User Guide

VectorStar® mm-Wave Noise Figure Measurements

Using a VectorStar ME7838A VNA System and 3744A-Rx Receiver Module

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Chapter 1 — General Information

1-1 Introduction

This User Guide provides instructions for using the 3744A-Rx mm-Wave Receiver Module for making noise figure measurements.

VectorStar Noise Figure Option 041 provides noise figure measurements for frequencies from 70 kHz to 70 GHz using the standard two port platform. 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 is readily available compared to the calibration requirements of the noise source. The result is a simple, accurate method of noise figure measurements up to 70 GHz when using the VectorStar MS4640A 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. Often the use of spectrum analyzers and mm-Wave mixers were required. 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 a receiver with optimum noise figure. The new 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.

1-2 Related Manuals and Documentation

Manuals and Documentation related to the operation and maintenance of ME7838A VNA Systems are listed below.

VectorStar MS4640A Series VNAs

- VectorStar MS4640A Series VNA Technical Data Sheet – 11410-00432
- VectorStar MS4640A Series VNA Operation Manual – 10410-00266
- VectorStar MS4640A Series VNA Programming Manual – 10410-00267
- VectorStar MS4640A Series VNA Measurement Guide – 10410-00269
- VectorStar MS4640A Series VNA Maintenance Manual – 10410-00268

VectorStar ME7838A Broadband/Millimeter-Wave VNA Measurement System

- VectorStar ME7838A Broadband/Millimeter-Wave VNA System Technical Data Sheet – 11410-00593
- VectorStar ME7838A Broadband/Millimeter-Wave VNA System Quick Start Guide – 10410-00292
- VectorStar ME7838A Broadband/Millimeter-Wave VNA System Installation Guide – 10410-00293
- VectorStar Broadband/Banded Millimeter-Wave Modules Reference Manual – 10410-00311

Calibration and Verification Kits

- 3656B W1 Calibration/Verification Kit and 2300-496 System Performance Verification Software User Guide – 10410-00286

For additional literature related to the Anritsu VectorStar family of products, refer to:
http://www.anritsu.com/en-US/Products-Solutions/Products/MS4640A-Series.aspx

1-3 VectorStar Cold-Source Noise Figure Measurement Review

A typical noise figure measurement using option 41 requires a few simple steps:

Cold-Source Noise Figure Measurement Procedure requires the following steps:

1. Measurement of DUT gain or S-parameters (over an appropriate frequency range and at an appropriate power level).
2. Performing an optional user power calibration over the frequencies of interest to optimize receiver calibration accuracy.

   This step is performed using the internal power cal routine in the Power Menu and verifies absolute power at the test port (usually at the end of the test port cable).
3. Assembly of composite receiver for the noise figure measurement.

   This step usually includes the Uncertainty Calculator to determine the optimum preamp gain required for acceptable measurement uncertainty.
4. Receiver calibration (transferring the traceable power accuracy to the receiver) as shown in Figure 1-1.

   Attach the calibrated test port to the composite receiver to calibrate the receiver.

