Application Note

NxN Measurements using VectorStar

MS4640B Series Vector Network Analyzer

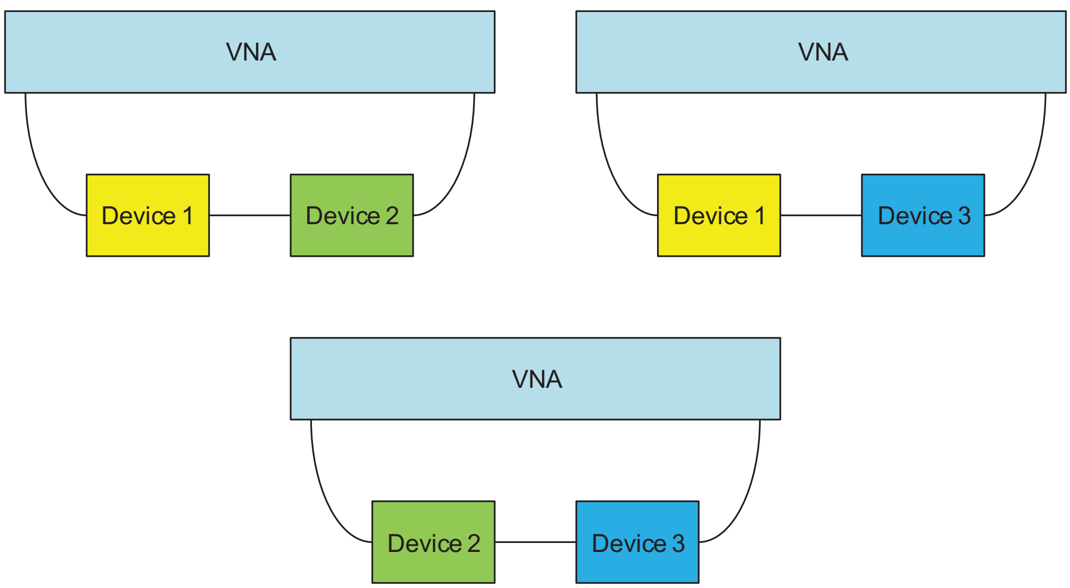

Figure 1: NxN Technique Measurements

1. Introduction

The NxN technique is an application for measuring devices that can only be measured in pairs (non-separable devices) and information about the individual devices is required. Examples of NxN measurements include:

- Mixers - where one of each pair is an up converter and one is a down converter so that the VNA sees no frequency translation.
- Long cable runs - where two cables are needed to complete a round trip to the VNA.
- Fixture parts - where an individual part cannot be easily measured since one of its interfaces is non-coaxial/ non-waveguide.

This application note provides a brief overview of the NxN method and how the application within the VectorStar™ MS464xB Series Microwave Vector Network Analyzer is used. The concept of the NxN technique is that there are three devices that need to be measured in pairs in order to obtain the transmission characteristics of each of the devices. The technique involves measurement of each pair of the N devices to obtain N sets of measurement data. The minimum number (N) of devices to start this technique is three. The information obtained on any one of the first three devices can then be de-embedded from any other device measurements in which this device is used as a reference. The measurements pairings to get started are shown in Figure 1. Note that Device 2 is required to be reciprocal.

2. Measurement Considerations

If the devices are non-translating, few precautions are needed. If the loss of the devices gets high relative to the dynamic range of the VNA (in whatever state it is being used), then accuracy will be degraded. Normally a full 2-Port calibration is performed on the VNA so that outbound matches can be corrected, but under certain conditions, simple normalization calibrations may be adequate. Note that the inner port match errors cannot be corrected since no access is available; hence match is not an extracted parameter. Full S2P files will be generated for the devices but S11 and S22 will be set to zero.

If the devices are poorly matched, it may be necessary to place a pad or other network between them. As long as this inner network is present for all measurements and its S-Parameters are known, its effects can be removed. This technique was originally used in mixer measurements, hence it is termed an IF network. This measurement setup is shown in Figure 2. The three measurements required to execute NxN are shown here when using an inner network N (which may be a pad or filter combination). Device 2 is required to be reciprocal.

