Application Note

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Procedure for a Higher Accuracy Receiver Calibration for Use in mm-Wave Noise Figure Measurements

Introduction

VectorStar™ Noise Figure Option 41 provides noise figure measurements for frequencies from 70 kHz to 110 GHz. Option 41 uses the cold source method using terminations and absolute power measurements instead of hot/cold noise sources. The cold-source noise figure measurement removes the errors associated with mismatch differences between the hot and cold states of the noise source and simplifies calibration and traceability. Using the cold source method provides traceability paths through the power sensor and the traceability information is usually readily available, compared to what can happen with the calibration requirements of the noise source. The result is a simple, accurate method of noise figure measurements up to 110 GHz when using the Vector Network Analyzer (VNA) platform.

Measuring noise figure above 70 GHz (in mm-wave waveguide bands) in the past resulted in complex configuration of mm-wave receivers and multiple paths of traceability. The result is time consuming system setups with minimal traceable paths to a standards laboratory and often with less than optimum uncertainties. Millimeter-Wave VNAs were often not used since the mm-wave modules used for the upper frequency bands did not provide an optimum noise figure receiver with adequate noise figure specification. The 3744A-Rx mm-wave receiver, based on the 3743A mm-wave module, provides the noise figure performance required and now makes possible true mm-wave noise figure measurements taking advantage of the accuracy and ease of use of the VectorStar VNA.

In order to obtain accurate measurement results, the noise figure receiver must be calibrated. The standard procedure for transferring power accuracy to the receiver for a mm-wave noise figure measurement with the 3744A-Rx module involves a few steps:

- In T/R mode with the source module connected directly to the 3744A-Rx module with the factory receiver calibration (for that module) applied, store b2/1|P1. This measurement is performed at a low power level (e.g., –55 dBm) that will be used during the actual receiver calibration (involving pre-amplifiers and filters) and with the magnitude reference plane shifted by that power value. This stored file is called a ‘receiver offset correction’ file and accounts for differences between the measured signal level and the ALC set level.
- While still in T/R mode, connect the amplifiers and filters desired to the receiver module and connect the port 1 module to the input and perform a standard receiver cal. This transfers the ALC accuracy to the receiver assembly.

These two steps together do a fairly good job of establishing the needed power accuracy at the receiver input plane. The ‘receiver offset correction’ step, in particular, takes the difference between the actual measured |b2| value at the 3744A-Rx using its more accurate calibration and the stated ALC setting as a measure of residual inaccuracies in the ALC calibration. In some cases, however, this level of accuracy, of order 1-2 dB, may not be good enough when considering the level of other uncertainty terms such as those due to mismatch and uncorrected harmonic effects. This note describes a process for improving that accuracy in those cases where it is required.

Full Composite Receiver Calibration Procedure

There are a couple of different approaches to obtain higher accuracy receiver calibrations:

- Manually modify the Receiver Offset Correction (ROC) file for its shortcomings.
- Attack the actual composite receiver calibration process directly and correct for its shortcomings.

Both require some separation of the fundamental signal from the total integrated power that a power meter measures, but the former (#1) also requires some more substantial source and load match corrections. Since the usual composite receiver contains an isolator at its input, these match corrections are less important, so attacking the composite receiver calibration process directly has some advantages. Because of these reasons, it is recommended to use approach #2.

Equipment Requirements:

- Spectrum Analyzer and Harmonic Mixer
- Power Meter and W-band Sensor
- VectorStar ME7838A/D/E with 3743A/E module

Calibration Procedure:

Calibrate drive power of source

The objective is to get all harmonically related products below–30 dBc. The power source can be either:

- VectorStar ME7838A/D/E with 3743A/E module
- External Synthesizer and Multiplier

For the purposes of this paper, the VectorStar ME7838A with 3743A module will be used and careful attention to the filtering bands will be required. A waveguide feeding structure can help with implicit high-pass filtering.

This is a manual process and must be repeated for each frequency point of interest. The results from the measurement must be manually captured. For convenience, one may consider using a spreadsheet program such as Microsoft™ Excel to capture the results and for performing calculations in the next steps in this process.

