

On making corrected measurements of multipliers

While match-corrected measurements of mixers have been well-documented for a number of years, similar measurements of multipliers are somewhat less frequently published. With the advent of mm-wave subsystems for radar, backhaul communication and other applications that often rely on multipliers for frequency generation, this type of characterization is perhaps becoming more important. This document will review some classical multiplier measurement techniques and how using some principles from other frequency conversion measurements may help.

Background

Multipliers may take on many topological forms ranging from a diode or diode pair to a limiting amplifier to more complex differential transistor pair circuits. In addition, the multiplier block may contain additional gain stages, filters (switched or otherwise), amplitude control and other functions. Traditional S-parameter characterization, of course, is of limited value since some of the power dynamics and conversion behaviors have been lost. Some example configurations are shown in Fig. 1. The last block diagram shown may be more common at higher mm-wave frequencies as high frequency gain stages may be more challenging to implement. Depending on the components involved, different levels of characterization may be of interest.



Figure 1. Some example multiplier block diagrams are shown here.

Classically, one approach to measurement conversion has simply been a power-in \rightarrow power-out analysis operating on some frequency-selective basis. As with mixer measurements, this has its limitations as match interactions with the test equipment are ignored. While adding padding to the setup is a possibility, this may limit drive level or dynamic range in an unacceptable way. There are linearity issues to consider with the embedding admittances (particularly for purely passive mixers) so one must be careful with the limitations of mismatch analysis. Particularly for active mixers and block structures where the nonlinear element is more isolated, however, correcting for the input and output match behaviors can sometimes improve measurement performance.

Setup

Although the nomenclature may be confusing, the mixer setup wizard can be used to facilitate these corrected multiplier measurements. A number of the measurements described in the multi-channel version of the wizard do not apply so we will begin with the single-channel variant.

An example is shown in Fig. 2 for a tripler but there are only two real requirements:

- Set the LO as 'None'
- Make sure the input and output frequency ranges differ precisely by the DUT's multiplication factor. (e.g., in the below example for a tripler, the output start frequency must equal 3x the input start frequency and the output stop frequency must equal 3x the input stop frequency).

Mixer Setup [F	requency Sweep]	(Ch1)			E
Sweep Type: Configure Port RF Port:	Freq Sweep (Linear) ts (Note: Each port must Port 2	► be unique)	IF Port:	Reverse IF and RF Enable Modular-BB Port 1	~
LO Port Po 31 GHz f 8 dBm Eff. Pwr:	none rt 2 to 37 GHz 8 dBm	RF LO	IF	Port 1 93 GHz to 111 GHz	
X-Axis Disp RF Define Mixer N Set 1	Veasurements Frequency Dor	Set Power Lev	els Cancel	Import Channel Setup	

Figure 2. The use of the single-channel mixer setup wizard to facilitate a tripler measurement is illustrated here.

In the example, note that a broadband frequency range was used so the 'Enable modular BB' checkbox was selected (requires a ME7838X system). The dialog shows 'RF' and 'IF' connections but these are more correctly interpreted as 'input' and 'output' for this application (and, of course, those assignments flip if the 'reverse IF and RF' checkbox had been checked).

When the setup is completed, the multiple source equations are automatically filled out (as discussed in the MS4640B Measurement and Calibration Guide) as shown in Fig. 3. Here we can see the receiver and receiver source equation (the latter is used for indexing receiver calibrations and normally these last two equations will be the same) are set to look for the third harmonic of the input frequency. An additional function of the wizard tools is to create the 'mixer mode' button shown on the right menu bar in Fig. 3. The primary function of this mode is to enable the frequency converting calibration tools on the Calibration/Calibrate/Manual Cal menu. While the frequency plan can be changed in the multiple source screen, the availability of that mode is conditioned upon the setup wizard having been run.



Figure 3. The resulting multiple source screen for the tripler example of Fig. 2 is shown here.

As an aside, note the 'Ext. Mod. Ctrl.' Field in the lower right of the screen. The dialog beneath this button shows that the modular BB mode has been configured for this mm-wave multiplier measurement.

As with the mixers, two types of converting calibrations are available: normalization-based and enhanced match (as shown in Fig. 4). The normalization-based calibration performs receiver calibrations at input and output frequencies and measures the input power to the DUT (all using a thru line and power calibrations). On applying that type of calibration, the power at the output frequency is then normalized by the previously measured input power to give the conversion result.

As discussed in the MS4640B Calibration and Measurement Guide, the enhanced match calibration computes reflectometer calibrations for input and output frequencies (generally using three reflect standards at each port) and performs match corrected receiver calibrations (using a thru line connection). On applying this calibration, the DUT match (input and output) and output power are measured and the results used to generate a matchcorrected conversion value.