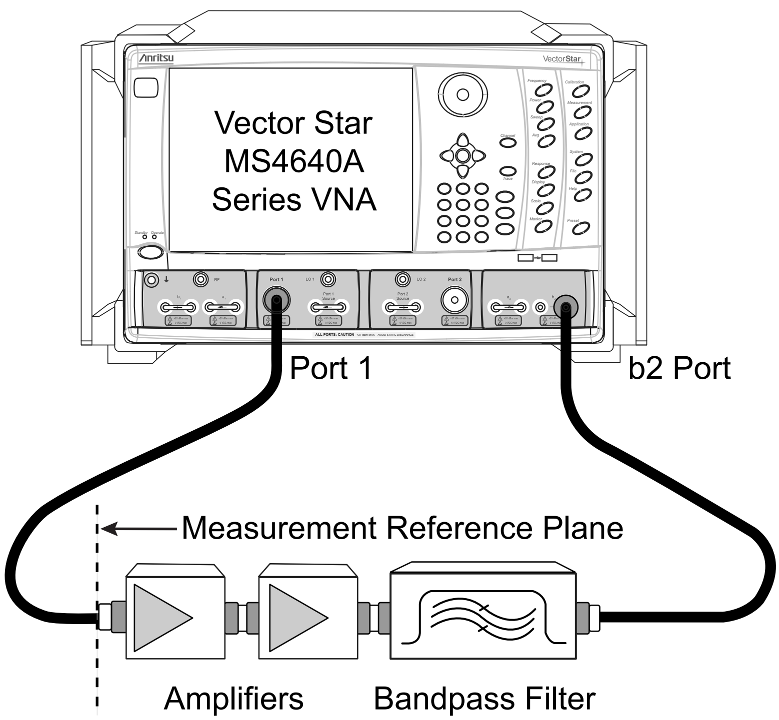


Figure 1-1. Composite Receiver Calibration

5. Basic setup (frequency range, number of points, etc).
6. Recalling DUT gain and receiver calibration data.

7. Noise calibration (measurement of the receiver noise power so it can be removed from the calculations). See Figure 1-2