- Setup VectorStar system to generate CW signal at some convenient level like –20 dBm (within the power meter range, but not so high that the spectrum analyzer harmonic mixer will compress).
- Frequency = Desired frequency point
- CW Mode = ON
- # Points = 1,000
- Power = –20 dBm
- With the power meter, W-band sensor, and filters (possibly in sub-bands depending on the measurement bandwidth), measure drive power.
- Repeat this process for each frequency point desired and tabulate the results.

Use the calibration in step 1 to calibrate the spectrum analyzer + harmonic mixer in absolute power terms.

As with step 1, this is a manual process and must be repeated for each frequency point of interest. The results from each measurement must be manually captured.

- Set the RBW of the spectrum analyzer as close as possible to the IFBW used during the receiver calibration process. In most cases, one can only get down to 10 kHz RBW on the Spectrum Analyzer, but this is close enough. Note that the RBW is less important for the case where an external synthesizer/multiplier is used as the source.

  The use of attenuation on the mixer or on the source side of the drive path is desirable to reduce the effect of mismatch. The loss can be built into the calibration depending on its placement or can be partially removed as a lumped term.

  The spectrum analyzer calibration can only be done explicitly at the power level set above and linearity will be assumed down to the desired drive level for the composite receiver assembly.
- Connect the Source path used in step 1 (a ME7838X and mm-wave modules + filters in this note) to the spectrum analyzer.
- Use the marker function of the spectrum analyzer to measure the power level of the fundamental and record the result.
- To calculate the spectrum analyzer calibration factor, subtract the spectrum analyzer power measurement results in this step from the power meter measurement results from step 1.
- Repeat this process for each frequency point desired and tabulate the results.

An example spectrum analyzer calibration result is plotted below in Figure 1. In this case, the spectrum analyzer was always reading low although it is possible to have positive and negative values.

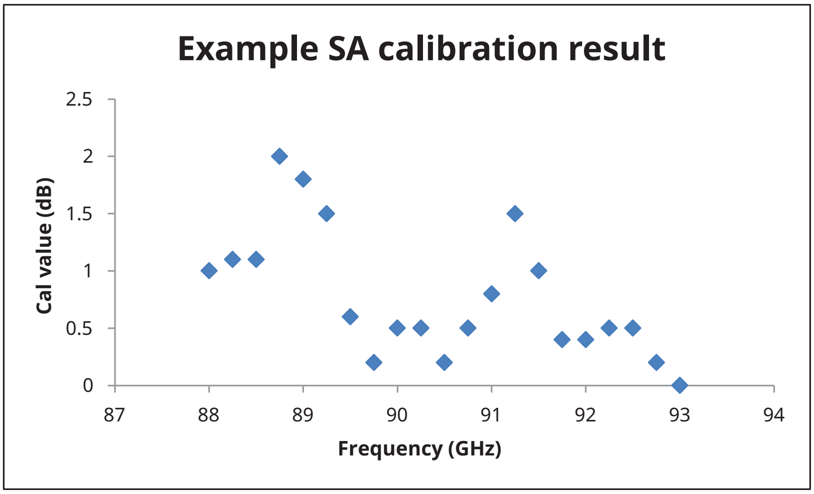

Figure 1: Example Spectrum Analyzer Calibration Results

Connect the source module combination set for the target receiver calibration power level (e.g., –55 dBm) and transfer the spectrum analyzer calibration to the source.

- Connect the 3743A + filter source (again, a synthesizer/multiplier/filter combination could be used instead although this example uses the ME7838A/E) to the spectrum analyzer
- Set the VectorStar source for the target receiver calibration power level

  Power = –55 dBm (as an example)
- For each frequency of interest, record the absolute power of the fundamental.

The difference between this level and the integrated power that the spectrum analyzer was calibrated against in step 2 is generally due to harmonic content from the 3743A. Particularly when operated at low power levels, other harmonic products can have a significant impact on total integrated power (the power set point essentially incorporates by virtue of the power meter calibration).

For output frequencies between 80 and 120 GHz, the 2/3 and 4/3 products are normally of interest. The 2/3 product is more important for system frequencies closer to 120 GHz and the 4/3 is more important closer to 80 GHz. For output frequencies between 54 and 80 GHz, the 3/2 and 1/2 products are normally of interest. The 3/2 product is more important for system frequencies closer to 54 GHz and the 1/2 product is more important closer to 80 GHz.

