Application Note

CHARACTERIZATION OF SATELLITE FREQUENCY UP-CONVERTERS

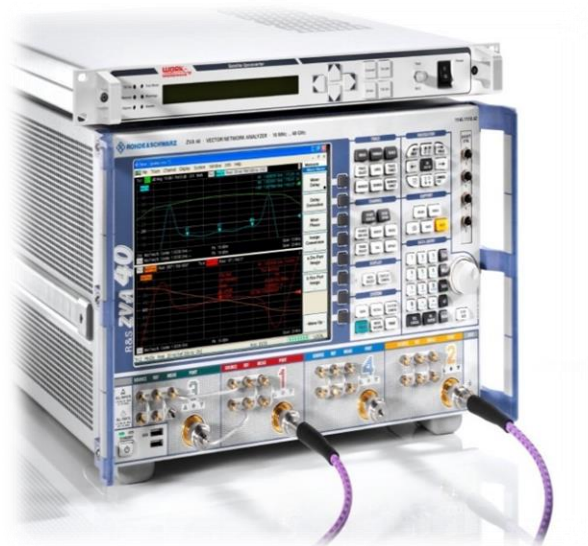
Products:

► R&S®ZVA

► R&S®FSW

► R&S®NRP

► R&S®SMB100A



M. Naseef, R. Minihold | 1MA224 | Version 3e | 11.2021

Note:

Please find up to date document on our homepage http://www.rohde-schwarz.com/appnote/1MA224

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1 Overview

Frequency converters e.g. in satellite transponders need to be characterized in terms of amplitude transmission but also for phase transmission or group delay performance.

Other parameters such as phase noise, 1dB compression point, conversion gain, spurious outputs and 3rd order intermodulation are interesting too for the quality of traditional analog as well as for modern digital modulation schemes used for RF signal transmission systems.

Often access to the internal local oscillator is not provided.

This application note describes methods using an R&S®ZVA network analyzer, one or two R&S®SMB100A signal generators and an R&S®FSW signal analyzer to accurately measure all the key parameters of frequency converters with embedded local oscillator. A commercial satellite up-converter is used as a device under test example.

2 Abstract

Frequency converters which use one or more mixers are fundamental for any communication- or electronic ranging system to down-convert an RF signal to IF or baseband or to up-convert a baseband or IF signal to RF. They include filters, normally selective band pass filters, to get rid of strong adjacent channel signals, local oscillator feed-through, image responses and other mixing products. For not to degrade transmission quality of a communication system these filters must have well -controlled amplitude, phase and group-delay responses. Especially phase- and group-delay linearity is essential for low bit error rates of communication systems or high target resolution for radar systems. In order to characterize a frequency converter, a key characteristic is the relative and/or absolute group delay. In addition, intermodulation products (3rd order), phase noise, 1dB compression point, conversion gain and spurious outputs are also interesting parameters to consider for measurement.

Relative phase and group delay can be measured using the so-called reference or golden mixer technique, as long as the local oscillator is accessible. However, due to increasing integration and miniaturization often neither the local oscillator (LO) nor a common reference frequency signal is accessible.

This application note describes a new technique for measurements on frequency converters with an embedded LO source and without direct access to a common reference signal. Central to this new technique is that the device under test (DUT) is stimulated with a two-tone signal.

Treated first are measurements using an R&S®ZVA vector network analyzer. By measuring phase differences between the two signals at the input and the output the analyzer calculates the phase transfer function and in a further step, the various components of group delay of the DUT.

It is shown that measurement accuracy does not depend on the DUT's embedded LO frequency stability as long as that deviation is within the measurement bandwidth of the analyzer's receiver.

The test and measurement procedures described include group delay measurements, Intermodulation product- (3rd order), 1dB compression point- and, conversion gain- measurements.

In addition, a detailed description of test and measurement procedures for Intermodulation product- (3rd order), phase noise-and spurious outputs using one or two R&S®SMB as a stimulating signal and an FSW Signal and Spectrum analyzer is included in this application note.

A commercial satellite up-converter from Work Microwave company type SCU-C70/140 -50 which up-converts an IF signal of 70/140 MHz to the L-band 5.85 to 6.45 GHz is used as an example device under test for the described measurements in this application note. All the measurements are carried out at 5.98 GHz output frequency and a conversion gain of 15 dB.

Figure 1: LO-Band satellite up-converter from Work Microwave company as device under test characterized by R&S®ZVA40 Vector Network analyzer

The following abbreviations are used in this Application Note for Rohde & Schwarz test equipment:

The R&S®ZVA vector network analyzer is referred to as the **ZVA**.

The R&S®FSW signal and spectrum analyzer is referred to as the **FSW**.

The R&S®SMB100A signal generator is referred to as the **SMB**.

The R&S®NRP-Z21/Z11 three-path power sensor is referred to as the **NRP-Z21/Z11**.

3 Theoretical Background

3.1.1 Group Delay Measurements

Group delay measurements are based on phase measurements. The measurement procedure corresponds to the definition of group delay τ_{gr} as the negative derivative of the phase φ (in degrees) with respect to frequency f:

$$\tau_{gr} = -\frac{1}{360^0} \cdot \frac{d\varphi}{df} \quad (1)$$

For practical reasons, Vector Network Analyzers measure a difference coefficient of the transmission parameter S_{21} instead of the differential coefficient, which yields a good approximation to the wanted group delay τ_{gr}, if the variation of phase φ is not too nonlinear in the observed frequency range Δf, which is called the aperture.

$$\tau_{gr} = -\frac{1}{360^0} \cdot \frac{\Delta\varphi}{\Delta f} \quad (2)$$

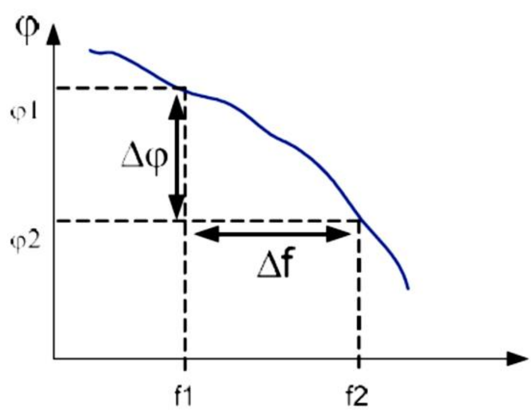


Figure 2: Definition of phase shift Δφ = φ2-φ1 and aperture Δf = f2-f1

Figure 2 shows the terms $\Delta\varphi = \varphi_2 - \varphi_1$ and $\Delta f = f_2 - f_1$ for linearly decreasing phase response, e.g. of a delay line.

For non-frequency converting devices e.g. such as filters and amplifiers the measurements of S21 at two different frequencies can be done sequentially.

With frequency converting devices like mixers, the phase between the input and output signal cannot be measured directly, because the frequency ranges are different. Also, the phase is additionally influenced not only by the component itself, but also by the phase of the local oscillator employed for the conversion.

Therefore, phase and group delay measurements on mixers and converters use the so-called reference or "golden" mixer technique. The reference mixer uses the same local oscillator as the device under test to re-convert either the RF or IF signal in order to get identical frequencies at the reference and measurement receivers of the Vector Network Analyzer (VNA).

The technique is designed to reduce the effect of LO phase instabilities.

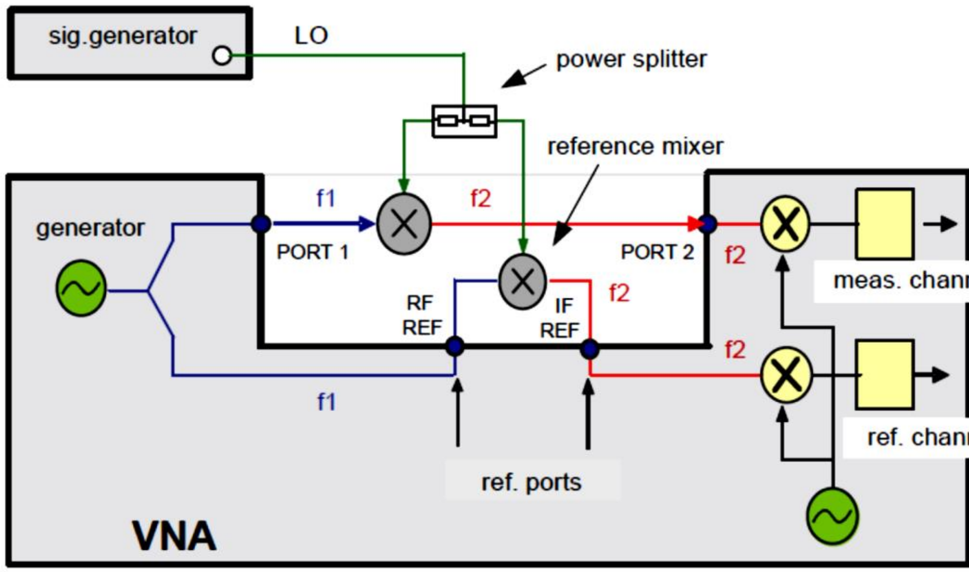


Figure 3: Block diagram of conventional test setup for mixer/converter phase and group delay measurement using a reference mixer

This measurement delivers phase and group delay relative to a golden mixer that was measured for calibration instead of the mixer under test (MUT). The measurement result of the MUT shows the phase and group delay difference with respect to this golden mixer. Typically, the golden mixer is assumed to be ideal.