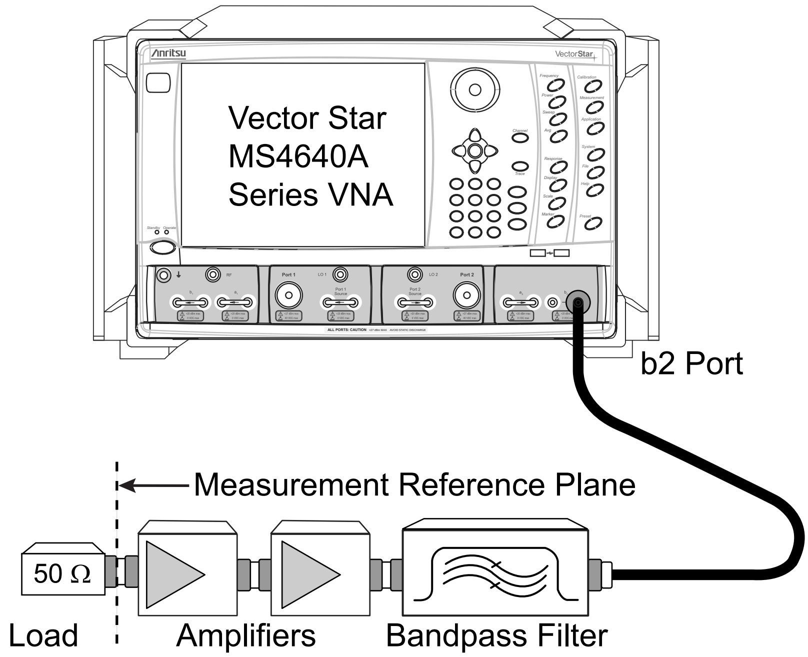


Figure 1-2. System Noise Calibration

8. DUT Measurement (Figure 1-3).

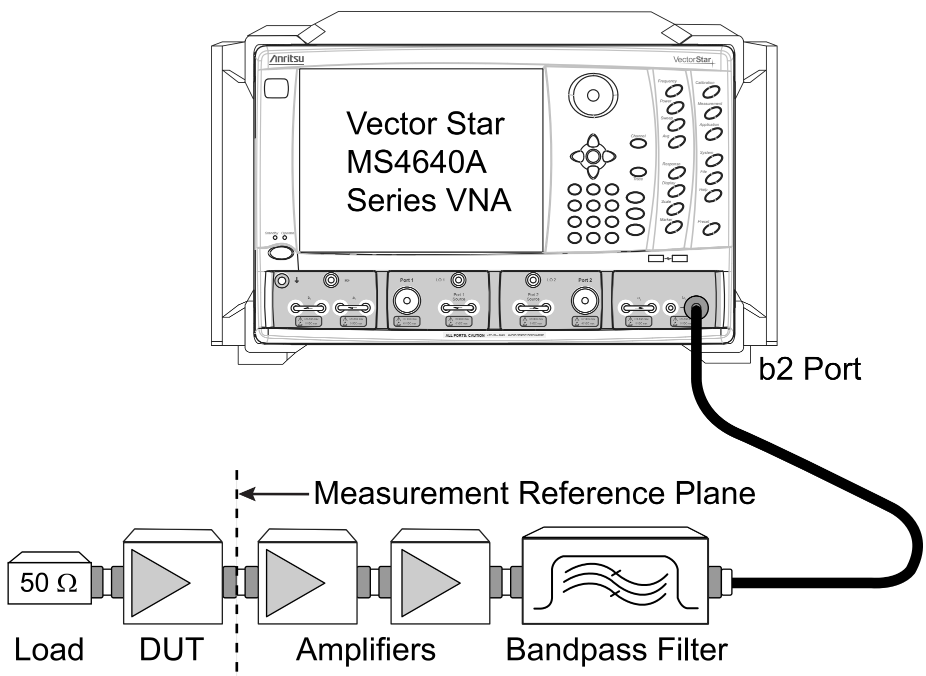


Figure 1-3. DUT Measurement

Note	Note that the composite receiver is connected directly to the sampler via the b_2 port. This is done to improve the noise figure performance of the receiver.

1-4 Contacting Anritsu

To contact Anritsu, please visit:

http://www.anritsu.com/contact.asp

From here, you can select the latest sales, select service and support contact information in your country or region, provide online feedback, complete a “Talk to Anritsu” form to have your questions answered, or obtain other services offered by Anritsu.

Updated product information can be found on the Anritsu web site:

http://www.anritsu.com/

Search for the product model number. The latest documentation is on the product page under the Library tab.

Example URL for the MS4640A:

http://www.anritsu.com/en-us/products-solutions/products/ms4640a-series.aspx

Chapter 2 — Millimeter-Wave Noise Figure Measurements

2-1 Introduction

This chapter provides information and steps for using a VectorStar ME7838A System and a 3744A-Rx mm-Wave Receiver Module to make noise figure measurements.

The need for direct access to the sampler (or harmonic mixer) down converters is what has prevented using VNAs in the past from performing reasonably accurate mm-Wave noise figure measurements. The diagram in Figure 2-1 illustrates why this has been a problem.

- Typical mm-Wave modules do not have direct access loops.
- Performing cold-source mm-Wave NF measurements using standard mm-Wave modules would not provide adequate measurement uncertainty.
- The loss introduced by the couplers (and thus increase in noise figure) results in unacceptable noise figure uncertainties.