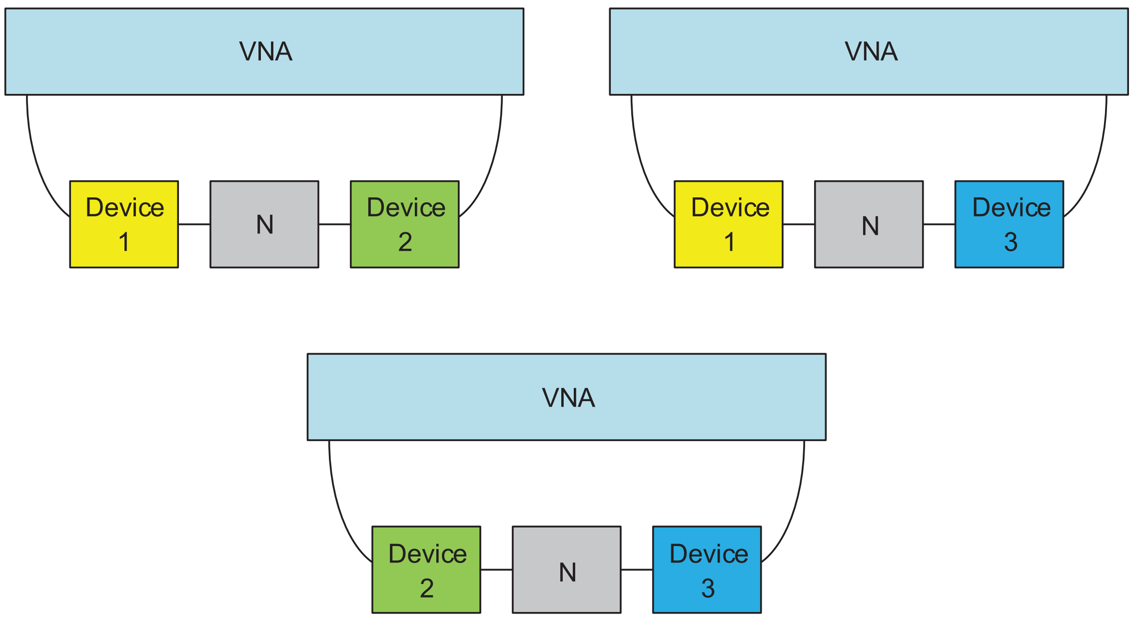

Figure 2: Measurement Setup using an inner IF Network (N)

3. NxN Technique for Mixer Measurements

NxN is a popular technique for making mixer measurements since the VNA sees the same input and output frequencies. Thus, normal calibrations can be used as no frequency offsets are needed and there are no reference complications. The first device in each pair will be used as an up converter or down converter and the second device will be the opposite. Device 2 must be able to fulfill both roles so it must be a passive mixer. The same frequency plan must be used in all of the measurements.

Typically, a common LO is used for all devices (with some splitter assembly) but multiple LOs can also be used as long as they share a common 10 MHz reference. These sources can often be controlled using multiple source control (see Chapter 17 “Multiple Source Control” of [1]). If one of the devices has multiple conversion stages, it may be desirable for the other devices to have the same conversion pattern for optimal trace noise. If this is not feasible, the only real requirement is that the input and output frequencies for all devices match.

The nature of the frequency plan between the devices must be known if the IF network (N in Figure 2) is to be removed. If the first device is not performing an inversion (i.e., if the input signal ramps up in frequency, the output signal ramps up in frequency) then the lookup table of the IF network behavior is not inverted. If the first device does perform an inversion, then the lookup table of the IF network must be inverted.

4. Using the NxN Application

Selecting the NxN button will open the main NxN dialog as shown in Figure 3. The measurements shown in Figure 1 or Figure 2 must first be performed and those measurement results saved as S2P files. The match information in these files will be ignored, but the file format for a full 2-Port measurement is used for convenience. These S2P files are entered in this dialog using the Browse buttons shown.