Normally a MUT like e.g. a satellite up- or down converter has one or more internal filters in its signal path which have considerable group delay. Therefore, it can be assumed that:

group delay(MUT)>>group delay(ref mixer)

If the LO of the device under test is not accessible, group delay measurements with a reference mixer are not possible. AM or FM modulated stimulus signals may be used as an alternative. Other methods try to reconstruct the LO. They use an external signal generator as LO for the reference mixer and aim to tune the generator frequency until the phase drift versus time of the IF is minimized.

These techniques have limitations in terms of dynamic range, measurement accuracy, and throughput. In addition, internal local oscillators of the device under test often are not very stable, which makes it hard for the external generator to follow or "track" the inaccessible LO.

The R&S ZVA offers a different approach, which overcomes problems of the more traditional techniques outlined above.

3.1.2 Two tone method using the ZVA

The measurement of Group Delay of converters without access to the internal LO, and without access to a common reference frequency signal means a challenge to the test equipment: Typically, the internal LO shows an offset, is drifting versus time, and its unknown phase impacts the group delay. Option ZVA-K9 provides a rugged and reliable solution to overcome this problem: Based on the ZVA/ZVTs unique dual digital frontend, the phase difference of a two tone signal is measured before and after the DUT. This allows directly to calculate the group delay, As any drift of the internal LO signal or phase noise affects both carriers, it is simple cancelled out. Thus, the drift of the internal LO can be up to the width of the selected IFBW of ZVA, typically 1 kHz or 10 kHz.

This new method uses a two tone signal which is input to the device under test. It is offered with option ZVA-K9 Embedded LO Mixer delay measurement. The ZVA measures the phase differences between both carriers at the input and the output of the device under test.

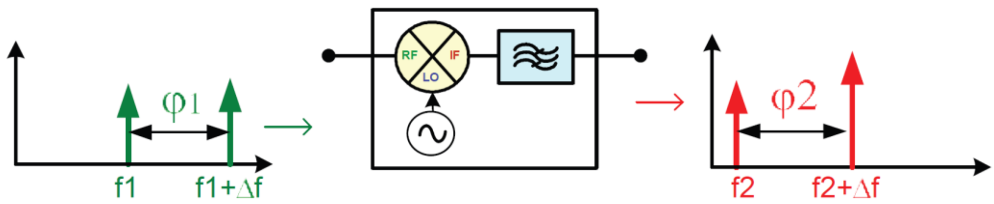


Figure 4: Phase differences of a 2-tone signal at the input and output of a frequency translating device

Then, the group delay is calculated as:

$$\tau_{gr} = -\frac{1}{360^0} \cdot \frac{\Delta\varphi}{\Delta f} \tag{3}$$

with $\Delta\varphi = \varphi_2 - \varphi_1$

Again, the frequency difference Δf between both carriers is called the aperture.

To measure the phase difference of two carriers, the ZVA provides two digital receivers (for each analog receiver channel) that allow to measure both signals simultaneously.

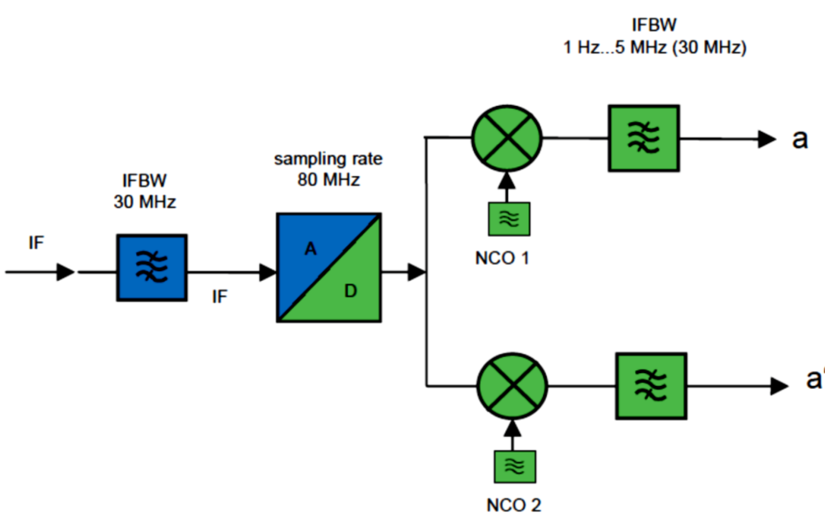


Figure 5: Block diagram showing two digital receivers for one analog receiver channel of the ZVA

This technique also works in case of a frequency converting DUT, because frequency and phase instabilities of the DUT's LO are cancelled out when calculating Δφ.

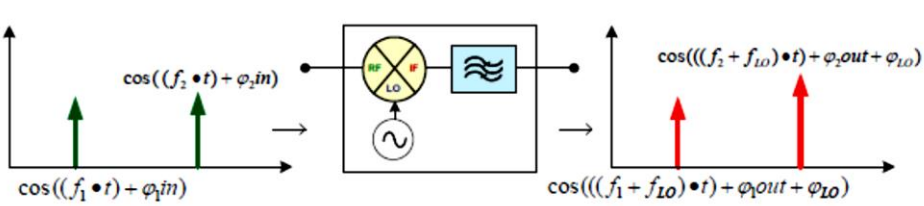


Figure 6: Visualization of phase/frequency transfer of a frequency converting device

$$\Delta\varphi = (\varphi_2 out + \varphi LO - \varphi_1 out - \varphi LO) - (\varphi_2 in - \varphi_1 in) \tag{4}$$

Besides group delay, the ZVA calculates the relative phase of the DUT by integration of the group delay as well as the dispersion (by differentiation of group delay).

Using a mixer with known group delay for calibration provides an absolute group delay result. If only relative group delay results are necessary, any golden mixer is sufficient for calibration.

3.2 Harmonics and Intermodulation

Harmonics and Intermodulation distortion originate from non-linearities in electronic circuits. Chapter 3.1.1 describes the mathematical background on harmonic signals caused by non-linear elements, whereas chapter 3.2.2 introduces intermodulation.

3.2.1 Harmonic signals

This section will show the basic equations for harmonics created in a single tone scenario.

Given the case that a single CW tone is applied to a non-linear element, additional signals, the so-called harmonics, will be generated at n times of the original frequency, with n being the order of the harmonic.

Any non-linear element can be described by a Taylor-series:

$$P(s) = a_0 + a_1 \cdot s + a_2 \cdot s^2 + a_3 \cdot s^3 + \cdots \quad (5)$$

with P(s) being its transfer function and s being the input signal. We will not look in detail on the factors a_n, but focus on the powers of s.

Assuming a CW input signal without DC component, the general formula for a signal s as a function of time t is:

$$s(t) = B \cdot cos(2\pi \cdot f \cdot t + \phi) \quad (6)$$

Using the addition theorem for the cosine function, it is straight forward to figure out that the square term in Eq. (5) creates a signal with twice the original frequency (the second harmonic), the cube term the third harmonic and so on.

For a more in-depth look, please refer to Rohde & Schwarz Application Note 1EF78.

3.2.2 Intermodulation as a result of harmonic signals

Clearly, harmonics of a single tone are outside the usable band of an application, since they are at multiples of the original frequency. Once a second tone joins the input signal at a small frequency offset – the resulting output signal looks different. In contrast to the single tone scenario above, the signal s is now:

$$s(t) = B_1 \cdot cos(2\pi \cdot f_1 \cdot t + \phi_1) + B_2 \cdot cos(2\pi \cdot f_2 \cdot t + \phi_2) \quad (7)$$

Since the dominating intermodulation products typically are third order products, the following equations focus only on those. Calculating the third power terms (responsible for the third order intermodulation and third order harmonics) of the Taylor series (Eq. 1) with the two tone input signal from Eq. 3 yields the following result:

$$s^3(t) = B_1^3 \cdot \cos^3(2\pi \cdot f_1 \cdot t + \varphi_1) + B_2^3 \cdot \cos^3(2\pi \cdot f_2 \cdot t + \varphi_2) + 3 \cdot B_1^2 \cdot B_2 \cdot \cos^2(2\pi \cdot f_1 \cdot t + \varphi_1) \cdot \cos(2\pi \cdot f_2 \cdot t + \varphi_2) + 3 \cdot B_1 \cdot B_2^2 \cdot \cos(2\pi \cdot f_1 \cdot t + \varphi_1) \cdot \cos^2(2\pi \cdot f_2 \cdot t + \varphi_2) \quad (8)$$

The first two lines describe the third order harmonics for each of the input tones (cos3-terms), whereas lines 3 and 4 represent the third order intermodulation terms (mixed terms). From the above equation, the third order intermodulation (TOI) frequencies can be derived using the addition theorem (for trigonometric functions) as:

$$f_{TOI1} = 2 \cdot f_1 - f_2 \quad (9)$$
$$f_{TOI2} = 2 \cdot f_2 - f_1$$

While the 3rd order harmonics ($3*f_1$ and $3*f_1$) of the individual input tones can be easily suppressed by a low-pass filter, the third order intermodulation terms are often more critical for the application. The resulting frequencies are often in-band for a given application and therefore interfere with the wanted signal. Additionally, under the assumption B1 = B2, i.e. both tones have the same level, the intermodulation terms exceed the harmonic terms by a factor of 3 in amplitude (Eq. 8); i.e. 9.54 dB difference between the third order harmonics of the individual tones and the third order intermodulation products.

3.2.3 Characterizing IMD

There are a number of ways to visualize intermodulation distortion. Fortunately, the measurement method is identical and the results can be converted.

