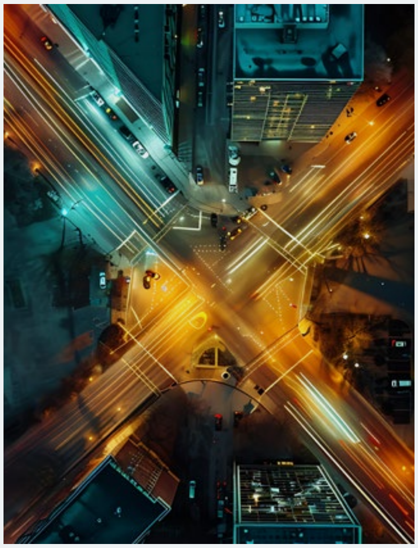
TECH BRIEF

Characterizing Wide-band Converters for EW

ERZIA

Contents

Introduction



Wide-band radiofrequency converters are widely used in EW and Satcom applications. Their adjustment and characterization are not easy tasks due to all possible combinations including variable LO frequencies, different sub-bands, switched filter banks and the high number or mixers included in the modules. In order to fully characterize these frequency converters, equipment and methodology need to be optimized for both improving measurements accuracy and reducing characterization time. In this tech brief we present efficient approaches that optimize resources while giving accurate performance data of the converters.

RF converters are used to shift the frequency of a signal from one band to another. Converters are essentially multiports modules (since they use mixers) in which a local oscillator plays a crucial role in determining the frequency conversion process. These signals are typically called IF, RF and LO—IF being the low frequency band, RF the high frequency band and LO the LO signal. RF converters can be down-converters when RF frequency signals are translated to IF frequency and up-converters when the RF frequency translation is from IF to RF. These converters can be single band or multi-band. Single band converters translate a fixed BW in IF/RF to the other band, using a single LO signal. When the converters are multiband both IF and RF can be variable, or one of them (typically IF) is fixed and the other one is variable. When both are variable, typically IF and RF have the same BW and multiple LO signals are used. When IF BW is fixed and RF BW changes, typically a synthesizer (and maybe some additional fixed LO signals), are required to change the LO signal and to cover all the RF BW.

TYPE OF MEASUREMENTS REQUIRED

In RF frequency converters, several key measurements are crucial for assessing performance as the ones shown below.

- **Conversion gain**, that represents the ratio of the output power to the input power.
- **Input and output return loss**, which assesses how much of the incident power is reflected back due to impedance mismatches. In this case, input and output return loss unlike in amplifiers are measured at different frequencies.
- **Noise Figure**, which is a critical parameter in RF frequency converters, reflecting the degradation of signal-to-noise ratio (SNR) as the signal passes through a device.
- **Gain Compression**, often measured as 1 dB compression point, refers to the phenomenon where the output power of the converter does not increase linearly with increasing input power beyond a certain threshold. As the input power reaches this threshold, the gain of the device compresses, leading to a reduction in the expected output level.
- **Intermodulation distortion** (IMD) is measured to evaluate the linearity of the converter, determining how well it can handle multiple input frequencies without generating unwanted spurious signals.
- **Group Delay** which is an essential parameter in RF converters that measures the time delay of the envelope of a modulated signal as it passes through the device. It indicates how different frequency components of the signal are delayed differently, which can lead to signal distortion if not managed properly. In RF applications, especially those involving wideband signals, a consistent group delay across the frequency range is desirable to ensure that the signal maintains its integrity. Variations in group delay can result in phase shifts that affect the quality and performance of the communication system
- **Phase Matching** between channels is another critical consideration in multichannel RF systems, such as those used in diversity receivers o multiple Input and Output systems with several similar components that should be synchronized. Phase matching ensures that the signals from different channels are synchronized and maintain consistent phase relationships. This is vital for coherent detection and signal processing techniques, which rely on phase alignment to combine signals constructively or to maximize signal fidelity. Any discrepancies in phase between channels can lead to destructive interference and degraded performance. This is maybe one of the most complex parameters to measure

All these measurements and other can be done with modern VNAs, allowing to reduce the number of setups, the calibration time, and the measurement time and helping to perform automatic measurements and reducing the required time to characterize a unit.

DIFFERENCE ON MEASUREMENTS DEPENDING ON LO SIGNALS RECEIVED

To characterize Wideband frequency converters, it is also very important to know how the LO will be injected to the converter, the number of LO signals and if the signals are going to be fixed frequency or variable. On the following page, different types for each feature are shown. The optimum way to use the instrumentation will depend on them.