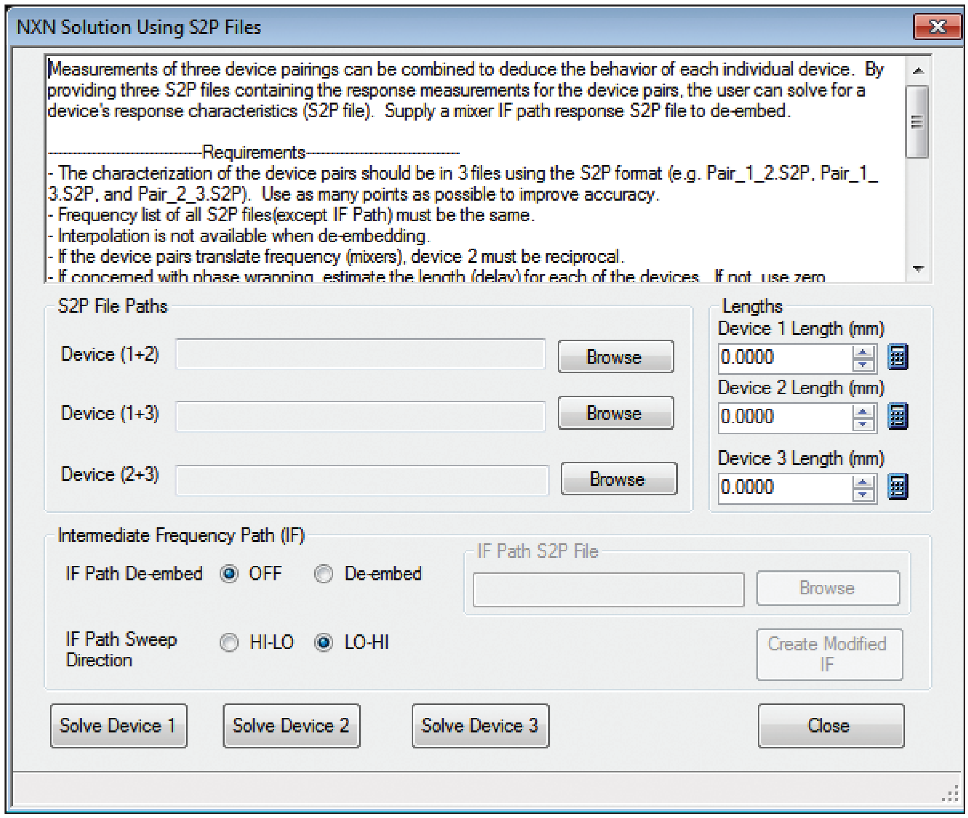

Figure 3: NxN Configuration Dialog

If the scheme of Figure 2 is used, then the inner or IF network must be specified. Select IF Path De-embed in this case and use the browse function to locate the S2P file for the IF network. Note that all of these S2P files must have the same number of points and the frequency range of the IF file must be appropriate for the IF sweep range between the devices. If the devices are non-converting, the frequency range of the IF file must match that of the other files.

If the devices are frequency converting, the sweep direction in the inner or IF zone must be specified. If the inner frequency sweeps up for a sweep up in the input frequency, then select LO-HI (non-inverting). Otherwise, select HI-LO.

The computation produces a phase ambiguity when it solves for the devices so some information about the electrical length of the devices should be entered. Boxes are provided for entering the approximate equivalent electrical length of each device. The calculator icon can be used if time delay estimates are known instead and a conversion calculator will appear. If the phase shift for the devices is not of interest, these lengths may be left at zero. If they are of interest, the estimate should be accurate to within a half wavelength at the lowest input frequency being used.

Once all of the information is entered, the Solve Device x buttons at the bottom of the dialog (x = 1, 2, or 3) will trigger the computation. Each invocation will bring up a file dialog to name the S2P file describing the device in question. If only the information for one device is needed, only that button need be selected.

If more devices are to be tested in the same configuration (e.g., one has a collection of mixers to measure of the same model), then these devices can be combined, one at a time, with a now known device (1, 2, or 3). Since the S2P file for the now known device has been generated, it can be de-embedded using the standard embedding/de-embedding utility described in Chapter 10-2 of [1].

5. NxN Measurement Example

The following measurement example uses the configuration and device parings as shown in Figure 1, where an inner IF network is not used. The devices used in this example are passive mixers. These mixers do not need to be identical; however, their operational IF, RF, and LO frequency ranges need to be compatible. Also note that at least one of the mixers needs to be reciprocal (i.e. can be used as an up converter as well as a down converter). The measurement configuration and frequency plan of the device pairs for this example measurement is show in Figure 4. The frequency plan was chosen so that an image reject filter is not needed in the IF plane. Notice that the VNA does not see any frequency translation.

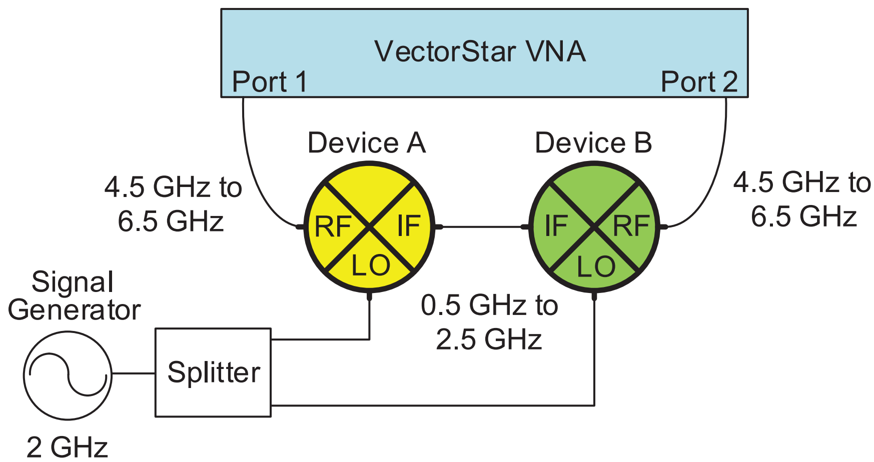

Figure 4: Measurement Configuration and Frequency Plan for Device Pairs

5.1 Equipment Used

- Anritsu MS4644B 70 kHz to 40 GHz VectorStar VNA
- Anritsu MG3694C 2 GHz to 40 GHz Signal Generator
- 3 mixers
- Splitter

5.2 Calibration Considerations

For the most accurate results, a full 12-term two port calibration is recommended so that outbound matches can be corrected. If DUT match is reasonable (<-12 dB or so), a simple normalization calibration could be sufficient as it would not result in more than a fraction of a dB of additional error.