The measurement method used to characterize the IMD behavior of a DUT is the so-called two tone scenario. Two continuous wave (CW) tones with equal tone power (P_{InTone}) and spaced by a given frequency (Δf) are applied to the DUT input (see **Error! Reference source not found.**). On the output side, the power level of the original tones may have changed to P_{Tone}. The intermodulation products can be measured with their absolute power or their relative power related to P_{Tone}, referred to as P_{Δ}. In practice P_{Δ} is also called intermodulation free dynamic range. Clearly, the 3rd order intermodulation tones have the same spacing to the upper and lower tone as the two original tones have (Δf).

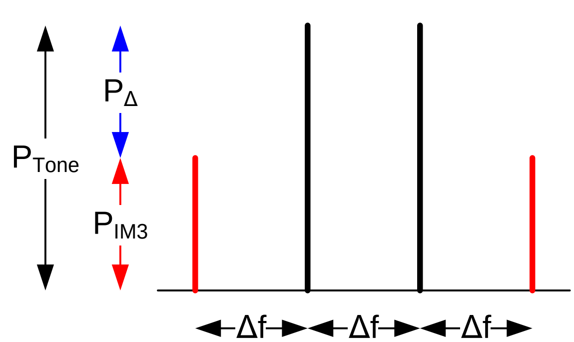


Figure 7: 2-Tone scenario used for IMD testing

Additionally, the so-called third order intercept point (IP3) can be calculated. It is a theoretical point, where the intermodulation products at the DUT's output grow as large as the original tones at the DUT output side. The IP3 can be derived on a logarithmic scale (i.e. all values in dBm or dB) as:

$$IP3 = P_{Tone} + \frac{P_{\Delta}}{2} \quad (10)$$

Knowing the IP3 point, 3rd order intermodulation products can be calculated easily for any lower power levels of P_{Tone}:

$$P_{IM3} = IP3 - 3(IP3 - P_{Tone}) \quad (11)$$

for $P_{Tone}: << IP3$

Figure 8 shows graphically the relation of Eq. 10. It shows the theoretical lines of the fundamental and 3rd harmonic at the output of a 0 dB gain DUT.

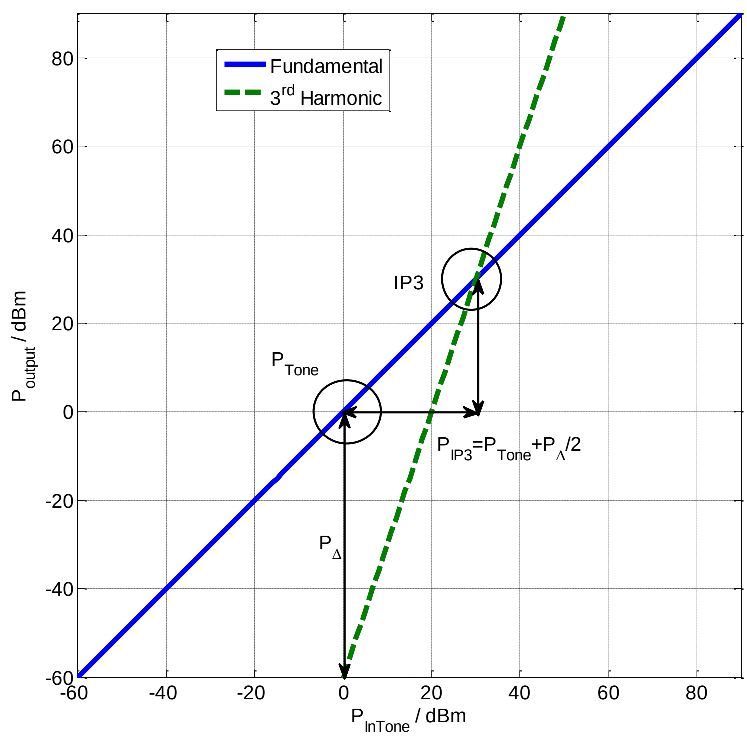


Figure 8: Graphical representation of Eq. 10

3.3 Conversion loss measurements

Conversion Loss (or Gain) is a measure of the power change when a mixer converts the RF frequency to the IF frequency. It is defined as the ratio between the Pout (IF) level and the Pin (RF) level and is expressed in dB.

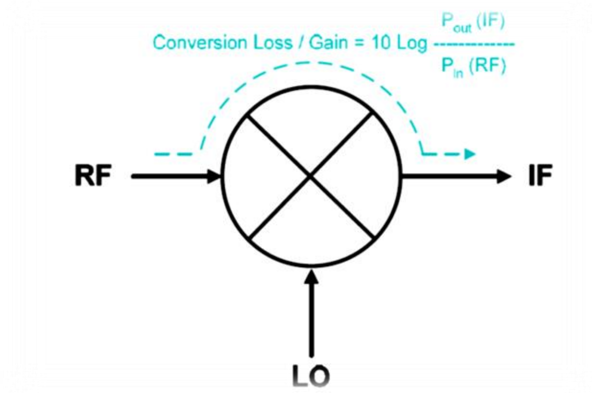


Figure 9: Definition of conversion loss/gain of a device

Conversion measurements can be performed as a function of both frequency and amplitude. The most important conversion measurements on a mixer include:

► Conversion Loss / Gain over frequency range of interest.

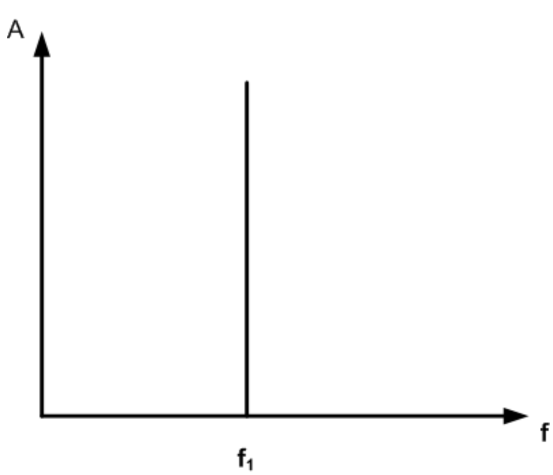
► Mixer dynamic range / compression of the RF input signal.

► Conversion Loss / Gain as a function of LO power level.

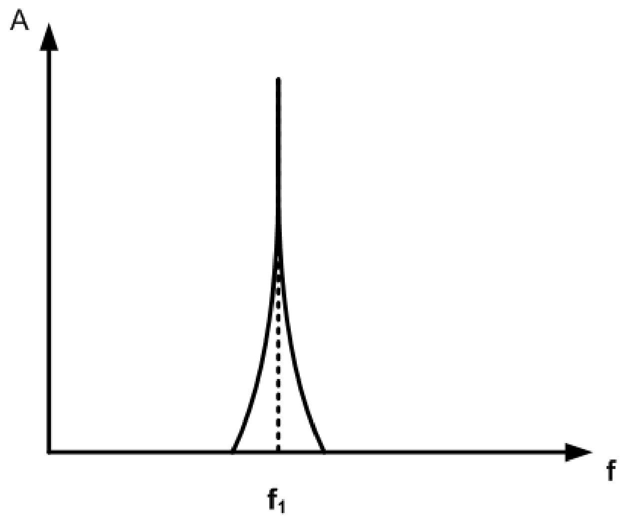
3.4 Phase Noise

Phase noise can be considered as a random phase modulation around an “ideal” carrier. The following equation describes an ideal carrier:

$$s(t) = A \cdot cos(2\pi \cdot f_1 \cdot t) \quad (12)$$



This kind of phase modulation (PM) results in a carrier looking quite a bit “broader” in the frequency spectrum.



Two parameters are commonly used to determine phase noise:

- ► Noise power density and
- ► Single sideband noise

3.5 Noise power density

One measure of phase noise is the one-sided noise power density of the phase fluctuations $\Delta\varphi_{rms}$ with reference to 1 Hertz bandwidth:

$$S_{\Delta\varphi}(f) = \frac{\Delta\varphi^2{}_{rms}}{1}\left[\frac{rad^2}{Hz}\right] \tag{13}$$

3.6 Single sideband noise

In practice, single sideband (SSB) phase noise L is usually used to describe an oscillator's phase-noise characteristics. L is defined as the ratio of the noise power in one sideband (measured over a bandwidth of 1 Hz) P_{SSB} to the signal power $P_{carrier}$ at a frequency offset f_m from the carrier.

$$L(f_m) = \frac{P_{SSB}[1Hz]}{P_{Carrier}} \tag{14}$$

If the modulation sidebands are very small due to noise, i.e. if phase deviation is much smaller than 1 rad, the SSB phase noise can be derived from the noise power density:

$$L(f_m) = \frac{1}{2}S_{\Delta\varphi}(f_m) \tag{15}$$

The SSB phase noise is commonly specified on a logarithmic scale [dBc / Hz]:

$$L_c(f_m) = 10\,log\ \left(L(f_m)\right) \tag{16}$$

3.7 Compression Point

The output power of an amplifier typically exhibits a linear correspondence to the input power as it changes (Figure 10): the gain, i.e. the ratio or quotient of output power to input power remains constant over the linear range.