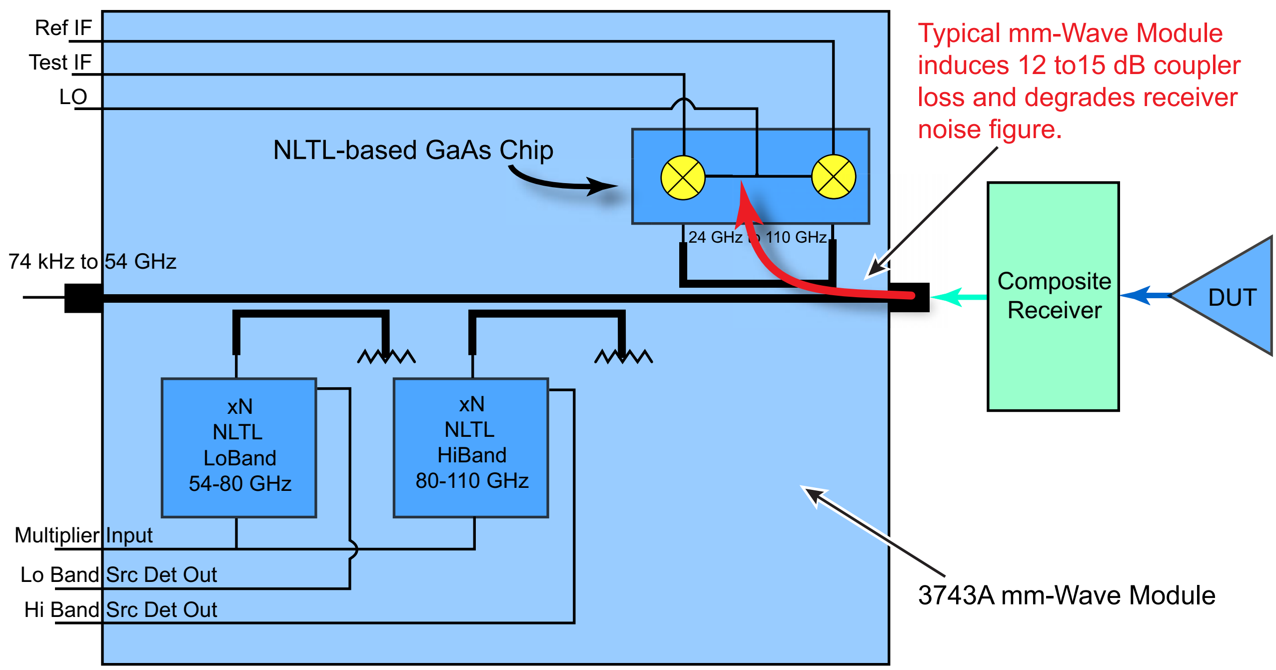


Figure 2-1. Millimeter-wave Noise Figure Measurements

The 3744A-Rx Receiver Module

Reconfiguring the architecture of the 3743A module (as shown in Figure 2-2) allows bypassing of the coupler and provides a direct connect to the mm-Wave module samplers. The result is a mm-Wave receiver (3744A-Rx) operating from 30 GHz to 125 GHz and with noise figure performance that now makes it possible to measure mm-Wave devices up to 125 GHz with more reasonable uncertainties.

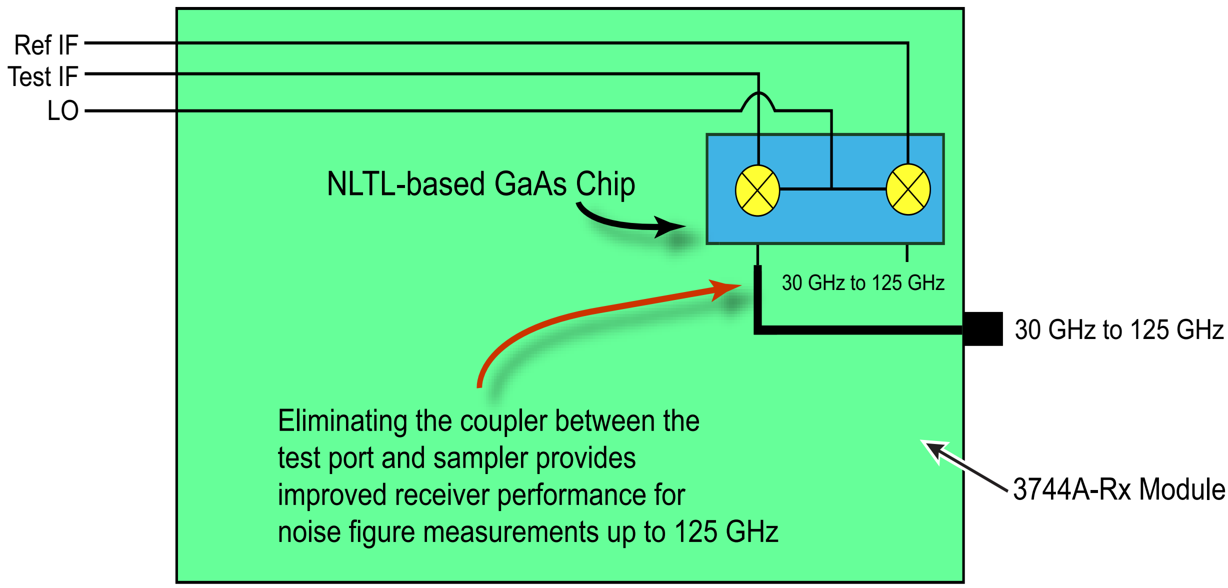
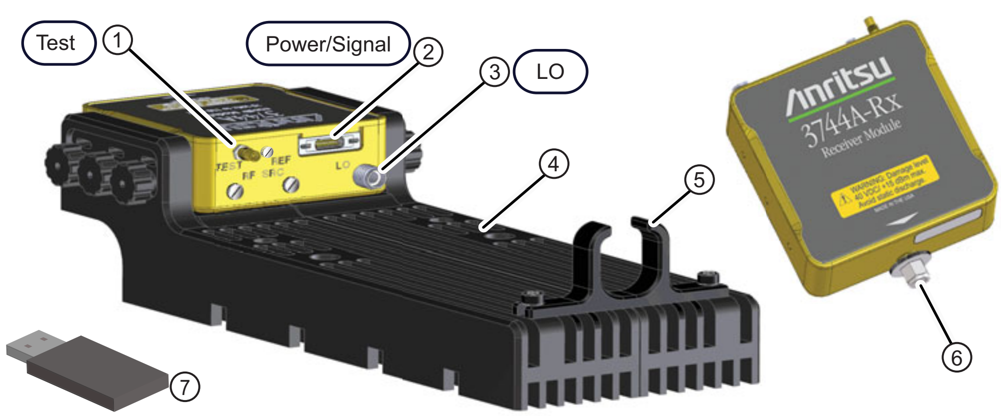


