Application Note

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User Power Calibrations with the VectorStar™ ME7838G Vector Network Analyzer

The millimeter-wave (mmWave) modules operating to over 220 GHz in the VectorStar ME7838G system are unique in that the connection interface is a coaxial flange-based structure. Often times a wafer probe is mounted directly to the module interface for DUT measurements. For situations requiring precise delivered-power, user power calibrations may be needed and the power sensors will require adapters to reach the module interface. This application note addresses how power sensors are combined to cover the wide bandwidths, and how adapters and probes can be de-embedded and embedded to move the power reference plane as close as possible to the DUT.

Which Power Meters and Adapters to Use?

Depending on the frequency range being calibrated, there are a number of permutations of power meters/sensors that can be used, including:

- ***Anritsu SC7770 Sensor*** (using the ML2438A Power Meter) 70 kHz-70 GHz, V(m) connector – usually adapted to 1mm (f)
- ***W-Band Sensor:*** Keysight W8486A sensor (using the 437B, N1914, and other meters); nominally 75-110 GHz but can be traceably characterized over 70-125 GHz, WR-10 waveguide – usually adapted to 1mm (f).
- ***Anritsu PowerMaster MA24510A 110 GHz Power Analyzer Broadband Sensor:*** 9 kHz to 110 GHz, 1mm connector (m).
- ***110 GHz Broadband Sensor:*** Rhode and Schwarz ZXXX and succeeding sensors (using the NRP2 meter), 9 kHz-110 GHz, 1mm (m) connector – usually adapted to 1mm (f)
- ***D-Band Sensor:*** Elva WR06/20 sensor (using the DPM-1 meter), 110-170 GHz (generally used above 125 GHz), WR-06 waveguide
- ***G-Band Sensor:*** Elva WR05/20 sensor (using the DPM-1 meter), 140-220 GHz (generally used above 170 GHz), WR-05 waveguide

The VectorStar VNA has a preference table listing the sensors it will use for a given band and identifies which meters are present on the GPIB bus when the calibration is initiated. The preferences (since the coverage of the above sensors overlap) are based on minimizing the number of sensor connections required and minimizing uncertainties (since some of the sensors have generically higher measurement uncertainties than others). Before each segment, the calibration routine will ask that a specific sensor be connected to the desired calibration plane. If the current frequency range cannot be covered by any combination of the meters/sensors currently on the GPIB bus, an error dialog will be generated.

Examples:

1. 10 MHz to 125 GHz calibration range
    a. First alternate: Broadband sensor + W-band sensor
    b. Second alternate: Anritsu SC7770 Sensor + W-band sensor
    c. Third alternate: Broadband sensor + D-band sensor
2. 10 MHz to 220 GHz calibration range
    a. First alternate: Broadband sensor + W-band sensor + D-band sensor + G-band sensor
    b. Second alternate: Anritsu SC7770 Sensor + W-band sensor + D-band sensor + G-band sensor
    c. Third alternate: Broadband sensor + D-band sensor + G-band sensor
3. 70 GHz to 220 GHz calibration range
    a. First alternate: W-band sensor + D-band sensor + G-band sensor
    b. Second alternate: Broadband sensor + D-band sensor + G-band sensor
4. 110 GHz CW range
    a. First alternate: Broadband sensor
    b. Second alternate: W-band sensor
    c. Third alternate: D-band sensor

Since the Anritsu MA25400A module has the 0.6 mm coaxial flange interface, the sensors need to be adapted to it. Some possible ways of doing this are:

- Anritsu SC7770, W-band, and 110 GHz broadband sensors: These are usually already adapted to 1 mm (f) for use with the ME7838A systems, but an additional adapter (33WG50) is needed to connect to the MA25400A.
- D-band sensor: An adapter to 0.8mm is used with the VectorStar ME7838D systems, but this sensor is used to 170 GHz with the VectorStar ME7838G so a different adapter (35WR5G) is used to connect this sensor to the VectorStar ME7838G. One may wonder about the band designations (WR5 vs. WR6), but we only use this sensor above 125 GHz and the WR6 cutoff frequency is ~115 GHz. This "mismatch" of guide sizes causes a mild discontinuity as shown below, but the induced error (less than a few tenths of a dB) is considerably less than the ~15% basic power sensor calibration error. The theoretical mismatch is shown in Figure 1.
- ***G-Band Sensor:*** The 35WR5G adapter is used to connect the sensor to the MA25400A module.