Part of the enhanced match calibration definition is the calibration kit that will be used to complete the reflectometer portion of the process. For those cases when the DUT has different connector types at input and output (e.g., coax and waveguide), the hybrid enhanced match calibration can be used. Here two one port calibrations are performed in the respective media and a thru step is performed with an adapter in place (that is characterized). The dialog for performing this final calibration step is shown in Fig. 5. As an example, if the input port was coaxial in a 2.92mm (K) connector and the output power was a 1mm connector, then the first calibration file may consist of a one port K calibration (e.g., using an Anritsu 3652A calibration kit or a 36585K Autocal module) and the second calibration file would consist of a one port 1mm calibration (e.g., using a 3656 calibration kit). The adapter step would use an adapter combination (2.92-1.85-1mm) that has been characterized using a standard S-parameter measurement (using either a SOLR calibration, adapter removal, or network extraction techniques, see the Calibration and Measurement guide for more information).

Manual Cal X					
2-Port Cal	►				
1-Port Cal 🕨 🕨					
Transmission Freq. Response	⊳				
Reflection Freq. Response					
Conversion Cal					
Rcvr Cal/ Normalization	•				
Enhanced-Match	•				

Figure 4. The manual calibration menu (when the converting mode is active) is shown here. Of relevance to this measurement are the bottom two buttons.

	One port calibration with the input connector type
Select Calibration files Recall File[File1 represents the media/connector of DUT input and File2 represents the media/connector of DUT output} File1 [DUT Input] File2 [DUT Dutput] File2 [DUT Dutput] Clear All Files	One port calibration with the output connector type
Description of output adapter Transmission Line Impedance (Dhm) Length (mm) Loss (dB/mm) @ Frequency (GHz) 50 000 Dielectric Air(1.000649)	Adapter description
O S2P File Perform Cal Cancel	

Figure 5. The hybrid enhanced match calibration dialog is shown here. This is used when the DUT has different input and output connector types.

Example measurement

The setup shown in Fig. 2 was used to make measurements on an actual multiplier. This particular DUT had block diagram similar to the bottom part of Fig. 1 and the output was well-matched (≤10 dB reflection coefficient at both input and output frequencies). The input, however, had a relatively low return loss. The measurement results for both normalization-only and enhanced match calibrations are shown in Fig. 6. Here one can see a difference in ripple and in absolute level. The latter was likely due to improvements in match correcting the receiver calibration.



Figure 6. An example measurement of a tripler is shown here (x-axis is the input frequency) with a normalization-only calibration (lower, darker trace) and an enhanced match calibration (upper, lighter trace).

Additional measurements are available in the multi-channel setup wizards and, as mentioned earlier, not all will apply to a multiplier (e.g., LO leakage). Power sweep conversion is, however, one measurement that can be relevant. Using a DUT with the same frequency plan, it was of interest to see the absolute power out. In this case, only the receiver-calibration portion of the calibration process is desired (this is turned on/off from the power menu and will be on after a normalization-only or enhanced match calibration). The Cal Status under the Calibration menu would be turned off. The plot of the output power versus input power for this DUT at an input frequency of 31 GHz (output of 93 GHz) is shown in Fig. 7.



Figure 7. A plot of multiplier output power vs. input power is shown here. Only a receiver calibration is applied in this case.

Uncertainties

The uncertainty in the conversion measurement has a number of contributors

- Mismatch during receiver calibration and during measurement
- Power calibration accuracy
- Noise floor and trace noise of the instrument
- Linearity of the instrument
- Reconversion and idler responses from the DUT

Most of these have been discussed previously and the last item is beyond the scope of this note. Calculations for different calibration types and assuming typical measurement instrument parameters are shown in Fig. 8. These values are simplified in that they do not account for embedding admittance effects on the DUT operating point and other environment-dependent nonlinear effects. These curves also assume that the signals to and from the VNA are well below the linearity limits (nominally 10 dBm for 0.1 dB compression on the MS4640A and the ME7838X at the test ports, lower for direct receiver access ports). The instrument linearity must be considered particularly for higher power multipliers.



Figure 8. Example uncertainty curves for conversion measurements using both normalization-only and enhanced-match calibrations are shown here.

Summary

Some setup suggestions and information for multiplier measurements have been presented in this note. While the nomenclature may not be obvious, setup wizards and calibration tools are available to help with the measurements and improve accuracy. Uncertainties are larger than for classical S-parameter measurements but they can be minimized through proper parameter and setup choices and some care on the calibration methods selected.

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