Figure 2-2. VectorStar 30 GHz to 125 GHz 3744A-Rx mm-Wave Receiver Module

The Receiver module kit consists of:

- One 3744A-Rx Receiver Module and Mounting Bracket
- One USB drive with receiver calibration file

  Characterization of the 3744A-Rx receiver is a factory characterization with appropriate files stored on the USB drive.



1	Test IF Port - SSMC Connector	5	Module I/O Cable Restraint
2	Power/Signal Connector	6	W Connector
3	LO Port - K Connector	7	USB drive with Receiver Calibration File
4	Module Mounting Bracket		

Figure 2-3. 3744A-Rx mm-Wave Receiver Module Kit

2-2 Cold-Source mm-Wave Noise Figure using 3744A-Rx

Advanced Noise Figure Menu - Receiver Cal Offset

The receiver cal offset is a file that can be used to modify the receiver calibration used in noise figure measurements when it is known that there are some power discrepancies within that receiver cal. Examples of this situation include:

- The only power calibration that could be performed was at a higher level than that where the receiver calibration was performed and one wishes to correct for the frequency response of a pad/attenuator (or other means of power reduction) used for the receiver cal.
- The source used for the receiver calibration had some harmonic content that could cause inaccurate power readings relative to the receiver calibration readings. Knowledge of these harmonic levels can be used for a correction.
- There are other known inaccuracies with the power calibration (due to fixturing, bandwidth, etc) that one wishes to correct for.

A common scenario for using this function is in mm-Wave noise figure measurements when high dynamic range power sensors are not available (bullet 1 above) and a factory receiver calibration of the mm-Wave module is available to help. This case will be covered in detail at the end of the section.

Loading Receiver Cal Offset

The receiver cal offset process simply involves loading a file. The menu button to load the file is shown in Figure 2-4. Once a file is loaded, a check box appears and the correction then can be turned off and on (also suggested in the same figure).