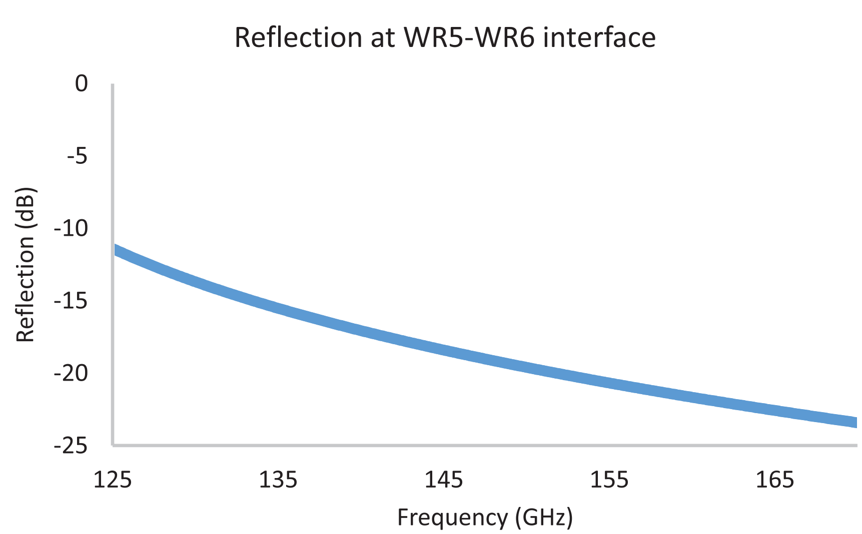

Figure 1. The mismatch between WR6 and WR5 waveguide sections as can happen when using the D-band sensor with a 35WR5G adapter. This mismatch has a smaller uncertainty impact than other terms and using this adapter combination reduces the number of connections.

Where Should the Reference Planes be and How are They Moved?

The power calibration reference planes can be moved using the power calibration network extraction (NE) tools shown in the user interface menus (Figure 2). This NW Extraction sublevel becomes available when a power calibration exists and allows .s2p files (describing adapters and probes) to be embedded or de-embedded into the power calibration coefficients.

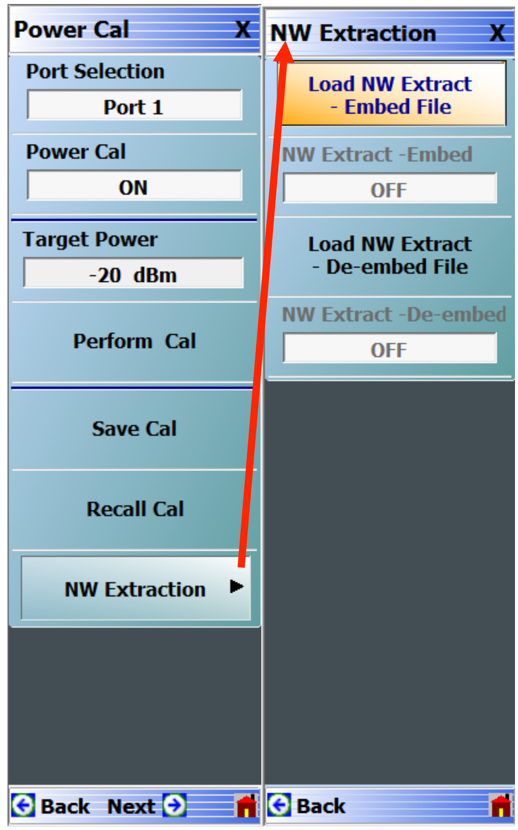

Figure 2. The user power calibration menu and the corresponding network extraction submenu are shown here.

For the present situation, we wish to de-embed the adapters used during the power calibration and embed the probe. These two steps together will move the power reference plane to the probe tips. The de-embedding and embedding steps are independent and use different .s2p files as inputs. The process is shown schematically in Figure 3.