5.3 Measurement Procedure

Initialize VectorStar

1. Preset Instrument to ensure it is in a known state
2. Set Frequency Range and Number of points to desired values
   a Start: = 4.5 GHz,
   b. Stop = 6.5 GHz
   c. # of Points = 201
   d. CW Mode = OFF
3. Set IF BW to desired value (i.e. 1 kHz)
4. Set Port 1 Power to -10 dBm

Perform 12-Term 2-Port Calibration

The next step is to perform a full 12-term, 2-port calibration. (It is assumed that the reader is familiar with performing proper VNA calibrations. For more information on performing calibrations, consult Chapter 1 “Calibration Overview” of [1]).

Measure the S-Parameter responses of the three device pairs

1. Connect Devices 1 & 2 as shown in Figure 5.
2. Setup Signal Generator as follows:
    a. RF Frequency: 4 GHz
    b. Output Power: +20 dBm

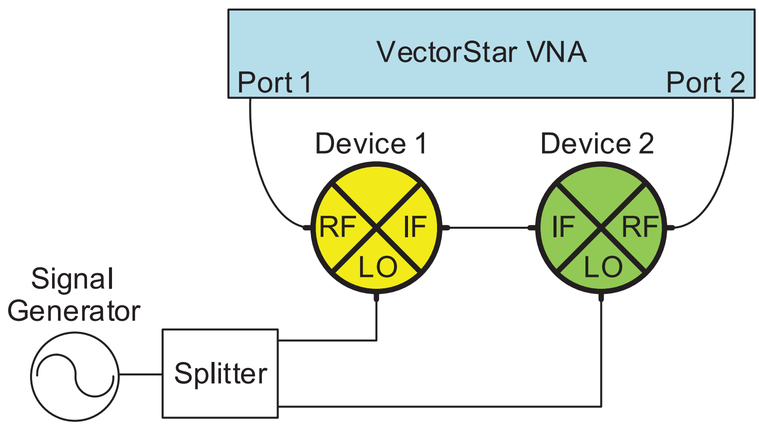

Figure 5: Device Pair 1-2

3. Make the S-Parameter measurements and save the resultant S2P file. (For convenience, name the file “Pair_1-2.S2P” or something similar)
4. Now do the same for device pairs 1 & 3 and 2 & 3 as show in Figure 6. (For convenience, name the files “Pair_1-3.S2P” and “Pair_2-3.S2P” respectively or something similar)

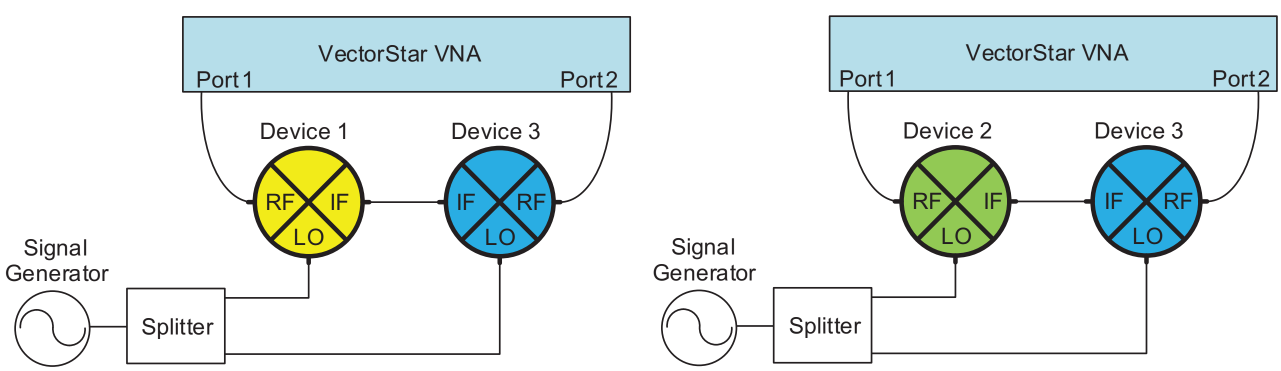

Figure 6: Device Pairs 1-3 and 2-3

Use the NxN Application to solve for each device's individual characteristics

Now that we have measured the S-Parameters of the three pairs and saved the S2P files, the next step is to start the NxN application to calculate the S-Parameter responses for the 3 individual reference devices.