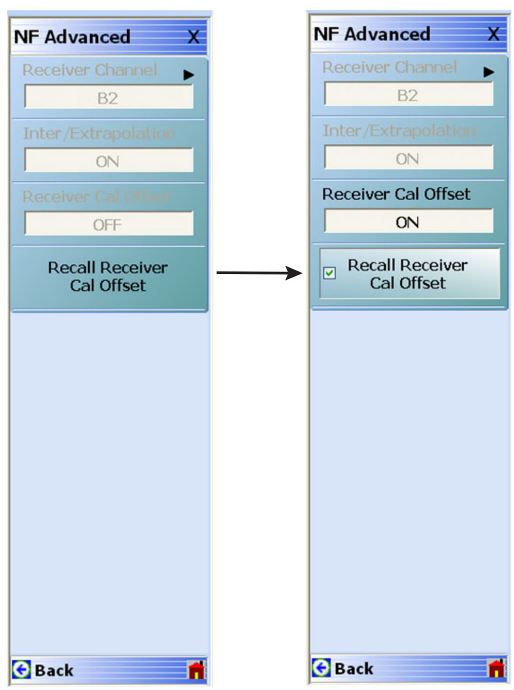


Figure 2-4. NF Advanced Menu - Receiver Cal Offset Functionality

The file format is a standard VectorStar .txt file and should be the result of a Save Data operation with a single trace enabled in Log Mag display format. An example segment of such a file is shown in Figure 2-5 on page 2-4. (Note that this segment happens to be from a ME7838A mm-Wave system, but that is obviously not required.) The response parameter is $b_2/1$ in this case but can be anything appropriate (usually it will be $b_2/1$ or S_{21}) to describe the response. *The data in this file should represent the power error incurred when doing the receiver calibration:* a value > 0 dB means the actual power was higher than the system thought during the receiver cal and a value < 0 dB means the actual power was lower than the system thought.

The segment of an example .txt file shown in Figure 2-5 is the file format used for the receiver cal offset correction. The response parameter can be anything but will most commonly be S_{21} or $b_2/1$.

```
MS4647A
!10/23/2012.12:32:31.PM
!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      80.001000000 -8.735106E+000
2      80.150995000 -6.820481E+000
3      80.300990000 -6.195999E+000
4      80.450985000 -6.687141E+000
5      80.600980000 -6.155944E+000
6      80.750975000 -6.188873E+000
7      80.900970000 -6.445963E+000
8      81.050965000 -6.779163E+000
9      81.200960000 -6.733072E+000
10     81.350955000 -6.922758E+000
11     81.500950000 -7.044048E+000
12     81.650945000 -7.252111E+000
13     81.800940000 -6.779829E+000
14     81.950935000 -7.133829E+000
15     82.100930000 -7.282691E+000
16     82.250925000 -7.258348E+000
17     82.400920000 -7.333891E+000
18     82.550915000 -7.438091E+000
19     82.700910000 -7.777820E+000
20     82.850905000 -7.632741E+000
21     83.000900000 -7.665494E+000
Etc.
```

Figure 2-5. Example .txt File Segment

Consider an example where an uncompensated adapter with 1 dB of loss was used for the receiver calibration, but was not present during the power calibration. Thus, the power seen by the receiver was 1 dB lower than what the power calibration is reporting. In this case the values in the file will all be around –1 dB. This can be measured with a simple S-parameter measurement of the adapter (using adapter removal or reciprocal techniques as necessary if the connections required cannot be mated).

Another common example is in mm-Wave systems where power sensors are difficult to find that operate at the desired levels for the receiver calibration (which may be –50 dBm or lower). When these measurements are performed with the 3744A-Rx direct receiver module, there is a correction path available. This module is supplied with a factory receiver calibration file that one can use to back–propagate accuracy to the source power so that when one performs the "real" receiver calibration for noise figure (with a pre-amplifier/filter assembly attached), the correct receiver calibration values can be obtained indirectly. The process can be described as follows.

Setup From Transmission/Reflection Mode

1. Connect the desired source reference plane to the 3744A-Rx module at the target power level (–60 dBm for this example). Load the provided factory receiver calibration file. Set the frequency range to the one desired for the noise figure measurement (with an adequate number of points) and set the display for single trace, $b_2/1$ | P1, log mag.

2. Set the reference plane magnitude to correct for the intended power level (–60 dB in this case) as shown in Figure 2-6. The resulting data then represents an error from the ideal power level and helps to describe the actual source power in a nominal bandwidth of interest.