- **Type LO signals received in the converter**: The type of signals will depend on how the converter is designed. The LO frequency can be external to the converter. In this case the LO signals can be used directly for the internal mixers (or by means of some multiplication). Another option is that the converter has an internal LO, and the clock or reference signal is provided from the outside (10, 50 or 100 MHz for example). Finally, the last option is that the LO is embedded and, in this case, no external signals except IF/RF signals are received in the frequency converter.

- **Number of LO signals**: Depending on the complexity of the frequency converters, one, two or even more LO signals can be required. When working with current RF measurement equipment, the SUM of all the LO signals in the chain can be considered to obtain the expected frequency conversion.

- **Fixed or variable signals**: This is an important topic that will impact dramatically the number of measurements required to characterize the frequency converters. When a fixed signal for frequency conversion is needed to characterize the frequency converter, a single calibration for each type of measurement will be needed. For example, an IF signal 2 to 18 GHz, LO of 20 GHz and then RF of 22 to 38 GHz.

Other RF converter will need different sub-bands, in these cases typically one of the frequency bands of the conversion is fixed and the other one is variable. For example, in SATCOM applications IF is typically fixed from 0.95 to 1.95 GHz, and the RF is wideband covering for example 27.5 to 31 GHz or 17.7 to 21.2 GHz, in 1 GHz BW discrete sub-bands and with minimum of sub-bands to cover the RF BW. This type of converters will require 3 to 6 conversion sub-bands (LO signals) to cover all RF BW.

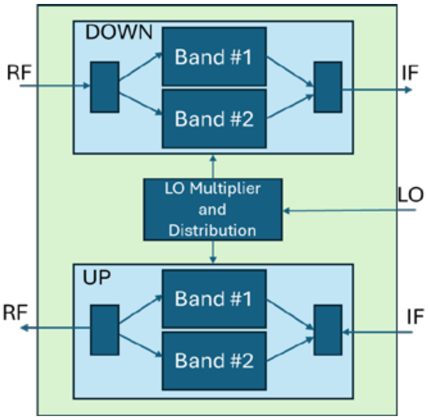
Finally, other cases require to cover similar BW like the previous ones, or even wider BW like 1 to 26 GHz, but with a tuning of MHz. Measure all the possible cases is not possible, but at least measuring all 1GHz sub-bands, and also considering some possible overlapping. This increases the number of measurements to perform and a careful strategy of calibrations is needed to reduce the requested time for calibration and measurements.

A PNA-X with multiple channels can significantly reduce calibration time by allowing you to calibrate multiple frequency bands or perform simultaneous measurements on different devices. This is particularly beneficial for RF converters with wideband characteristics or when measuring multiple components in a system.

EXAMPLE MEASUREMENT SETUPS

In this section we illustrate a few examples of measurement setups for complex microwave converters.

Additionally, to minimize measurements time, automatization with SW is required.



EXAMPLE 1: WIDEBAND UP/DOWN CONVERTER WITH EXTERNAL FIXED LO SIGNALS.

This module is an example of wideband RF converters designed and manufactured by ERZIA in which LO signals come from a fixed frequency signal provided from the outside.

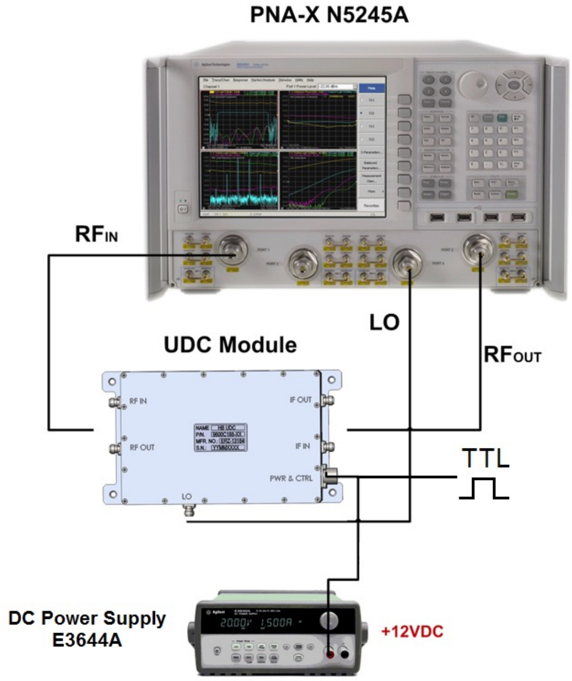
A 14 GHz LO signal is injected into the LO port. This signal is multiplied by 2 or by 3 depending on the selected sub-bands and split in two to feed the up and down converter mixers.

This module has two IF and two RF sub-bands, then 4 mixers are used. One of the sub-bands is selectable when using 28 GHz LO signal (14 GHz x2) and the IF signal covers 2 to 10 GHz and RF signal that is the result of LO – IF signal covers 18 to 26 GHz.