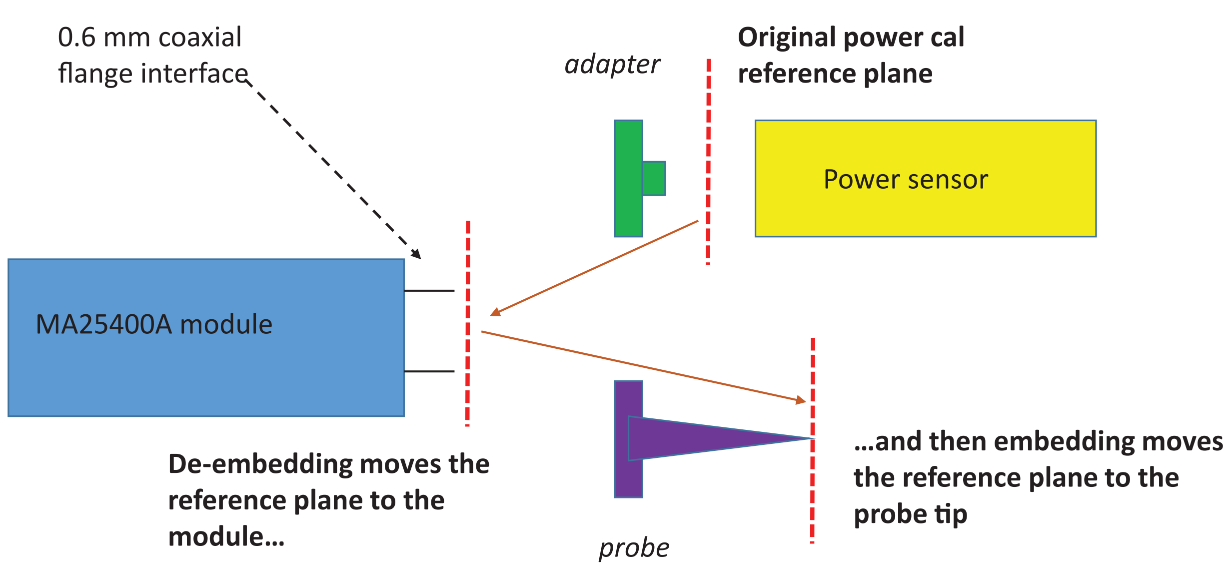

Figure 3. The power calibration network extraction process (embedding and de-embedding applied to a power calibration) is shown here for the adapter/probe configuration common with the VectorStar ME7838G system.

For the adapters discussed above, a generic .s2p file (based on measurements of a population of adapters at the factory and meant to be a representative description) is provided that merges the 33WG50 and 35WR5G values into a single .s2p file (with the crossover at 125 GHz where there is a transition in the power meters used). The insertion loss profile of that generic file is shown in Figure 4.