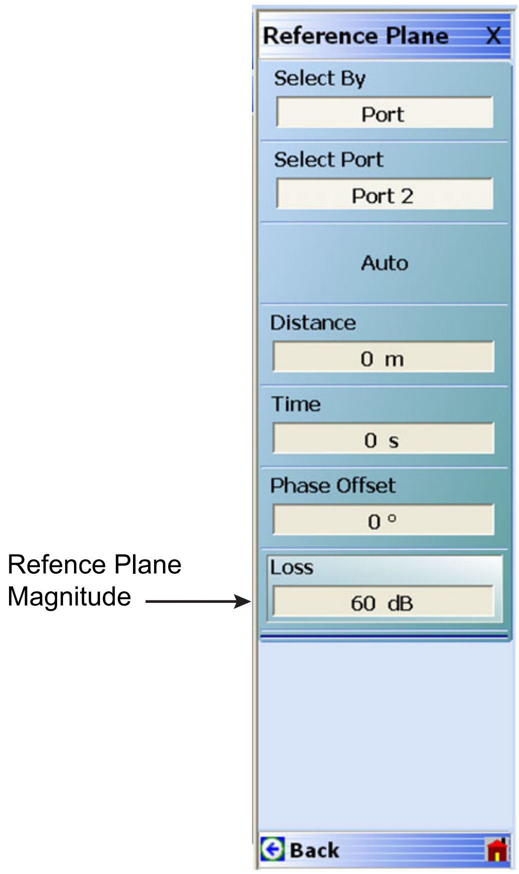


Figure 2-6. Reference Plane Settings

3. Save the resulting data as a .txt file. This forms the receiver cal offset file for the measurement.

4. Now connect the rest of the assembly for the noise figure measurement (pre-amplifiers and filters normally) between the 3744A-Rx module and the source reference plane leaving the power setting the same. Perform the receiver calibration on this setup and save that file as normal.

5. Activate Noise Figure Mode and select BB/mm-Wave (3739 Test Set).

Setup From Noise Figure Mode

6. To perform the noise figure calibration, load both the receiver calibration file from step 4 and the receiver cal offset file from step 3 using the appropriate menu items. The new .txt file is loaded using the Advanced\Recall receiver Cal Offset selection.

7. Load DUT S-parameters and perform the noise calibration as usual.

8. The display is now providing corrected noise figure measurements.

Appendix A — Specifications and Notes

A-1 Specifications

The technical data sheets and other reference material for the ME7838A, MS4747A, and other VectorStar VNA system components are:

- VectorStar ME7838A Broadband/Millimeter-Wave VNA System Technical Data Sheet – 11410-00593
- VectorStar MS4640A Series VNA Technical Data Sheet – 11410-00432
- VectorStar Broadband/Banded Millimeter-Wave Modules Reference Manual – 10410-00311

A-2 Noise Figure Composite Receiver Notes

Determining Filter Parameters for the Composite Receiver – Appropriate Filter Rejection Requirements

VNAs using the cold source noise figure measurement technique need to filter out potential signals that may be present that would distort the measurement. Common examples are the LO harmonics located in the VNA. Following is a procedure for determining potential LO harmonics that should be filtered in VectorStar.

- Generally one should aim for ~ > 15 dB of rejection at the offending frequency(ies). ~ 20 dB to –25 dB may be needed if the gain profile is peaking at the offending frequency.
- For NF measurements below 2.5 GHz, just a 2.5 GHz LPF should be adequate.
- For NF measurements from 2.5 GHz to 70 GHz, it is a three step process (unless the measurement range spans multipliers – in which case the measurement may need to be broken into segments).

Procedure 1 – Frequencies From 2.5 GHz to 70 GHz

1. Use the table below to determine the multiplier that will be needed to reach the measurement frequencies:

Frequency Range (GHz)	Multiplier
2.5 to 5	x1 (Watch out for the harmonic)
5 to 10	x1
10 to 20	x2
20 to 40	x4
40 to 70	x8

2. Take the lowest NF measurement frequency and divide by the multiplier. Take that number and multiply it by the next lowest and highest integer. Repeat the process with the highest NF measurement frequency.
3. Select a filter that avoids these harmonics you calculated above.