The second sub-band works with a 42 GHz LO signal (14 GHz x3) and in this case the IF signal covers 2 to 16.5 GHz and RF signals that is also the results of LO-IF covers 25.5 to 42 GHz.

The main parameters measured with the VNAs in this RF converter are S-parameters, P1dB and NF. In S-parameters, not only the result in band needs to be measured but also the out-of band S-parameters and Image signals to confirm the unit is able to reject out-of-band signals that can interfere with the desired input/output signals.

For these measurements, a setup like the one shown below could be used.



To cover all possible combinations, multiple calibrations are needed for both UP and Down converters. As mentioned before, to reduce the number of calibrations and measurements, consider how to group all the required measurements to minimize the calibration time.

Since P1dB and NF were only interesting for the in-band signals, two multichannel calibrations were done, one considering in band for P1dB, NF and S-parameters, for both sub-bands for the down-converter and another one for the up-converter. This results in 6 channels per converter. NF and S-parameters could be group in one, but at the end since NF and compression calibrations are slower, typically less points are chosen for them than for the S-parameters and also S-parameters should cover more BW to check the out of band performance.

Some additional multichannel S-parameter calibrations were done for the up and down-converters respectively, to measure out-of-band signals with different mixer combinations to consider that $F_{RF} = \pm F_{LO} \pm F_{IF}$ (then 4 possibilities). One of them is covered by the in-band measurements, and other two of the combinations are not typically critical for this kind of designs.

Finally, some additional calibrations are needed with no RF conversion to measure down to up or up to down leakage or IF to RF and RF to IF leakage.

It has to be considered that since the LO signals are external (14 GHz) this signal can be provided by the VNA (port 3) that allows an optimum synchronization (between RF/IF/LO signals) and a low IF Bandwidth can be used. Then, very accurate measurements can be performed. In any case, an external signal from a signal generator or an oscillator could be used but in this case the IF BW should be increased to obtain the adequate results, and they could not be so accurate or to be noisier.

In following tables all the calibrations required to fully characterize this RF converter with a VNA are shown:

S Parameter Calibration – Down Converter

	Calibration #1	Calibration #2	Calibration #3	Calibration #4
$F_{RF\ in}$	20-41.9 GHz	42.1-50 GHz	6-27.9 GHz	28.1-38 GHz
Mixing Product	$F_{LO} - F_{RF\ out}$	$F_{RF\ out} - F_{LO}$	$F_{LO} - F_{RF\ out}$	$F_{RF\ out} - F_{LO}$
F_{LO}	42 GHz	42 GHz	28 GHz	28 GHz
$F_{IF\ out}$	0.1-22GHz	0.1-8GHz	0.1-22GHz	0.1-10GHz
Purpose	Band-pass parameters (25.5-40) GHz	Image Rejection	Band-pass parameters (18-26) GHz	Image Rejection

S Parameter Calibration – Up Converter

	Calibration #5	Calibration #6	Calibration #7	Calibration #8
$F_{IF\ in}$	0.1-24GHz	0.1-22GHz	2-8GHz	2-10GHz
Mixing Product	$F_{LO} - F_{IF\ in}$	$F_{LO} - F_{IF\ in}$	$F_{LO} + F_{IF\ in}$	$F_{LO} + F_{IF\ in}$
F_{LO}	42 GHz	28 GHz	42 GHz	28 GHz
$F_{RF\ out}$	18-41.9 GHz	6-27.9 GHz	44-50GHz	30-40 GHz
Purpose	Band-pass parameters (25.5-40) GHz	Image Rejection	Band-pass parameters (18-26) GHz	Image Rejection

S Parameter Calibration -no conversion

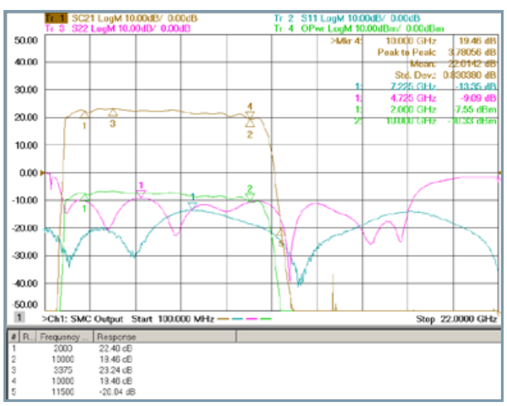
	Calibration #9
$F_{IF\ in}$	2-40 GHz
F_{LO}	—
$F_{RF\ out}$	-40 GHz
Purpose	Isolations