Create new Receiver Offset Correction File

- New Receiver Offset values can be created in Excel by combining the fundamental power readings from step 3 with the calibration data of the spectrum analyzer from step 2.

  The final column in the example in Table 1 shows the receiver offset in dB. The column values are as follows:

  – Frequency – Frequency of measurement

  – Source Power (Power Meter) – Source Power measured by power meter in step 1.

  – Source Power (Spec An) – Source Power measured by spectrum analyzer in step 2

  – SPA Cal – Spectrum Analyzer calibration value obtained from step 2

    - SPA Cal = Source Power (Power Meter) – Source Power (Spec An)

  – Receiver Power – Measured power level of source from step 3

  – Delta from Target – Difference in Measured power in step 3 and Target Power

    - Delta from Target = Target Power – Receiver Power

  – Offset – Receiver Offset Value to be used in ROC file

    - Offset = Delta from Target + SPA Cal

Frequency	Source Power (Power Meter)	Source Power (Spec An)	SPA Cal	Receiver Power	Delta from Target	Offset
88	20.2	19.2	1	–62.7	–7.7	–6.7
88.3	20.4	19.3	1.1	–61.8	–6.8	–5.7
88.5	20.5	19.4	1.1	–62.8	–7.8	–6.7
88.8	20.4	18.4	2	–64.5	–9.5	–7.5
89	20.2	18.4	1.8	–64	–9	–7.2
89.3	20.5	19	1.5	–62.8	–7.8	–6.3
89.5	20.5	19.9	0.6	–62.7	–7.7	–7.1
89.8	20.5	20.3	0.2	–61.5	–6.5	–6.3
90	20.3	19.8	0.5	–61.2	–6.2	–5.7
90.3	20.5	20	0.5	–59.8	–4.8	–4.3
90.5	20.3	20.1	0.2	–58.3	–3.3	–3.1
90.8	20.5	20	0.5	–58.3	–3.3	–2.8
91	20.3	19.5	0.8	–60.2	–5.2	–4.4
91.3	20.4	18.9	1.5	–58.5	–3.5	–2
91.5	20.4	19.4	1	–58.7	–3.7	–2.7
91.8	20.1	19.7	0.4	–58.7	–3.7	–3.3
92	20.2	19.8	0.4	–59	–4	–3.6
92.3	20.2	19.7	0.5	–60	–5	–4.5
92.5	20.5	20	0.5	–60	–5	–4.5
92.8	20.1	19.9	0.2	–60	–5	–4.8
93	20.3	20.3	0	–59.5	–4.5	–4.5

Table 1: Example Receiver Offset Calculation Spreadsheet

- One can create the properly formatted ROC file by pasting the last column above into a .txt file saved from the system with the same frequency points. Be careful not to destroy the header and to re-save the file as tab delimited text (.txt).
  - Preset VectorStar to get it into a known state
  - Configure Frequency Start, Frequency Stop, and # of Points to match the frequency points of the ROC file. In this case: Start = 88 GHz, Stop = 93 GHz, # of Points = 21 points
  - Set Number of Traces = 1
  - Set Trace Format = Log Magnitude
  - Save data as .txt file

Since we are using the ROC loader with this modified file, it is important to keep the same format (16 lines of header and then the index-frequency point-dB data column setup). This is pretty easy to maintain just pasting within Excel. An example of the data contained within the file is shown below:

```
MS4647B
!7/21/2015.10:41:30.AM
!CHANNEL.1
!TR.MEASUREMENT
!RF.CORRECTION.OFF
!AVERAGING.OFF
!IF.BANDWIDTH: 10HZ
!NUMBER.OF.TRACES: 1
!TRACE:     TRACE.1
!PARAMETER:         B2/1
!PORT:      PORT1
!GRAPH:     LOGMAG
!SMOOTHING:         OFF
!TIMEDOMAIN:        OFF
!SWEEPTYPE: FREQ.SWEEP(Linear)
PNT FREQ1.GHZ       LOGMAG1
1   88.000000000    –6.571595E+000
2   88.250000000    –6.607242E+000
3   88.500000000    –5.889495E+000
4   88.750000000    –4.940768E+000
5   89.000000000    –4.423860E+000
6   89.250000000    –6.956201E+000
7   89.500000000    –9.154461E+000
8   89.750000000    –7.954574E+000
9   90.000000000    –6.561428E+000
10  90.250000000    –6.554013E+000
11  90.500000000    –6.674458E+000
12  90.750000000    –6.230324E+000
13  91.000000000    –4.960042E+000
14  91.250000000    –3.627669E+000
15  91.500000000    –3.314635E+000
16  91.750000000    –3.116560E+000
17  92.000000000    –4.102502E+000
18  92.250000000    –4.047035E+000
19  92.500000000    –3.104189E+000
20  92.750000000    –3.331397E+000
21  93.000000000    –2.697932E+000
```