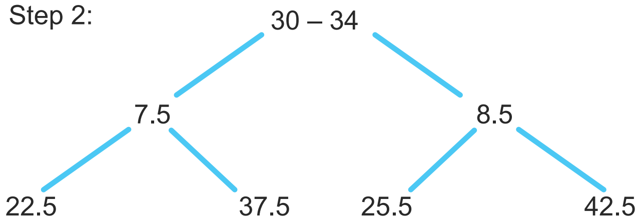
Note	If the amplifiers used in the composite receiver are band-limited, they may provide some natural filtering on their own.

Example 1

NF Measurement Range: 30 GHz to 34 GHz

Step 1: 30 GHz to 34 GHz requires a x4 multiplier.

Step 2:



Step 3: Select a 25.5 GHz to 37.5 GHz bandpass filter.

Procedure 2 – Frequencies Above 70 GHz

For frequencies above 70 GHz or for which the 3744A-Rx receiver is being used, it is a similar set of steps with the following multipliers:

1. Use the table below to determine the multiplier that will be needed to reach the measurement frequencies:

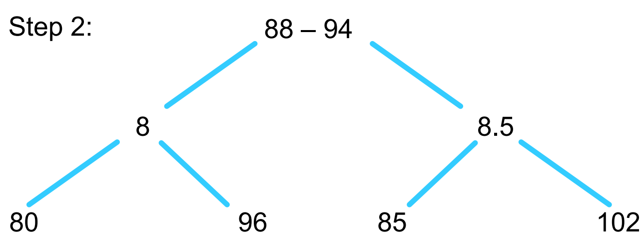
Frequency Range (GHz)	Multiplier
54 to 80	x9
80 to 110	x11
10 to 125	x13

Example 2

NF Measurement Range: 88 GHz to 94 GHz

Step 1: 88 GHz to 94 GHz requires a x11 multiplier.

Step 2:



Step 3: Select an 85 GHz to 96 GHz bandpass filter.

Ensuring Noise Figure Measurement is in Proper Noise Figure Measurement Range

In general, the user should target a noise power 5 dB to 10 dB below the receiver 0.1 dB compression point and above ~ –140 dBm. This is the power level going into the b2 receiver with the composite receiver in place. It should be measured after doing the receiver cal, but with no DUT connected.

Generally, the receiver gain + DUT gain should be between ~ 40 dB and 70 dB for linearity optimization. For composite receiver amps, lower receiver noise figures are better. But if the DUT gain exceeds ~ 10 dB, it does not matter much. A small pad on the input (1 dB to 2 dB) can reduce receiver noise parameter sensitivity if the DUT amp happens to be sensitive to source impedance; this is not typical.

When might an amplifier DUT need improved source match?

If the measured DUT NF has spikes (~ > 5 dB), checking the sensitivity of the composite receiver to the load it sees may be helpful. This check is done after the receiver cal and the noise cal have been completed. To check, users can add a small pad on the input of the composite receiver and measure the noise power (leaving the pad non-terminated/open). If there is a large difference (> 5 dB) between the noise power measured with the termination and with the open pad, then add the pad to the composite receiver and repeat the receiver and noise calibrations.

Determining Composite Receiver Noise Figure

Because of the composite receiver gain guidelines (between ~ 40 dB and 70 dB), the noise figures of the preamps will not be relevant for most DUT NF measurements unless the pre-amp NF values are very bad (> 20 dB or 30 dB). However, if one wanted to calculate the composite receiver NF (for use in the Uncertainty Calculator perhaps), it is dominated by the amplifier closest to the DUT. To do an actual calculation (or to prove to oneself the dominance of the amp closest to the DUT), Mini-Circuits® offers a calculator to help determine NF on cascaded amps. It is for two cascaded amps, but it would work well for N stages as well. For example, if there were three amps in the composite receiver, the user would calculate the composite NF of amps 2 and 3, and use that answer as stage 2 in a subsequent calculation (with amp 1 of course being the first stage).

http://www.minicircuits.com/applications/mcl_nf_calc.html

Notes

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Anritsu prints on recycled paper with vegetable soybean oil ink.

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