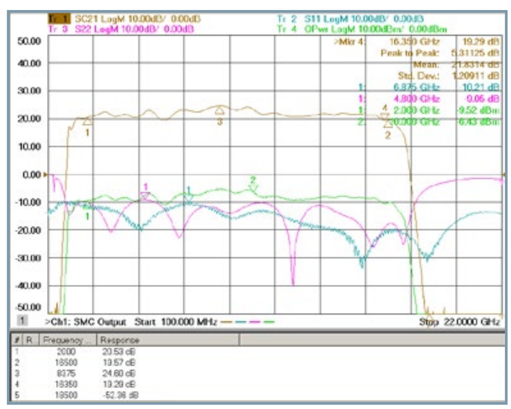
Power/NF Calibrations – Down Converter/Up Converter

	Calibration #P1/#NF1	Calibration #P2#NF2	Calibration #P3#NF3	Calibration #P4#NF4
$F_{RF\ in}$	25-40.5 GHz	17.5-26.5 GHz	1.5 – 17GHz	1.5 – 10.5GHz
Mixing Product	F_{LO} - $F_{IF\ OUT}$	F_{LO} - $F_{IF\ OUT}$	F_{LO} + $F_{IF\ in}$	F_{LO} + $F_{IF\ in}$
F_{LO}	42 GHz	28 GHz	42 GHz	28 GHz
$F_{IF\ out}$	1.5 – 17 GHz	1.5 – 10.5 GHz	25-40.5 GHz	17.5-26.5 GHz

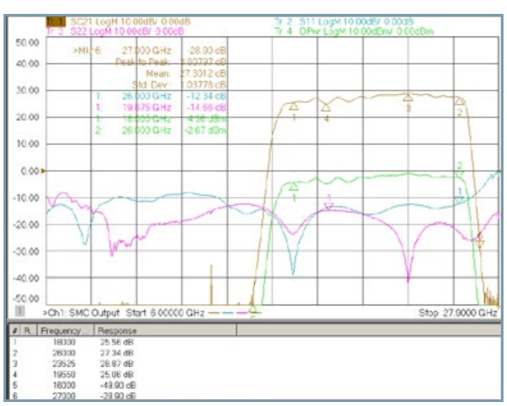
In the following figures, the S-parameter measurements for both S-parameters at in-band combinations are shown.