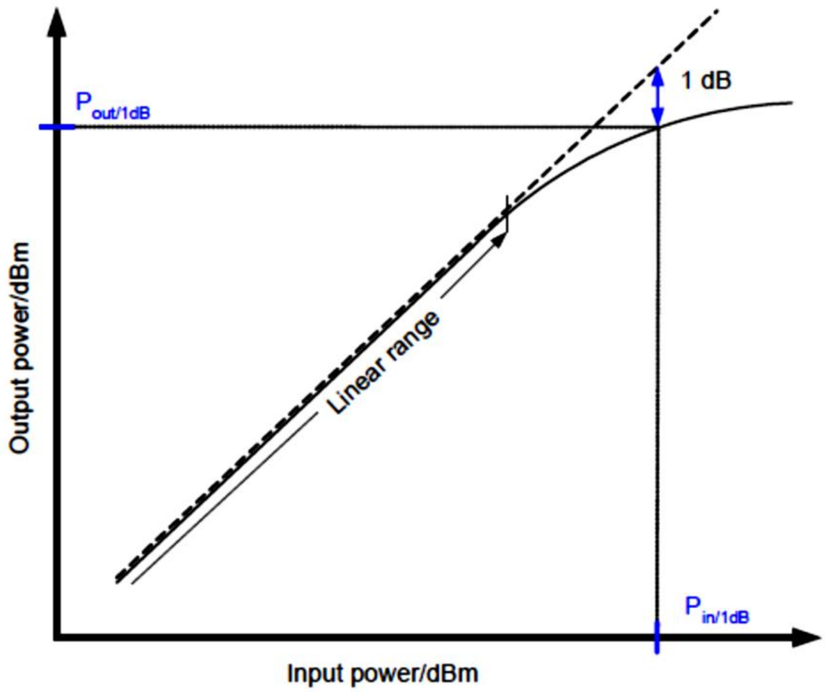


Figure 10: Definition of the 1 dB compression point at the amplifier input and the amplifier output

If the input signal level is successively raised above a certain point, the output power is no longer linear proportional to the input power. Typically, this deviation increases the closer output level comes to the amplifier's maximum output power: the amplifier compresses. The 1 dB compression point specifies the output power of an amplifier at which the output signal lags behind the expected/wanted output signal by 1 dB.

An alternative representation of amplifier compression characteristics is shown in Figure 11, where gain is plotted versus output power. Less common is a plot of gain versus input level.

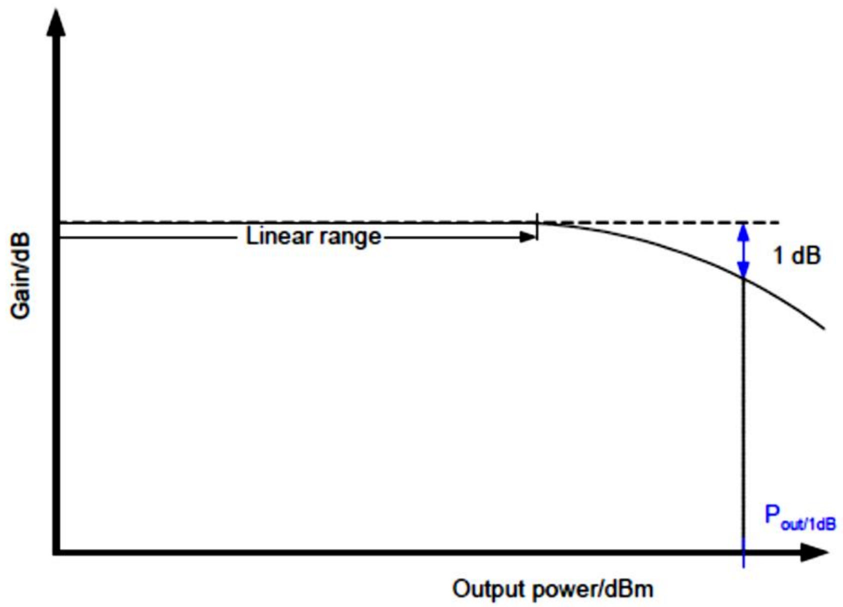


Figure 11: Gain versus output power of the 1 dB compression point at the amplifier output

A linear gain, i.e. a gain as observed at a sufficiently low driving signal, would yield the expected/wanted output signal. The difference of the expected output signal level to the output signal level as observed, can be at least qualitatively be explained by the over-proportional rise in harmonic output signal components towards high input level.

Harmonics may not be the only mechanism at play, but in order to prevent the power of harmonic signal content from corrupting the measurement result of the wanted components, the output power needs to be selectively measured.

3.8 Unwanted Emissions

An ideal transmitter emits its signal only on the operating frequency in use and nowhere else. However, in reality, all transmitters emit undesired signals, known as "unwanted emissions", in their output spectrum. For the purpose of this paper, it can be said that unwanted emissions are typically measured at the RF output port.

A "spurious emission" can be defined as any signal produced by equipment that falls outside of the band in which the equipment is meant to be operating (wanted band).

Spurious emissions are caused by unwanted side effects such as harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude the so-called out-of-band emissions.

"Out-of-Band emission" describes emissions of unwanted signals immediately outside adjacent to the wanted channel bandwidth, but also not overlapping the range of bands defined for spurious emissions.

Out of band emissions result from the modulation process and non-linearity.

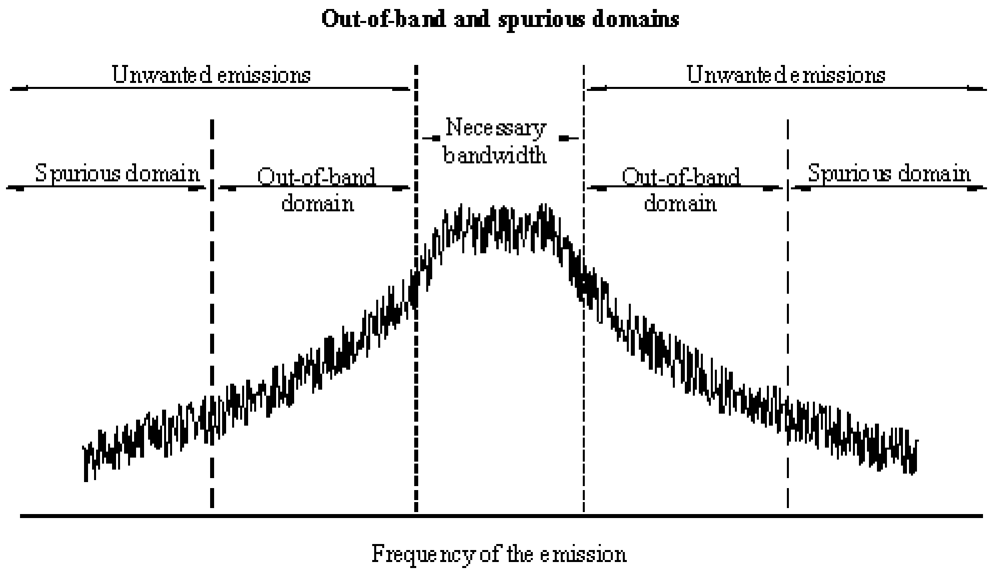


Figure 12: Out of band and spurious domains of unwanted emissions

Within this frequency band of unwanted emissions, a spectrum emission mask is often defined for the measurement.

The ITU (International Telecommunication Union) defines the Out of Band (OoB) domain depending on the necessary bandwidth (B_n) and whether Bn below the lower threshold value (B_L), between B_L and the upper threshold value (B_u), or beyond B_u, see Table 1.

TABLE 1

Start and end of OoB domain

Type of emission	If necessary bandwidth B_N is:	Offset (±) from the centre of the necessary bandwidth for the start of the OoB domain	Frequency separation between the centre frequency and the spurious boundary
Narrow-band	$< B_L$ (see Note 1)	0.5 B_N	2.5 B_L
Normal	B_L to B_U	0.5 B_N	2.5 B_N
Wideband	$> B_U$	0.5 B_N	B_U + (1.5 B_N)

NOTE 1 – When $B_N < B_L$, no attenuation of unwanted emissions is recommended at frequency separations between 0.5 B_N to 0.5 B_L.

NOTE 2 – B_L and B_U are given in Recommendation ITU-R SM.1539.

Table 1: Start and end of OoB domain according to ITU-R-REC-SM.1541-4 and ITU-R-REC-SM.1539-1

4 Measurement Setup for Measurements on a Satellite Up-converter using the ZVA

For accurate group delay measurements with the two-tone method R&S®ZVA-K9, as well as for intermodulation measurements, it is necessary to generate a two-tone signal with an accurate and stable frequency offset. The ZVA can provide this signal by using 2 sources of a 4-port model. The two signal sources signal are combined by using an external combiner or using one of the ZVA's internal couplers as combiner.

For that purpose, perform the following connections:

– Src out (Port 1) -> Meas out (Port 2)

– Port 2 -> Src in (Port 1)

With the accessory ZVA-B9, Rohde & Schwarz offers a cable set for the different types of ZVA. This way, the two-tone signal runs via the reference receiver of Port 1 to the input of the DUT. This setup is recommended for all ZVA models, as long as IF and RF frequencies are above 700MHz.