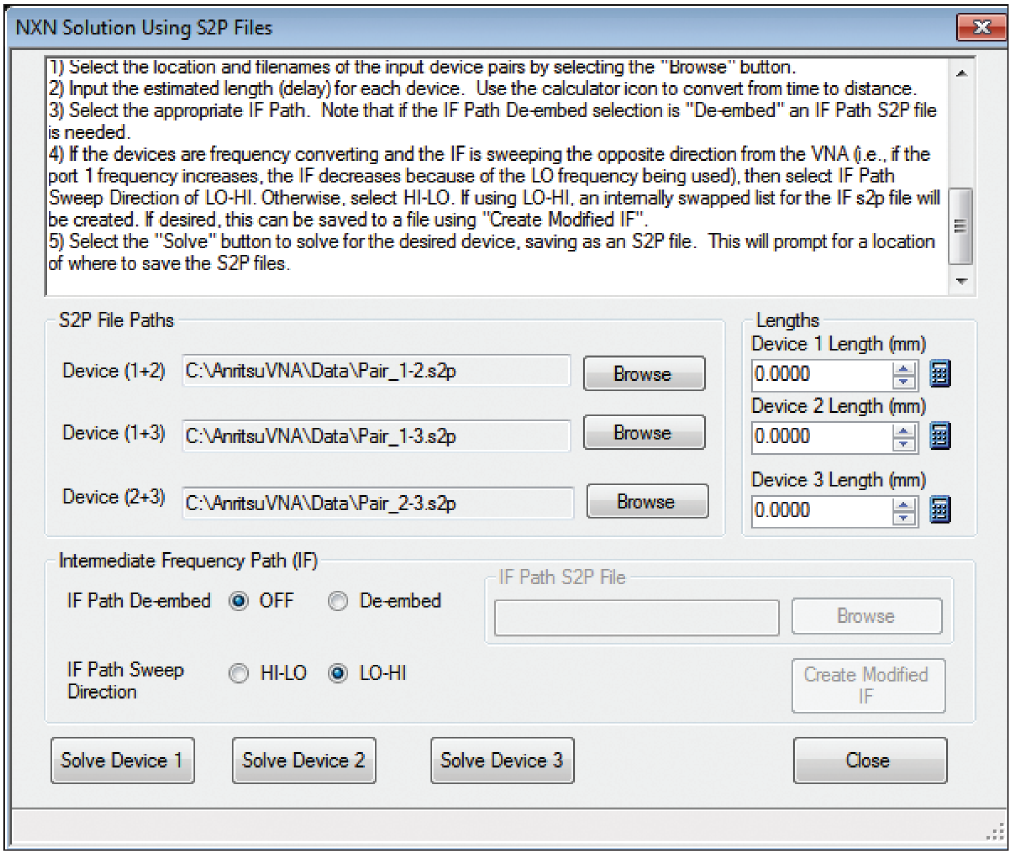

Figure 7: NxN Measurement Example Setup

1. Start the NxN Application
   a. Application → Mixer → NxN
2. Select the location and filenames of the input device pairs by selecting the "Browse" button.
3. Input the estimated length (delay) for each device.
   a. For this example we are not concerned with phase wrapping, so we will use a length of zero for all the devices.
   b. If concerned with phase wrapping, estimate the length (delay) for each of the devices. If necessary, use the calculator icon to convert from time to distance.
4. Select the appropriate IF Path.
   a. For this example we do not have an IF network, so we will select "Off"
   b. If the IF Path De-embed selection is "De-embed" an IF Path S2P file is needed.
5. If the devices are frequency converting and the IF is sweeping the opposite direction from the VNA (i.e., if the port 1 frequency increases, the IF decreases because of the LO frequency being used), then select IF Path Sweep Direction of HI-LO. Otherwise, select LO-HI. If using HI-LO, an internally swapped list for the IF S2P file will be created. If desired, this can be saved to a file using "Create Modified IF".
   a. For this example measurement we will select "LO-HI" as the IF frequency sweeps in the same direction as Port1 of the VNA (which is from Low to High).

6. Select the "Solve" button to solve for the desired device, saving as an S2P file. This will prompt for a location of where to save the S2P files.
   a. Solve for all three devices and save their individual S2P files.

We have just solved for each of the individual device's characteristics and saved them to individual S2P files. As noted earlier in this application note, the information extracted only shows the transmission characteristics of the devices. The match characteristics cannot be calculated since no access is available to the inner matches of the pairs; therefore, the match characteristics (S11 & S22) of the individual devices are set to zero.

Use Characterized Device and De-Embedding to Measure Unknown Devices (DUT)

Now that the NxN application has solved the responses of the 3 "reference" devices, we can now use any one of these devices and pair them up as a reference device with any unknown device that we want to make measurements on (our DUT). To do this, we will use the de-embedding functionality of the VectorStar VNA.

For demonstration purposes, we will use devices 1 & 2 from the previous steps. Device 1 will be our "Characterized Device" and device 2 will be our DUT. The reason for this is so that we can verify our measurement results with the calculated results for device 2.

1. Use the same VNA Settings for this measurement as was used when making the NxN measurements.
2. Connect the DUT between one of the characterized devices (Device 1) and port 2 of the VectorStar as shown in Figure 8.
   a. Note the the DUT's does not have to be the same as the characterized device. However, the IF, RF, & LO frequency ranges must be compatible with the characterized device.