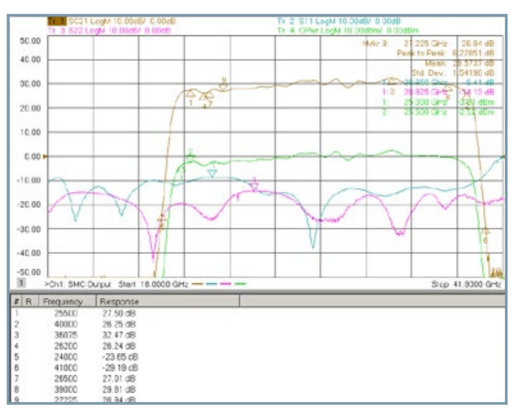
Down converter S-parameters



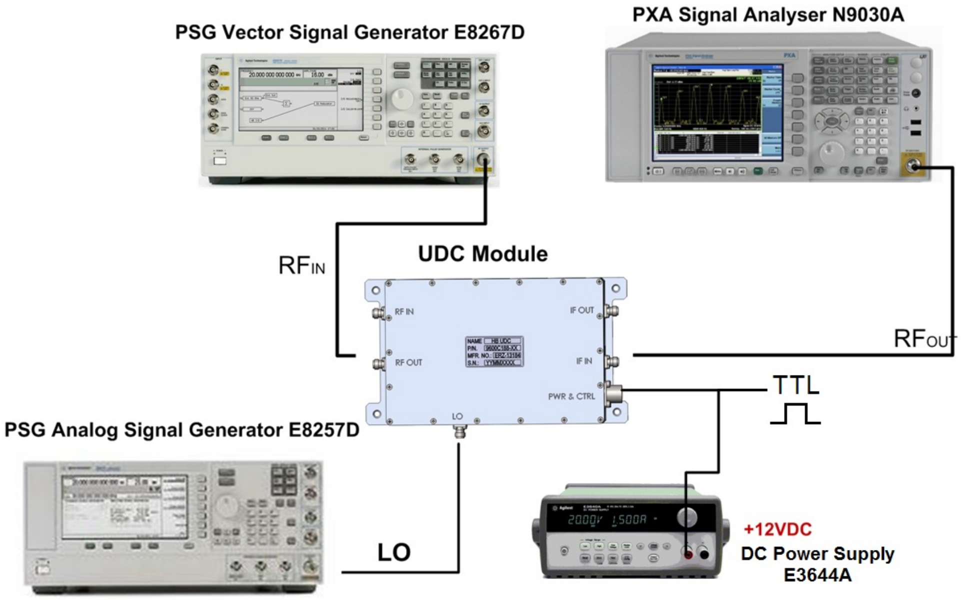


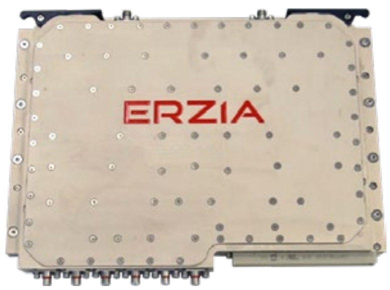
Up Converter S-parameters





To fully characterize this kind of RF converter, Signal Generators and Analyzers are needed to measure LO isolations, harmonics or intermodulation products. The setup required would be like the one shown below.

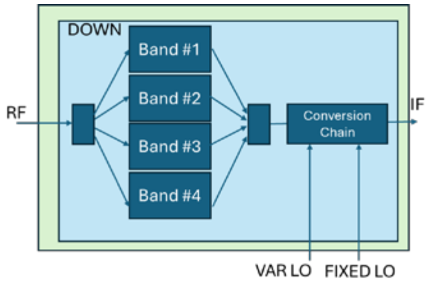




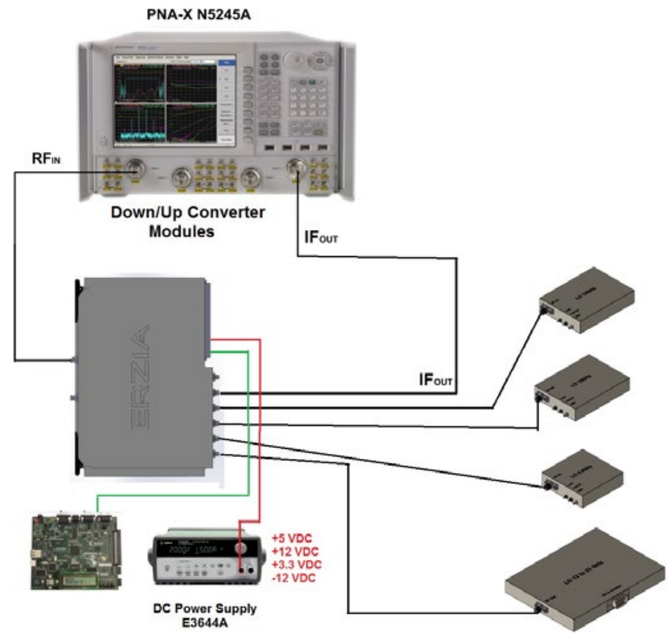
EXAMPLE 2: ULTRA-WIDEBAND UP/DOWN CONVERTER WITH SELECTABLE CHANNEL (VARIABLE INTEGRATED LO)

In this example, the RF BW is ultra-wideband covering 1 to 26 GHz, but the IF is narrow band, only 1 GHz, from 0.4 to 1.4 GHz. This makes the LO to be variable. But only making it variable is not enough to be able to reject correctly spurious signals created in-band and out-of-band. This converter integrates two down-converter channels in the same unit, then 8 connectors are needed. Two for RF signals, two for IF signals and 4 LO signals. A 5th signal will be created internally by splitting and multiplying one of the provided signals.

Then, this converter needs four LO fixed signals and one LO variable signal. One of the fixed and the variable ones are needed for all the possible sub-bands, and then, depending on the sub-band and using a switching matrix with filters and mixers (fed by different fixed LO signals) as can be seen in following fixture.



To perform the required measurements a setup similar to the one shown below should be used.



In this case, to measure P1dB, NF and S-parameters 26 channels are needed to cover all possible sub-bands for the down-converter. Due to the big number of channels, different calibrations were done for each type of measurement. In this case, due to the complexity, image signals or possible leakages were measured with the Signal Generator and Analyzer, by applying signals covering frequencies from 0.1 to 40 GHz for all the sub-bands.