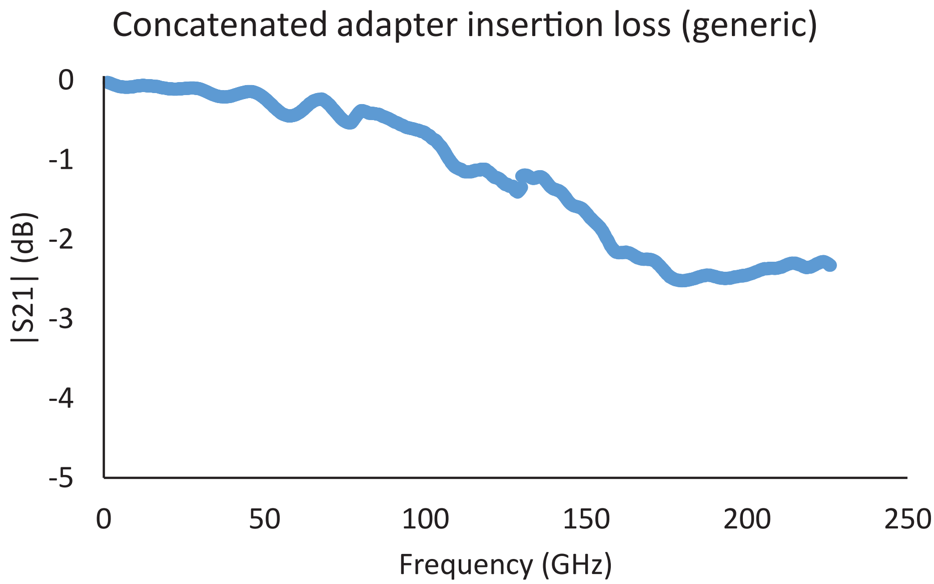

Figure 4. An example plot of the insertion loss of the combined 33WG50 and 35WR5G adapters (concatenated in frequency) is shown here.

The probe being used will likely have a different loss profile and an example is shown in Figure 5. As the adapter loss is de-embedded and the probe loss embedded, the net shift at 220 GHz is about 2.5 dB. That is, to keep the same power at the probe tip as targeted, the instrument has to aim about 2.5 dB higher at 220 GHz than would without the adapter/probe exchange.

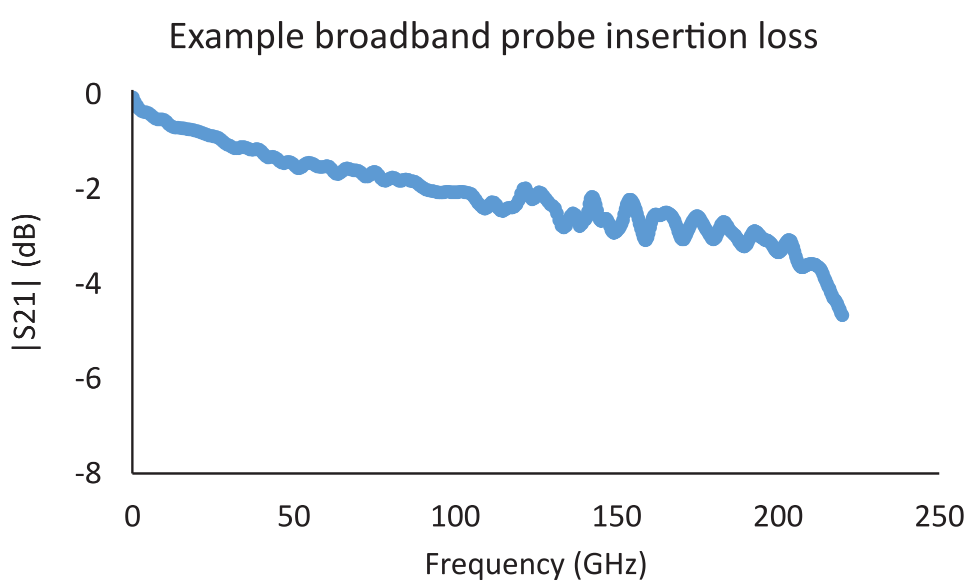

Figure 5. An example plot of probe insertion loss over the frequency range of the VectorStar ME7838G is shown here.

Example Sequence

Consider an example sweep setup covering 150-220 GHz. The calibration was performed with a target value of –25 dBm using the 35WR5G adapter and the G-band power sensor. The adapter was then de-embedded and the wafer probe embedded. A plot of the VNA measurement of a1/1 is shown in Figure 6. Effectively, a receiver calibration has been applied to this data so, just after calibration and before embedding and de-embedding, the response was a flat line at -25 dBm. With embedding and de-embedding applied, the VNA has to change its drive levels relative to the original calibration to achieve the target power at the new reference plane. In this case, since the probe has slightly more insertion loss than the adapter, the VNA drive level must be higher to achieve –25 dBm at the probe tip. At 220 GHz, the a1/1 value has moved by about 2.5 dB, as would have been guessed based on the discussion in the previous section.