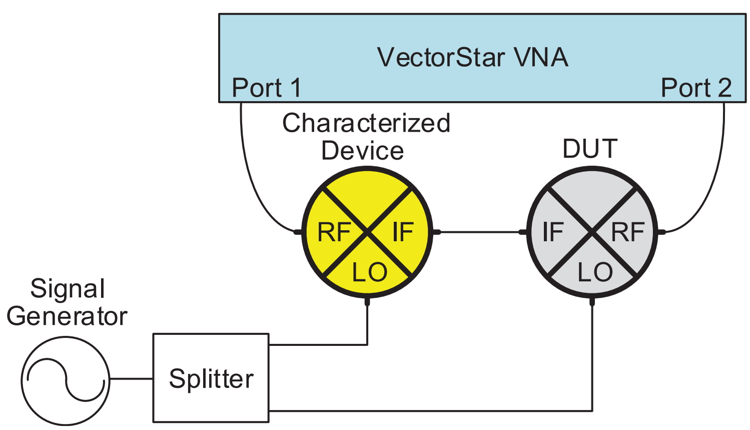

Figure 8: DUT Measurement Setup

3. Set up De-Embedding as shown in Figure 9.
   a. Measurement → Edit Embed/De-embed → Edit Network
   b. VNA Port Config = Port 1
   c. Select De-embedding
   d. Create 2 Port Network = S2P File
      i. Load S2P file of characterized device used in this measurement
   e. Swap port assignment = unchecked
   f. Click "Add/Change Network"
      i. Ensure the S2P file appears in the Embedding/De-embedding Table
   g. Click Apply and then Close

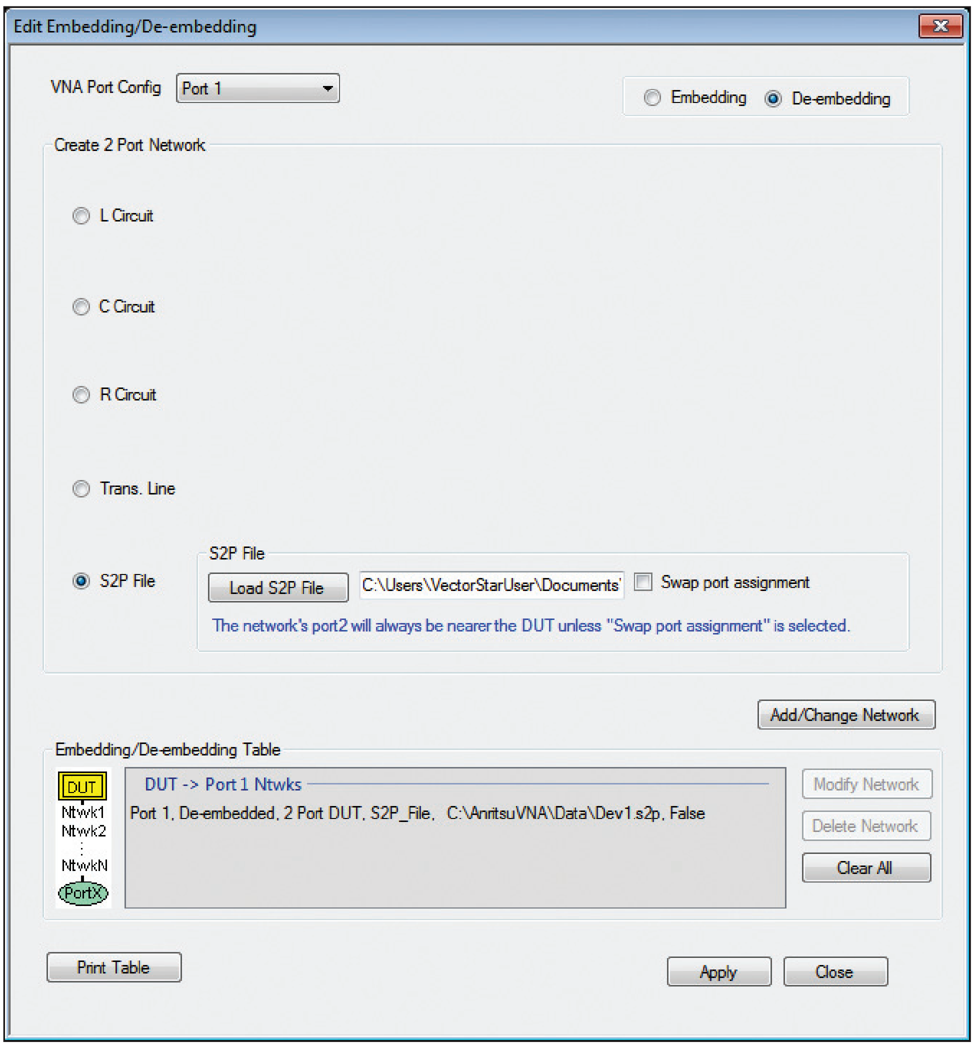

Figure 9: De-embedding Setup Dialog

4) From the Embedding menu bar on the right hand of the screen, Turn Embed/De-embed to “ON”.

5) The plot of S21 now shows the IF to RF conversion Loss of device 2. A plot of S12 would show RF to IF Conversion Loss (not shown). S11 and S22 are not valid for reasons already discussed.