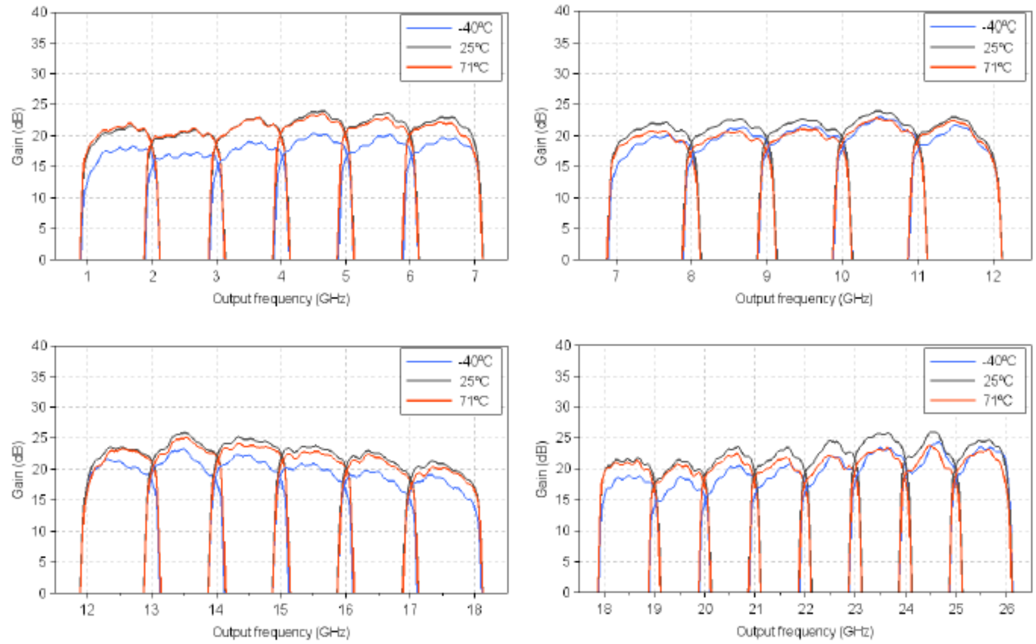
It must be considered that, since the LO signals are generated internally by the unit, the LO signals are not provided by the VNA, then, to properly measure the unit, the IF BW has to be increased, and then slightly noisier measurements could be obtained than in the module shown in previous example.

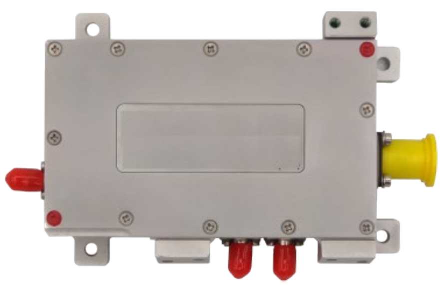
S-Parameter Calibration – Ultra-Wideband Down Converter

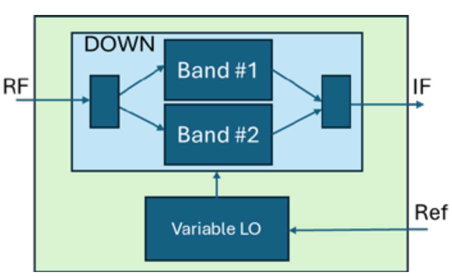
	Sub-Band	Dwell Band	RF	LO1	LO2	IF
Calibration #1	1	1-2 GHz	0.7-5 GHz	MIX1	MIX2+MIX3	0.1-4.4 GHz
Calibration #6	1	6-7 GHz	5.7-10 GHz	MIX1	MIX2+MIX3	0.1-4.4 GHz
Calibration #7	3	7-8 GHz	6.7-11 GHz	MIX4	MIX2+MIX3	0.1-4.4 GHz
Calibration #11	3	11-12 GHz	10.7-15 GHz	MIX4	MIX2+MIX3	0.1-4.4 GHz
Calibration #12	4	12-13 GHz	9-13.3 GHz	MIX5	MIX2+MIX3	0.1-4.4 GHz
Calibration #17	4	17-18 GHz	14-18.3 GHz	MIX5	MIX2+MIX3	0.1-4.4 GHz
Calibration #18	2	18-19 GHz	17.7-22 GHz	N/A	MIX+MIX3	0.1-4.4 GHz
Calibration #25	2	25-26 GHz	24.7-29 GHz	N/A	MIX2+MIX3	0.1-4.4 GHz

In the following figures the result of gain measurements are shown for all sub-bands of a down-converter vs temperature.

Ultra-Wideband Down Converter S-parameters







EXAMPLE 3: BLOCK DOWN CONVERTER (BDC) WITH SELECTABLE CHANNELS (VARIABLE INTEGRATED LO BUT EXTERNAL REF SIGNAL)

Unlike previous examples, this one consists of a downconverter but with different overlapped sub-bands covering an RF BW of 17.7 GHz to 21.2 GHz and fixed IF BW from 0.95 to 1.95 GHz, then a variable LO is required. For this example, the unit has an internal VCO+PLL component controlled by a Microcontroller that allows the LO signal to change. The PLL receives and external reference signal of 100 MHz from the outside, through the output connector by means of an internal diplexer that separates the 100 MHz from the 0.95-1.95 GHz.