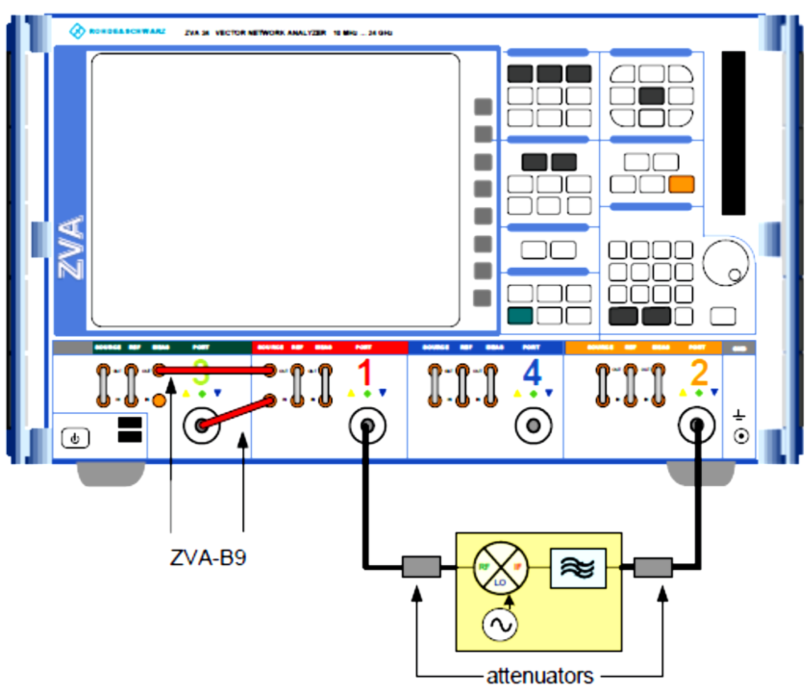


Figure 13: Test setup using ZVA-B9

If a VNA type ZVA8, ZVA24, ZVA40 or ZVA50 is used at lower frequencies like for measurements on a Satellite Up-Converter with 70 or 140 MHz IF input frequency, the attenuation of the internal coupler leads to an increased trace noise. To overcome this, an alternative is described below. To increase the accuracy, well matched 6 dB attenuators are recommended to be used at both ports, directly attached at the measurement plane.

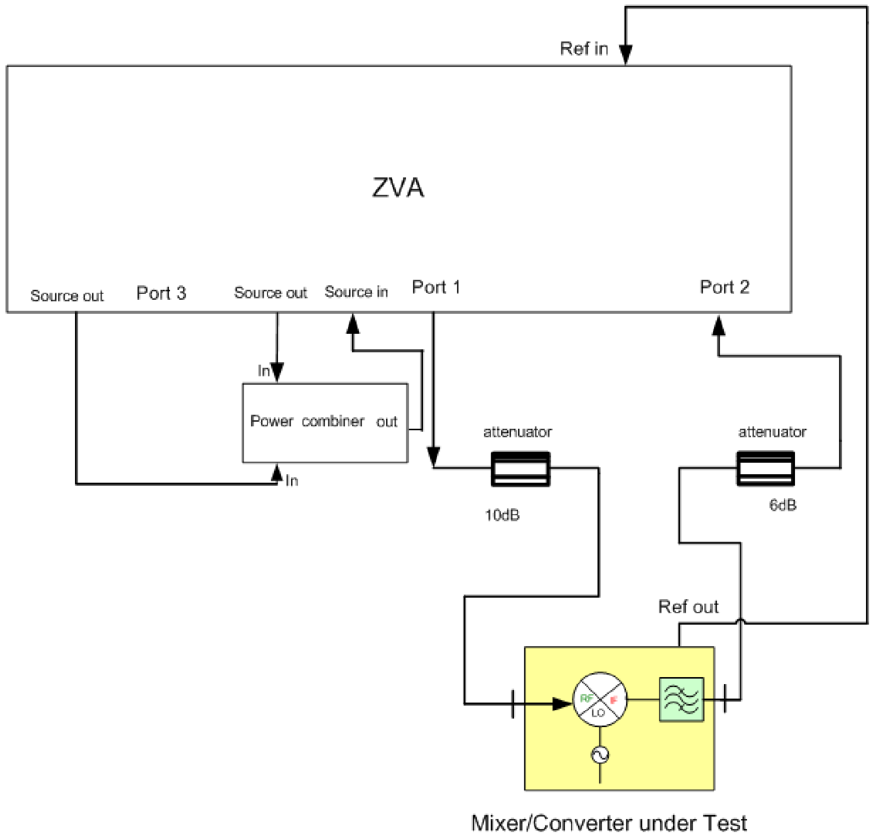


Figure 14: Converter Test setup using the ZVA

A two-tone signal is generated using ZVA port 3 and port 1 Source out signals combined by a power combiner (e.g. Resistive Power Divider, 4901.19.A, Huber+Suhner). The output of the sum port of the power combiner goes into "source in" of port 1. A connection is made via a 6 dB attenuator to the IF input of the frequency up-converter under test. The up-converted signal is feed to port 2 of the ZVA via a 6 dB attenuator. The two attenuators serve for improved matching characteristics in this setup.

If possible, it is recommended to synchronize the converter under test with the test instrument e.g. the ZVA by using the same reference to get rid of frequency offsets due to different time bases. To get synchronization, a connection from the "Ref Out" of the converter under test to the "Ref In" of the ZVA is recommended (the opposite way: synchronizing the converter under test to an external reference could possibly cause problems because of poor loop design).

For converters under test **without** access to the internal time base (reference frequency), the drift of the internal LO and a potential constant offset of the internal LO signal must be taken into account. Using option ZVA-K9, focusing especially on such devices, a reliable solution is provided to overcome the problems arising from the LO drift. A constant offset of the internal LO with respect to the reference frequency of the test equipment can easily be evaluated and taken into account: A simple scalar frequency converting measurement, with fixed RF, but with the IF swept in the frequency range of the expected DUT IF output, delivers directly the LO offset. See chapter 5.1 how to measure and correct the offset.

Precondition of the following measurements is that this offset remains constant within the used measurement bandwidth e.g. 1 kHz.

The test setup shown in Figure 14 can be used for group delay measurements, conversion loss measurement as well as for intermodulation measurement and 1-dB compression point measurement.

5 Satellite Up-Converter Measurements

5.1 LO frequency offset correction for Frequency Converters under test without access to the time base

Skip this chapter for converters under test with reference frequency output!

As mentioned before, option ZVA-K9 is a unique solution for embedded LO measurements and allows reliable measurements even with a significant frequency drift of the internal LO (which can be within the IFBW, selected in the ZVA). An additional constant frequency offset of the LO can be identified by a scalar frequency converting measurement: A fixed RF is applied, but the DUT IF output is measured with a center frequency at the expected IF, and a frequency sweep span in the range of the estimated LO offset. Once the offset is known, it can easily be corrected in the ZVA settings.

► To do this set the source frequency of port 1 to a fixed frequency (e.g. 70 MHz) in the middle of the channel in the "Port Configuration" dialog of the ZVA. The receive frequency of port 2 is swept with a small span e.g. 10 kHz which covers the expected frequency offset of the converters output frequency. See Figure 15 for the according settings within the Port Configurations menu of the ZVA.

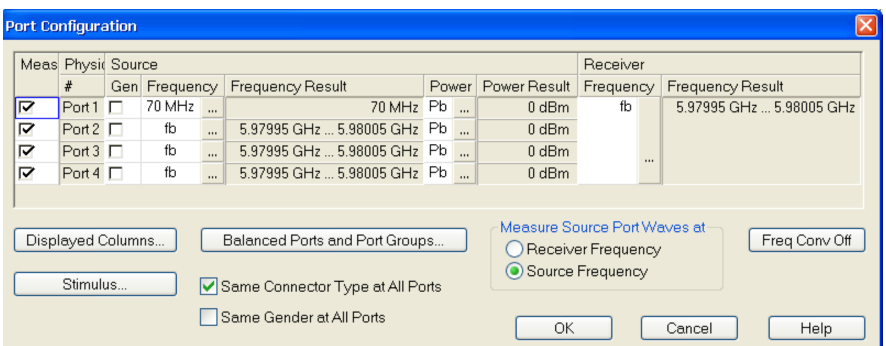


Figure 15: Port configuration for measuring the frequency offset of non-synchronized frequency converters

To use the ZVA as a kind of spectrum analyzer, use an IF filter with high selectivity (Pwr BW AVG : Fine Adjust: Selectivity High) and a bandwidth of 1 kHz or below, see Figure 16.

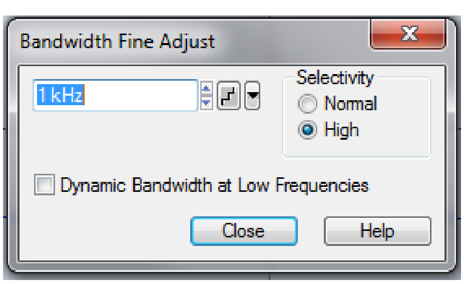


Figure 16: Bandwidth setting of the ZVA

► Select MEAS: Wave quantity: b2 Source Port 1

► Set the Ref Marker of the ZVA to the nominal output frequency of the converter under test (e.g. 5.98 GHz in this example)

► Set Marker 1 of the ZVA to Relative and Search Max

► Add the measured offset ΔM1 (=5 kHz in this example, see Figure 17) to the nominal LO frequency within the "Define Frequency" window (e.g. Figure 19) of the ZVA (5.910005 GHz instead of 5.91 GHz in this example).