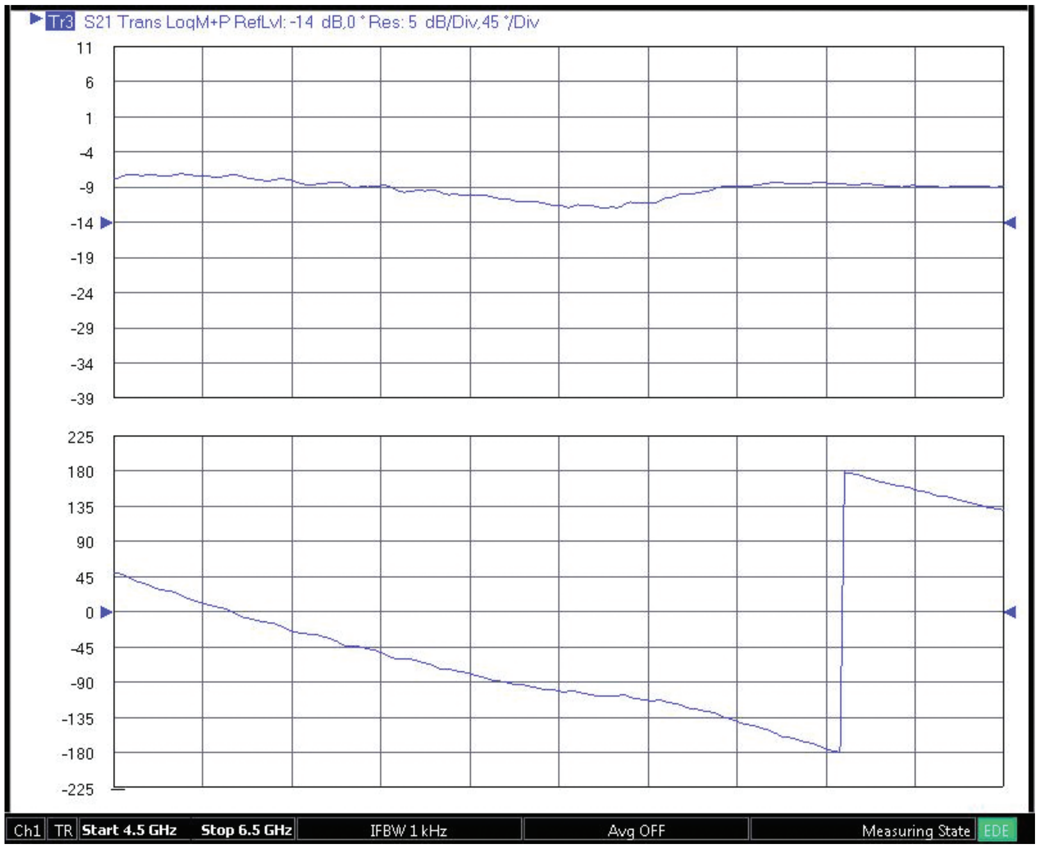

Figure 10: S21 measurement result with NxN characterized device de-embedded. The resultant data shows the IF to RF conversion loss of the DUT only

We have now measured the transmission characteristics of the DUT (Device 2) as shown in Figure 10. Next, let’s compare this measurement result (device 2 transmission characteristics) with the calculated characteristics we obtained using the NxN technique.

Compare NxN calculated characteristics to measured characteristics

We can easily compare the measured results with the calculated results by loading the calculated results into the VectorStar and saving the plot to memory. Then, using the Memory/Data display capability of the VectorStar, we can overlay the measurement result with the saved calculated result. For this example, we will use the S21 (IF-RF Conversion Loss) plot.

1. Put VectorStar Display in "Hold" mode.
    a. Sweep → Hold Functions → Hold
2. Load Calculated Device 2 S2P file and display results on screen
    a. File → Recall Data → Select the calculated S2P file for Device 2
3. Select the S21 plot and make it full screen by double clicking on the appropriate trace
4. Save this trace to memory
    a. Display → View Trace → Store Data to Memory
5. Now Change the display to Data and Memory
    a. Display → View Trace → Data & Memory
6. Turn off Trace Hold
    a. Sweep → Hold Functions → Continue
7. We have now overlaid the measurement results with the saved calculated results for device 2 as shown in Figure 11.