– Using Excel (or other text editor), replace the last column of the .txt file with the ROC Offset Data obtained in step 3. Note that the scientific notation in the data column is not required.

– Save the file as a tab delimited .txt file. The newly created ROC file should look like Table 2.

MS4647B		
!7/21/2015.10:41:30.AM		
!CHANNEL.1		
!TR.MEASUREMENT		
!RF.CORRECTION.OFF		
!AVERAGING.OFF		
!IF.BANDWIDTH: 10HZ		
!NUMBER.OF.TRACES: 1		
!TRACE:	TRACE.1	
!PARAMETER:	B2/1	
!PORT:	PORT1	
!GRAPH:	LOGMAG	
!SMOOTHING:	OFF	
!TIMEDOMAIN:	OFF	
!SWEEPTYPE: FREQ.SWEEP(Linear)		
PNT	FREQ1.GHZ	LOGMAG1
1	88	–6.70
2	88.25	–5.70
3	88.5	–6.70
4	88.75	–7.50
5	89	–7.20
6	89.25	–6.30
7	89.5	–7.10
8	89.75	–6.30
9	90	–5.70
10	90.25	–4.30
11	90.5	–3.10
12	90.75	–2.80
13	91	–4.40
14	91.25	–2.00
15	91.5	–2.70
16	91.75	–3.30
17	92	–3.60
18	92.25	–4.50
19	92.5	–4.50
20	92.75	–4.80
21	93	–4.50

Table 2: Example ROC file

Summary

More accurate measurement results may be obtained by carefully calibrating the noise figure receiver using the higher accuracy calibration method described in this application note. As an example of the change in the amount of scatter with the standard vs. this higher accuracy method, some LNA noise figure measurements are plotted below. This comparison is not meant to be entirely representative, since harmonic content and match levels vary from system to system, but it may give an idea of the size of changes possible.

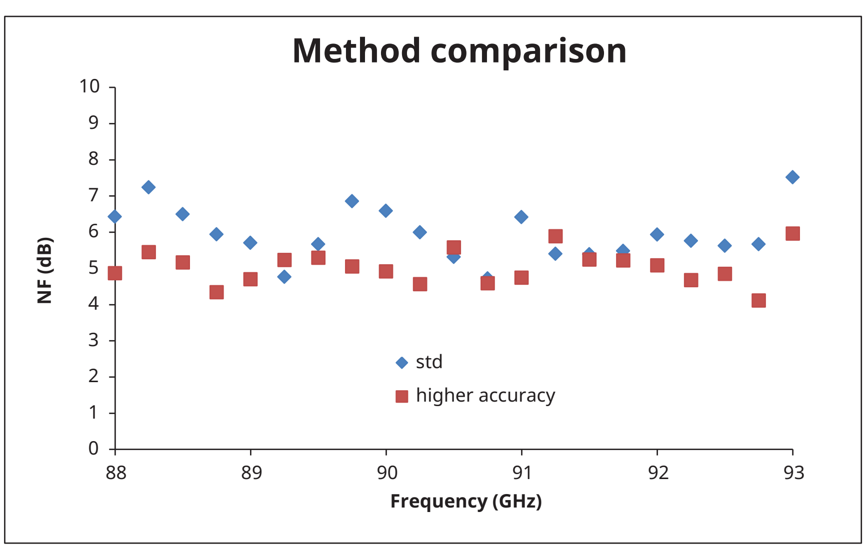

Figure 2: Comparison of Standard Calibration Method vs Higher Accuracy Method

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