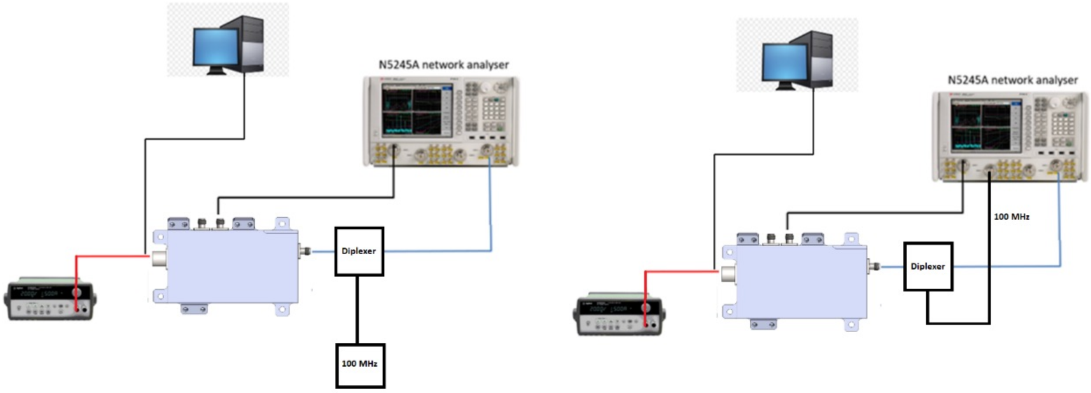
As IF BW is 1 GHz the RF BW is also 1 GHz. 6 sub-bands are measured to have an overlapping of the sub-bands and to cover the 17.7 to 21.2 GHz.

As in previous examples, different multichannel (6 channels) calibrations must be done to measure P1dB, NF, OIP3 and S-parameters. For S-parameters the BW is wider to measure also rejection from out-of-band signals. Additionally, other multichannel S-parameters calibrations is needed to measure the image rejection of the unit with another mixer frequencies combinations.

For this converter, group delay measurements have been performed using the option of SMC+phase calibration that requires an additional calibration to characterize a broadband mixer and that is simpler to use than the VMC calibration.

For this module, characterization can be done using an external Reference Signal (a 100 MHz OCXO) and selecting that the corresponding LO signal frequency for each calibration as the input (internally generated by the converter) or a 3rd port of the VNA to generate the 100 MHz signal and using a multiplication factor to generate the internal LO signals. This last option allows to work with low IF BW and obtaining more accurate measurements. This type of calibration is mandatory to accurately measure the group delay. For the rest of measurements, the final results would be very similar.

In the picture below both possible setups to measure with the PNA are shown.



In the following tables, different tables with required calibrations are shown.

BDC S-Parameters Calibration for high frequency rejection measurements

	Calibration #SHF0	Calibration #SHF1	Calibration #SHF2	Calibration #SHF3	Calibration #SHF4	Calibration #SHF5
RF	17.7-31 GHz	18.2-31.5 GHz	18.7-32 GHz	19.2-32.5 GHz	19.7-33 GHz	20.2-33.5 GHz
IF	0.95-14.25 GHz	0.95-14.25 GHz	0.95-14.25 GHz	0.95-14.25 GHz	0.95-14.25 GHz	0.95-14.25 GHz
LO	16.75 GHz	17.25 GHz	17.75 GHz	18.25 GHz	18.75 GHz	19.25 GHz
#pts	267 (50 MHz)	267 (50 MHz)	267 (50 MHz)	267 (50 MHz)	267 (50 MHz)	267 (50 MHz)

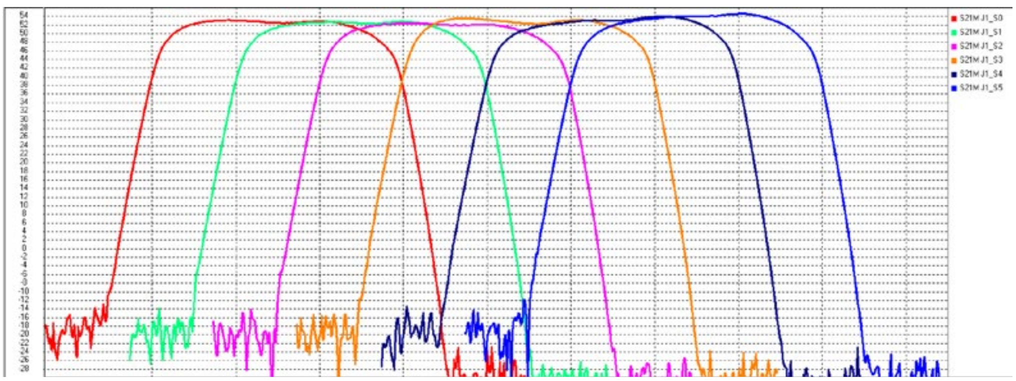
BDC S-Parameters Calibration for low frequency and image rejection measurements

