047	R5500-427	32-0046
Product Model	TPN								
R5500-408	32-0045								
R5500-418	32-0047								
R5500-427	32-0046								
<cl>	Compatibility level between the product version and the firmware. <b>For R5500-408 model, use 2; for -418 and -427 models, use 1.</b>								
<firmware>	The firmware version installed on the RTSA unit in the format listed on the "Device Status" page of the RTSA administration console (e.g., 1.4.3).								
<version>	The version of the XML file format, expressed as an integer. <b>Use 3.</b>								
<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 <b>rfe_mode</b> with the appropriate RFE tag name, such as <zif>, <sh>, <hdr>. See <i>R5500 Programmer's Guide</i> for the list of RFE modes. To be used with <inputmode> section only. This section contains: - zero, one or more frequency range <freqrange> element and one or more frequency <freq> sub-elements per range; and								

XML Tag	Description
	- zero, one or more temperature range <temprange> element and one or more temperature <temp> sub-elements per range.
<attenuator>	The attenuation path to be calibrated. <b>Use with R5500-408 and its variant models only.</b> When use, this section contains: - at least one attenuation value <att_val> element and one or more its sub-elements per <att_val>. - at least one temperature range <temprange> element and one or more temperature <temp> sub-elements per range.
<att_val>	The attenuation amount, use values 10, 20 or 30 dB (e.g., <10>). To be used with <attenuator> section only. When use, this section contains at least one frequency range <freqrange> element and one or more frequency <freq> sub-elements per range.
<psfm>	The downconverter path of the R5500. <b>Use with R5500-418, -427 and their variants only.</b>
<psfm_mode>	The PSFM mode to be calibrated, which includes <sh> and <dc>. To be used with <psfm> section only.
<lina_stage>	The LNA stages of the PSFM, which includes <lan_on>, <lina1_on> and <lina1_off>. To be used with each <psfm_mode> section and calibrated over frequency only. This section contains at least one frequency range <freqrange> element and one or more frequency <freq> sub-elements per range.
<b>Level Two Tags:</b>	
<freqrange>	The frequency range to be calibrated. You must specify values for the "start" (lower bound) and "stop" (upper bound) attributes in Hz. To be used with <inputmode> and <attenuator> sections only.
<temprange>	The temperature range to be calibrated. You must specify values for the "start" (lower bound) and "stop" (upper bound) attributes in Celcius.
<b>Level Three Tags:</b>	
<freq>	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. To be used with <freqrange> section only.
<temp>	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. To be used with <temprange> section only.



**Note:** You do not need to specify values for all RFE modes, attenuator or PSFM modes 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 Files

This section shows two example calibration files specifying the calibration reference level values for a R5500-408 (TPN 32-0045) and R5500-427 (TPN 32-0046) with various specific frequencies between 0 to 2 GHz, several specific temperatures, attenuation and PSFM modes, where applicable.

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 the examples. In addition, the values used in the examples are random, carry no significance.

### B.1 An Example for R5500-408

```
<cal>
  <created>2017/09/09 12:34:56</created>
  <tpn>32-0045</tpn>
  <cl>2</cl>
  <firmware>1.4.3</firmware>
  <version>3</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>
  </inputmode>
</cal>
```

```

<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>

<attenuator>
  <temprange start="-40" stop="85">
    <temp value="-40">-10</temp>
    <temp value="25">0</temp>
    <temp value="75">10</temp>
  </temprange>
<10>
  <freqrange start="0" stop="20e9">
    <freq value='100e6'>19.4</freq>
    <freq value='500e6'>20.1</freq>
    <freq value='2e9'>20.3</freq>
  </freqrange>
</10>
<20>
  <freqrange start="0" stop="20e9">
    <freq value='100e6'>18</freq>
    <freq value='500e6'>19.5</freq>
    <freq value='2e9'>20</freq>
  </freqrange>
</20>
<30>
  <freqrange start="0" stop="20e9">
    <freq value='100e6'>17</freq>
    <freq value='500e6'>19</freq>
    <freq value='2e9'>20.5</freq>
  </freqrange>
</30>
</attenuator>
</cal>

```

## ***B.2 An Example for R5500-427***

```

<cal>
  <created>2017/09/09 12:34:56</created>
  <tpn>32-0046</tpn>

```

```
<cl>1</cl>
<firmware>1.4.3</firmware>
<version>3</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>
```

```

<psfm>
  <sh>
    <lina_on>
      <freqrange start="0" stop="20e9">
        <freq value='100e6'>19.4</freq>
        <freq value='500e6'>20.1</freq>
        <freq value='2e9'>20.3</freq>
      </freqrange>
    </lina_on>
    <lina_off>
      <freqrange start="0" stop="20e9">
        <freq value='100e6'>10.4</freq>
        <freq value='500e6'>10.1</freq>
        <freq value='2e9'>10</freq>
      </freqrange>
    </lina_off>
  </sh>
  <dc>
    <lina1_on>
      <freqrange start="0" stop="20e9">
        <freq value='100e6'>19.4</freq>
        <freq value='500e6'>20.1</freq>
        <freq value='2e9'>20.3</freq>
      </freqrange>
    </lina1_on>
    <lina_off>
      <freqrange start="0" stop="20e9">
        <freq value='100e6'>10.4</freq>
        <freq value='500e6'>10.1</freq>
        <freq value='2e9'>10</freq>
      </freqrange>
    </lina_off>
  </dc>
</psfm>
</cal>

```

## Document Revision History

This section summarizes document revision history.

Document Release Version	Release Date	Revisions and Notes
v1.0	Sept 01, 2017	First release
v1.1	June 05, 2018	Corrected the maximum safe input for RF IN port to be +10 dBm with or without attenuation

## Contact us for more information

ThinkRF Support website provides online documents for resolving technical issues with ThinkRF products at <http://www.thinkrf.com/resources>.

For all customers who hold a valid end-user license, ThinkRF provides technical assistance 9 AM to 5 PM Eastern Time, Monday to Friday. Contact us at [support@thinkrf.com](mailto:support@thinkrf.com), [sales@thinkrf.com](mailto:sales@thinkrf.com) or by calling **+1.613.369.5104**.

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