► Use this corrected LO frequency for all further ZVA measurements

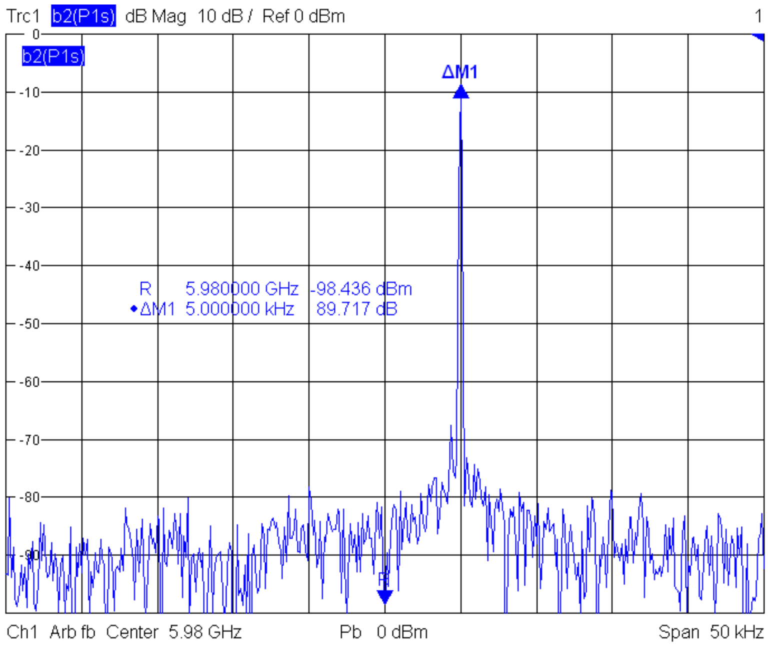


Figure 17: Measurement of the frequency offset of a non-synchronized frequency converter (5 kHz in this example)

5.2 Group Delay measurement on Satellite Up-Converters with the ZVA

5.2.1 Instrument Settings

First, generate a two-tone signal with 5 MHz aperture (difference in frequency)

► *Channel: Mode: Mixer Delay Measurement: Define mixer Delay Meas*

► Configure the window as shown in the Figure 18 below

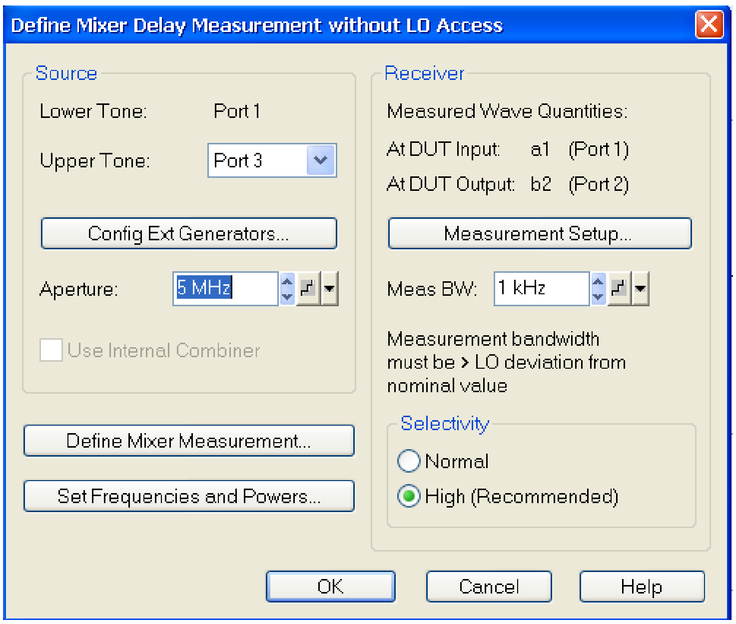


Figure 18: Define Mixer Delay Measurement Window

► Click on *Define mixer Measurement and then Set Frequencies* and configure as shown in **Error! Reference source not found.**

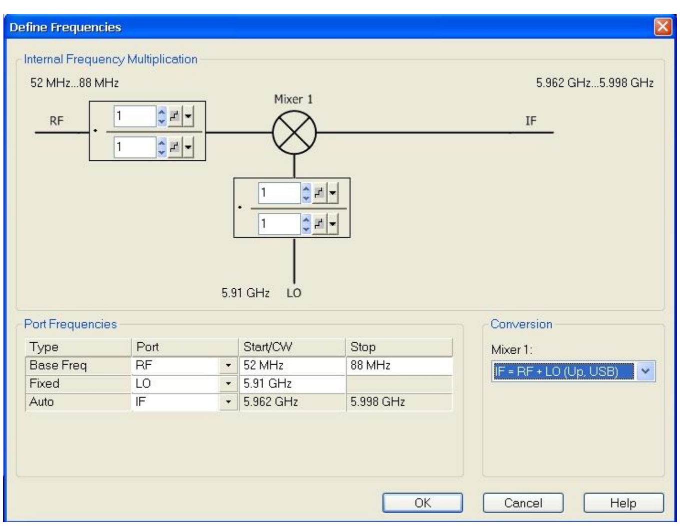


Figure 19: Define Frequencies Window

► Click *OK* to save the settings

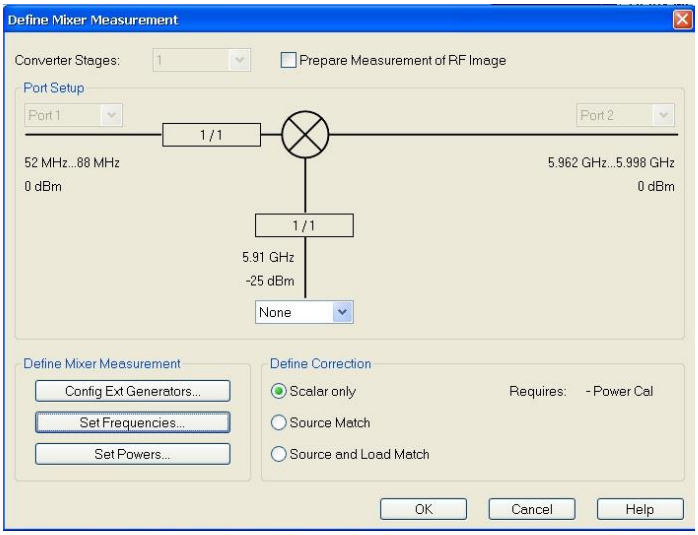


Figure 20: Define Mixer Measurement window

► Click *OK* to save the settings

An RF signal frequency range from 52 to 88 MHz is up-converted to an IF signal frequency range of 5.962 GHz to 5.998 GHz by an LO of 5.91 GHz.

► Click on *Set Frequencies and Powers* and configure as shown in Figure 21

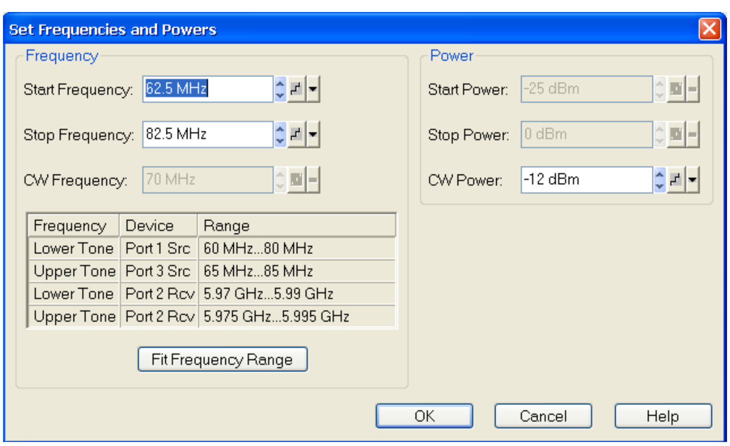


Figure 21: Set Frequencies and Powers window

These settings also select the span over which the measurement is performed. The CW power is set to -12 dBm.

► Click *OK*.

► Click *OK* to save the settings and exit the window

5.3 Calibration

For group delay measurements two different calibrations are required

► Power calibration

► Power calibration is performed by using an appropriate R&S NRP-Zxx Power Sensor (e.g. R&S NRP-Z21, R&S NRP-Z11) connected to an USB port of the ZVA.

► Mixer delay calibration

The calibrations done in the following chapters 5.3.1 and 5.3.2 are used for all described measurements executed with the ZVA.

5.3.1 Power Calibration

► Click **Channel** > mode > Scalar mixer Measurement > Mixer Power Cal

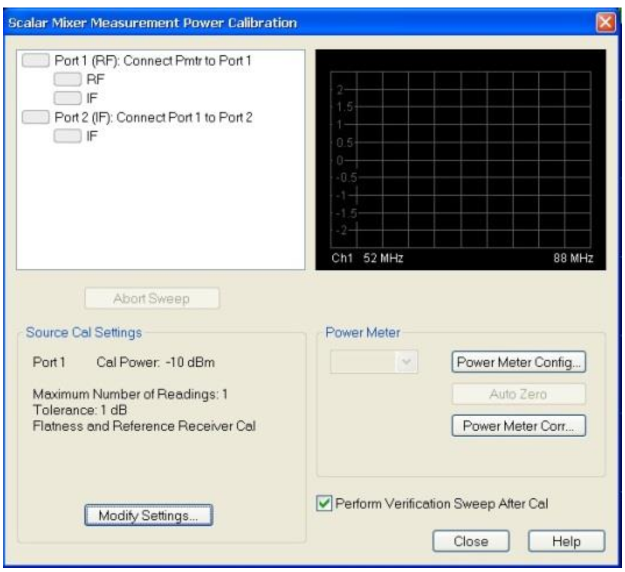


Figure 22: Scalar Mixer Measurement Power Calibration window

► Connect the power sensor via the USB port of the ZVA

► Click to *Power Meter Config…*

Click to *Refresh Tables*. A connected power sensor should appear as Pmtr 1 (power meter 1) in the *Configured* field of Figure 23.