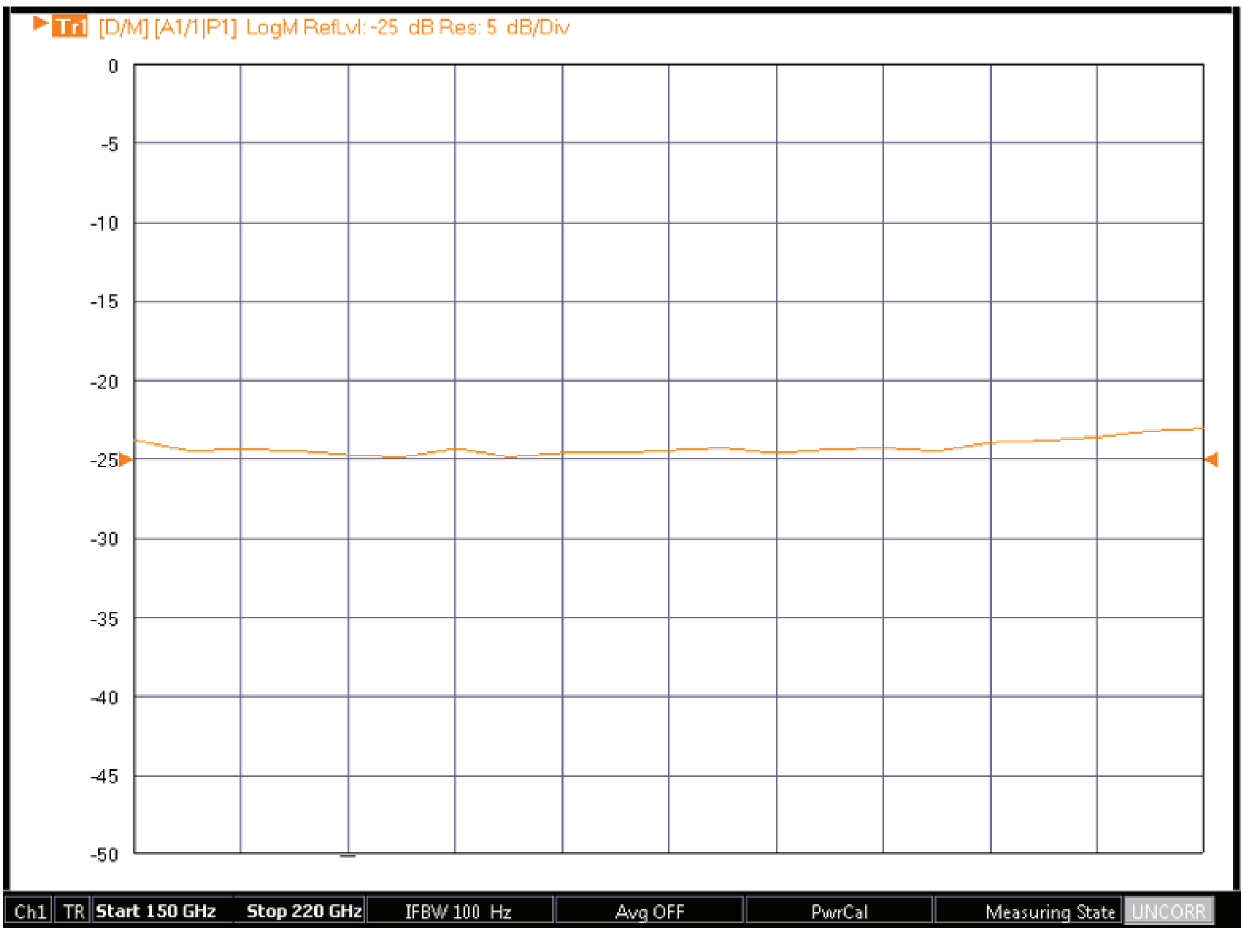

Figure 6. A plot of reference signal level (a1/1|P1) after the embedding/de-embedding sequence relative to the original calibration at –25 dBm.

Summary

Since the VectorStar ME7838G is a broadband system covering over 220 GHz, power calibrations can require multiple sensors and multiple adapters. Because power calibrations occur at a plane convenient for the power sensors and are used at a plane convenient for the DUT (e.g., at a probe tip), additional embedding and de-embedding steps can help move the power calibration accuracy to a more appropriate reference plane.

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