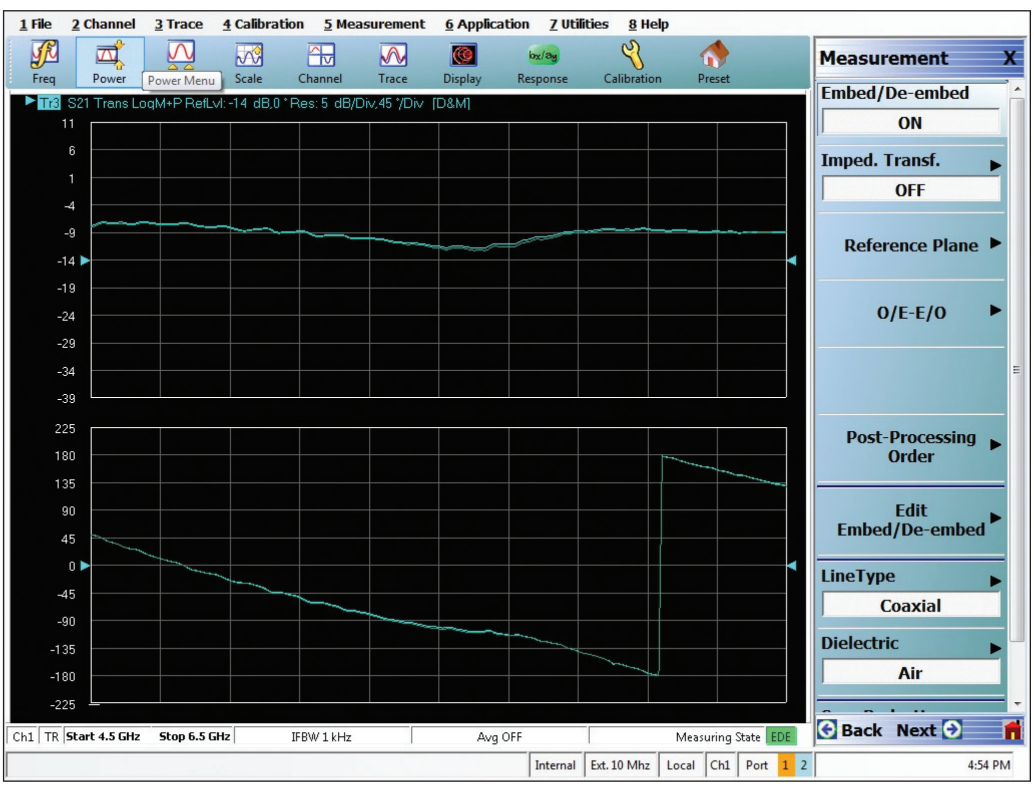

Figure 11: Measurement results and saved calculated results shown overlaid on top of each other.

8. We can now turn de-embedding on and off to see how the results change. Figure 12 shows plots with de-embedding on (device 2 response only) and off (response of device 1 & 2).

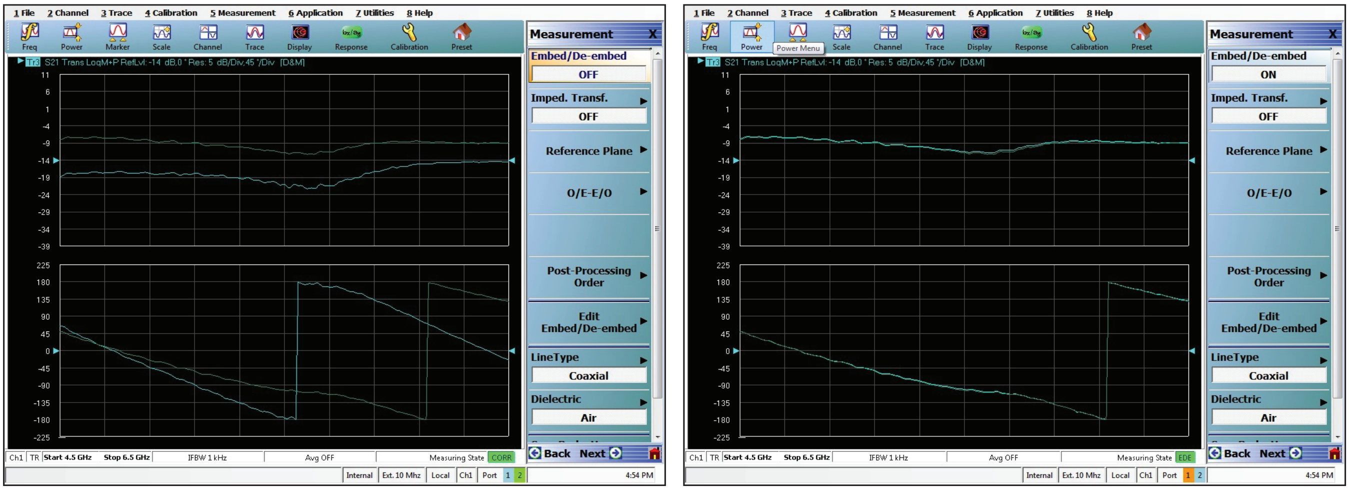

Figure 12: Measurement results with de-embedding turned off (plot on left) and on (plot on right)

5.4 Summary

Measurements of three device pairings can be combined to deduce the behavior of each individual device. By providing three S2P files containing the response measurements for the device pairs, the VectorStar VNA can then solve for each individual device's response characteristics (S2P file). Using the de-embedding feature of the VectorStar, we can pair a characterized device with any number of unknown devices and measure their response as well.

6. References

[1] “VectorStar MS464xB Calibration and Measurement Guide,” Anritsu publication 10410-00318D, May 2014.

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