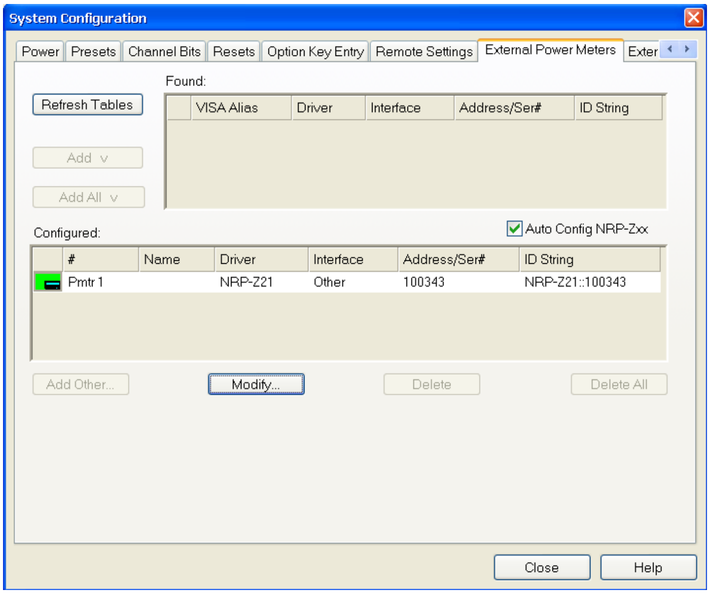


Figure 23: An NRP-Z21 power sensor connected to the ZVA via USB is recognized

► and configure as in Figure 24 (*Cal Offset* = sum of attenuation of power Click on Modify Settings combiner and 6 dB attenuator, *Max. Number of Readings*, *Tolerance and Power Meter Readings*)

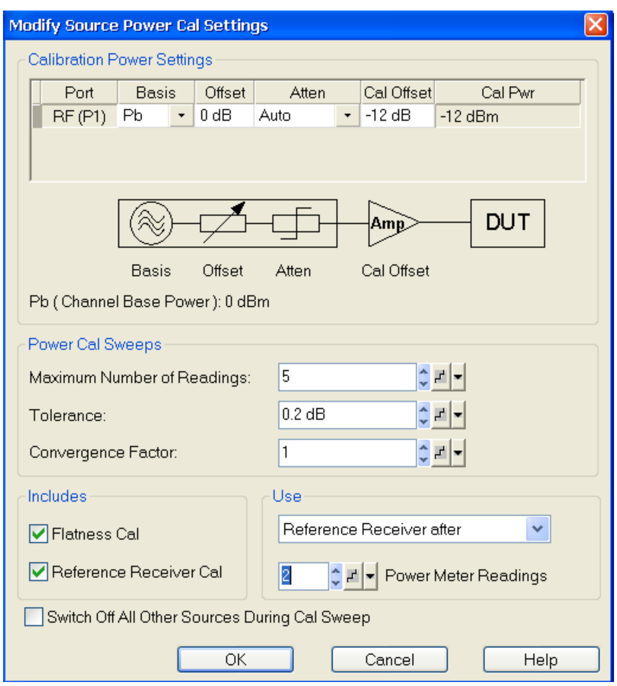


Figure 24: Modify Source Power Cal settings

Perform the power calibration systematically:

► Connect the power sensor (a NRP-Z21 in this example) to Calibration Plane (after 6 dB attenuator, see Figure 25):

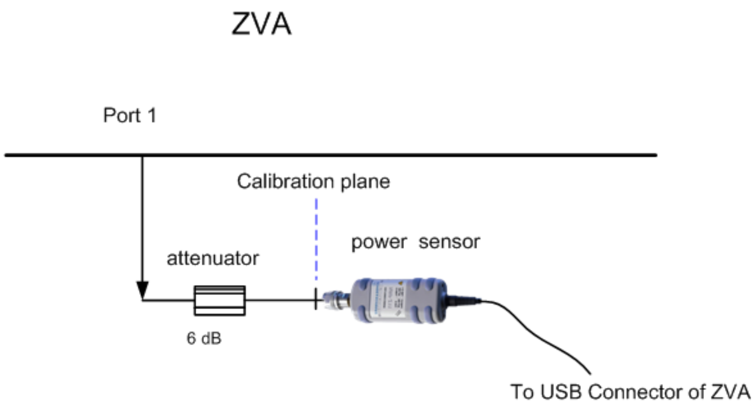
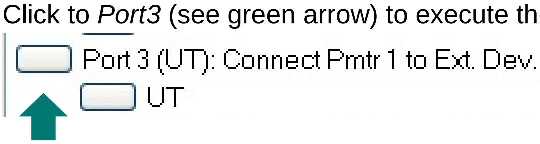


Figure 25: Connection of power sensor to Calibration plane (output)

► Click to *Port1* (see green arrow) to execute the Port 1 lower tone calibration (this takes a few seconds):

► Click to *Port3* (see green arrow) to execute the Port 3 upper tone calibration (this takes a few seconds):



► Connect both sides of calibration plane with through connector as shown in Figure 26:

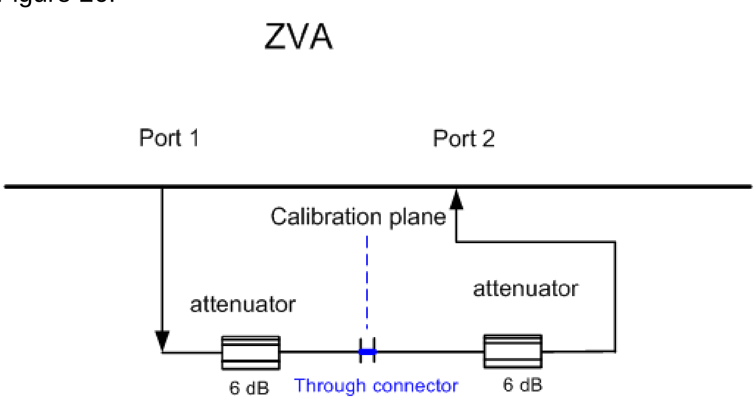
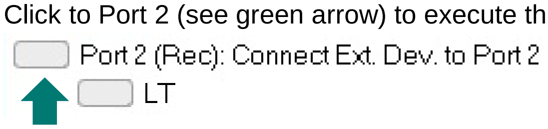


Figure 26: Through connector connects both sides of calibration plane for next step of power calibration

► Click to Port 2 (see green arrow) to execute the Port 2 calibration (this takes a few seconds):



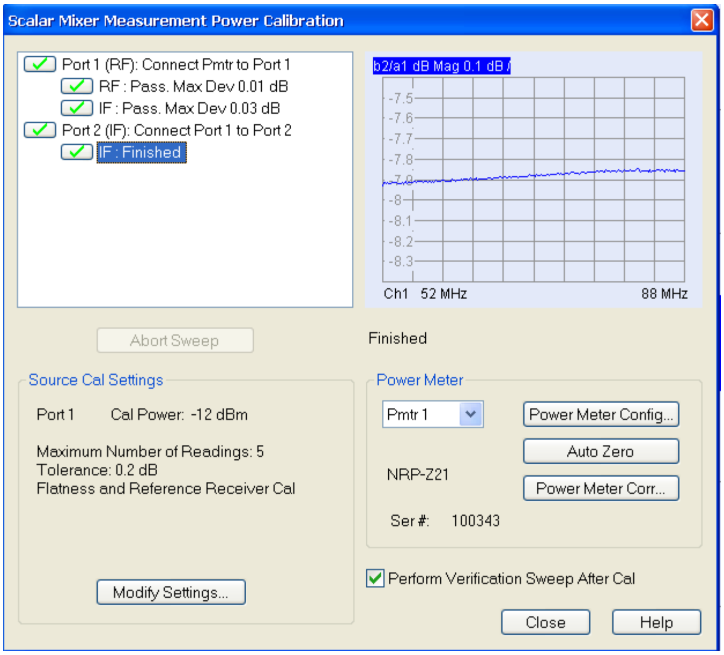


Figure 27: Successive scalar mixer power calibration

Now the output powers of each of the two tones at the reference plane are calibrated to -12 dBm.

5.3.2 Mixer Delay Calibration

This chapter can be skipped if the group delay of the converter under test is much higher than the group delay of the measurement path between port 1 and port 2 (cables and attenuators). This is the case for a typical frequency converter because of the inherent filters, which have typically much more group delay than RF cables and attenuators.

If there is any doubt, a calibration can be performed with known calibration mixer. Because only the knowledge of relative group delay (and not the absolute one) is typically required for satellite converters, it is sufficient to use a “golden” mixer with linear phase and flat group delay for calibration.

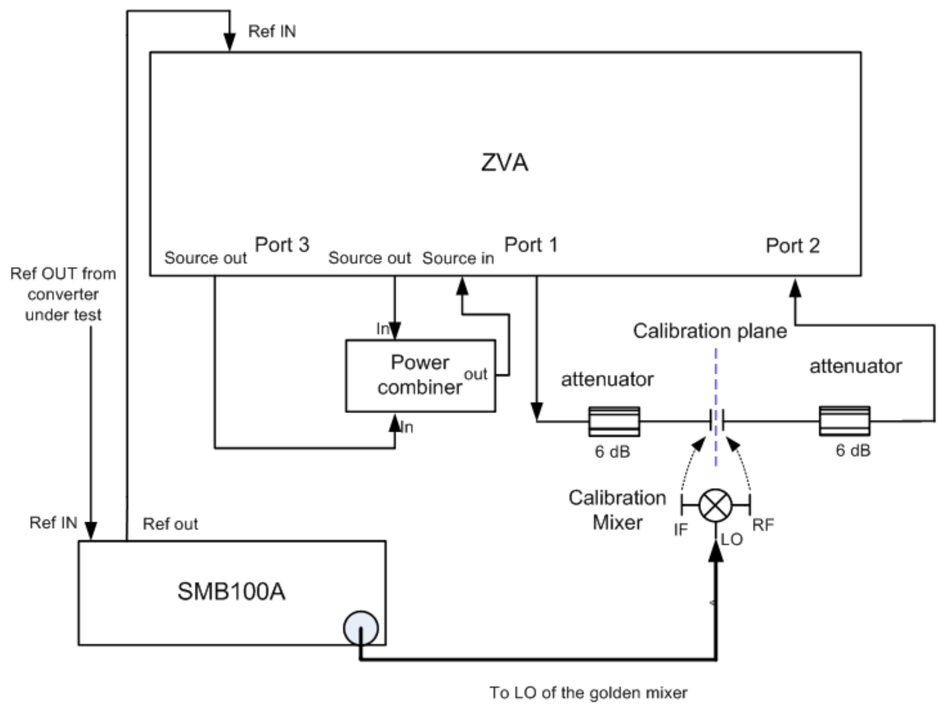


Figure 28: Mixer delay calibration setup with an SMB100A (also other signal generators could be used)