	Calibration #SHF0	Calibration #SHF1	Calibration #SHF2	Calibration #SHF3	Calibration #SHF4	Calibration #SHF5
RF	0.1-16.65 GHz	0.1-17.15 GHz	0.1-17.65 GHz	0.1-18.15 GHz	0.1-18.65 GHz	0.1-19.15 GHz
IF	0.1-16.65 GHz	0.1-17.15 GHz	0.1-17.65 GHz	0.1-18.15 GHz	0.1-18.65 GHz	0.1-19.15 GHz
LO	16.75 GHz	17.25 GHz	17.75 GHz	18.25 GHz	18.75 GHz	19.25 GHz
#pts	332 (50 MHz)	342 (50 MHz)	352 (50 MHz)	362 (50 MHz)	372 (50 MHz)	382 (50 MHz)

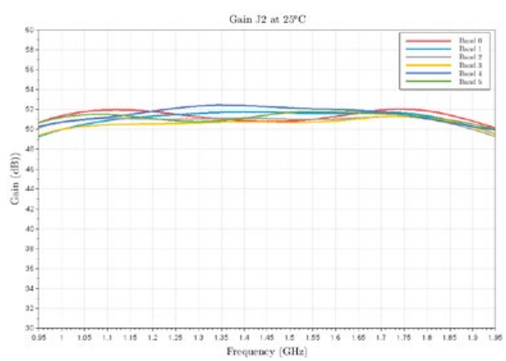
BDC S-Parameters Calibration for high frequency rejection measurements

	Calibration #P0/#NF0/#IP3_0	Calibration #P0/#NF0/#IP3_0	Calibration #P0/#NF0/#IP3_0	Calibration #P0/#NF0/#IP3_0	Calibration #P0/#NF0/#IP3_0	Calibration #P0/#NF0/#IP3_0
RF	17.6-18.8 GHz	18.1-19.3 GHz	18.6-19.8 GHz	19.1-20.3 GHz	19.6-20.8 GHz	20.1-21.3 GHz
IF	0.85-2.05 GHz	0.85-2.05 GHz	0.85-2.05 GHz	0.85-2.05 GHz	0.85-2.05 GHz	0.85-2.05 GHz
LO	16.75 GHz	17.25 GHz	17.75 GHz	18.25 GHz	18.75 GHz	19.25 GHz
#pts	121 (10 MHz)	121 (10 MHz)	121 (10 MHz)	121 (10 MHz)	121 (10 MHz)	121 (10 MHz)

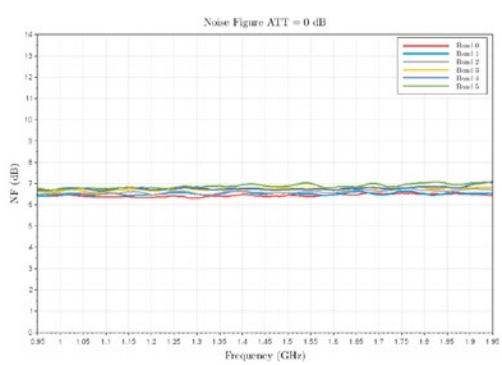
The following results are shown for gain, Noise figure and P1dB.

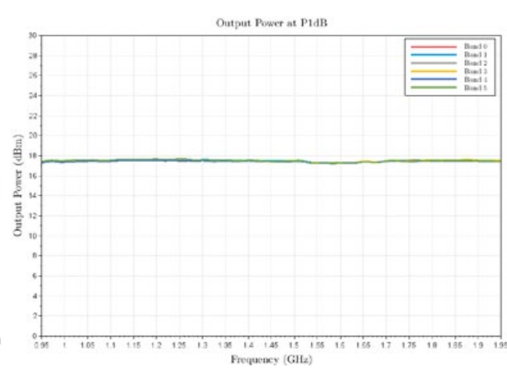


BDC Gain at 25ºC



BDC Noise figure and IP1dB at 25ºC





Conclusion

RF & Microwave converters are complex modules requiring specialized techniques for their measurement and characterization. In this tech brief we present three different examples of UP/Down converters and their different measurement strategies, looking for an accurate and efficient approach.

It is important to consider that there are multiple solutions possible, but all have in common that they use the full functionalities of multiport VNAs makes this characterization more efficient.

NEXT STEPS

ERZIA designs and manufactures advanced Integrated Microwave Assemblies (IMA) and specifically up/down converters for applications like Radar, EW and Satellite communications. Our equipment is focused on high performance and high reliability.

For more information about our Integrated Microwave Assenblies (IMA):
erzia.com/products/integrated-assemblies

We are ready to talk about your next project, please contact us at sales@erzia.com.