- Connect the “golden” or calibration mixer instead of the DUT (e.g. a ZX05-153MH-S+ from Mini-Circuits).
  The ZVA port 1 via 6 dB attenuator connects to the IF port of the golden mixer. The port 2 of the ZVA connects to the RF port of the golden mixer via the 6dB attenuator.
- **Use an external signal generator (R&S®SMB) as LO**.
  Set the frequency to 5.91 GHz and the power level at 13 dBm.
- Connect Reference Output of the converter under Test to the Reference input of the signal generator used. Setup the signal generator for External Reference.
- To lock the ZVA to the signal generator, make a connection from the Reference Output of the signal generator to the Reference Input of the ZVA. The signal generator should be locked to the Reference output of the converter under test.

Make the following operation steps at the ZVA:

- *System > External Reference.*
  The ZVA and the Signal Generator are now locked.
- *PWR BW AVG > Meas Bandwidth: 1 KHz*
- *AVERAGE FACTOR: 10*
- *AVERAGE ON*
- *Channel > Mode > Mixer Delay Measurement > Cal Mixer Delay Meas*

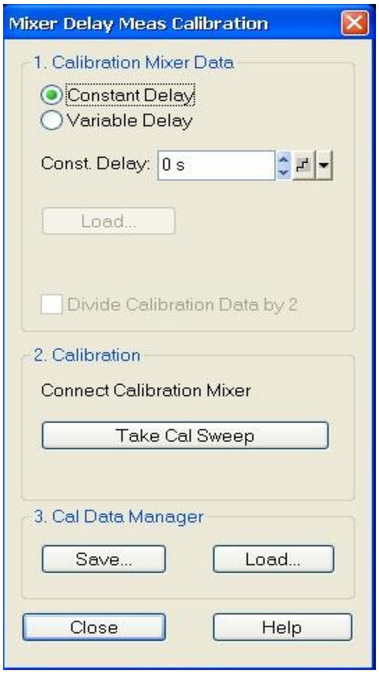


Figure 29: Mixer Delay Meas Calibration window

► For relative group delay, select *Constant Delay and input Const. Delay: 0s*

► Click *Take Cal Sweep*.

► Wait until the message "Finished" appears (this takes a few seconds) and close the dialog.

If necessary, the calibration data can be saved and recalled using the "Save" and "Load" buttons. The entire calibration process is now complete and the group delay measurements can now be made.

5.4 Group Delay Measurement and Results

To start the measurement part, use the test setup as shown in Figure 30 depending on the frequency range. The converter under test is specified for 70 and 149 MHz IF but the measurements are described only for 70 MHz. Tests at 140 MHz IF can be done accordingly.

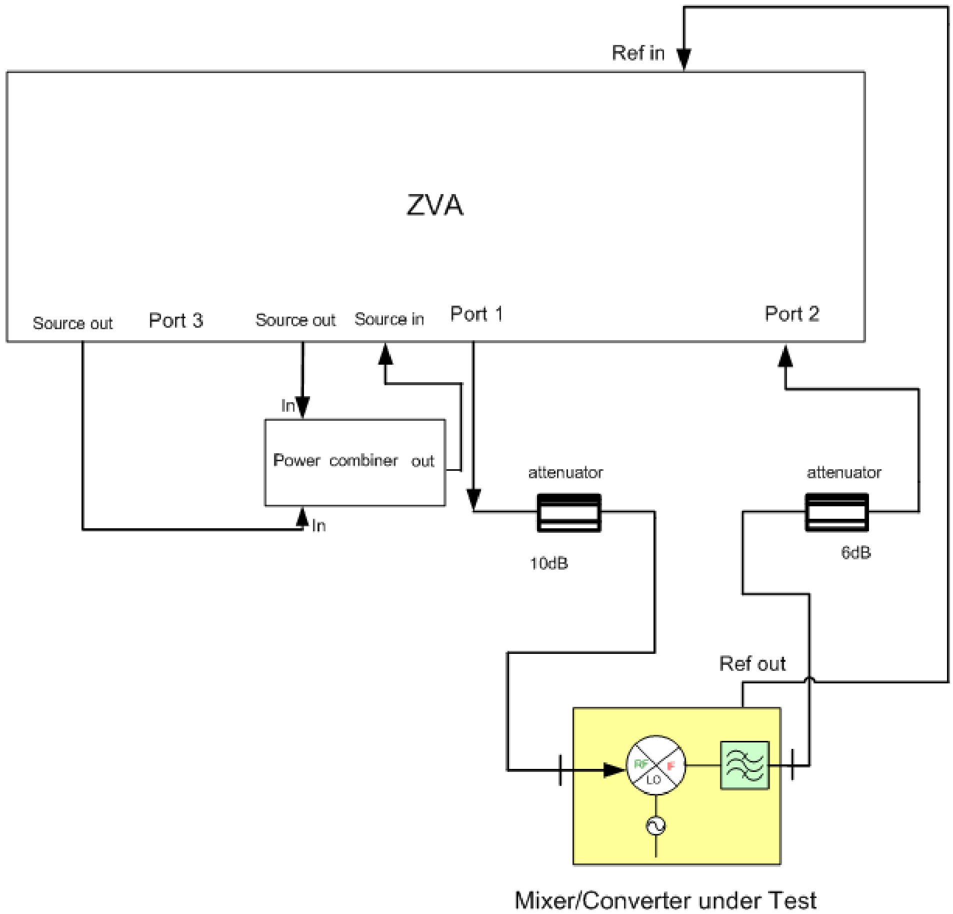


Figure 30: Test setup for group delay measurement on the converter under test with the ZVA. (The same setup is used for all other described measurements with the ZVA.)

Figure Figure 31 shows the group delay plot at 70 MHz IF and the up converted signal is at 5980 MHz. The span used is 36 MHz, which is also the bandwidth where the group delay specification of the converter under test is valid.

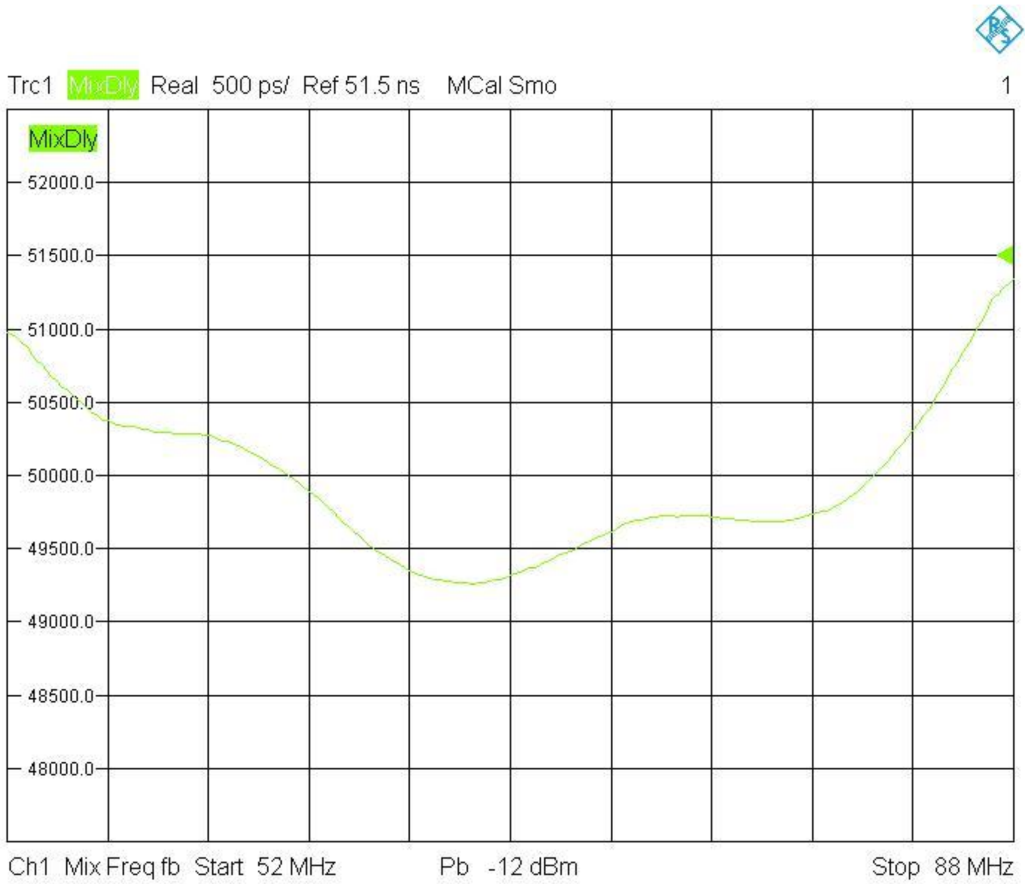


Figure 31: Measured group delay of Converter under Test at IF 70 MHz

5.5 Extracting Linear, Parabolic and Ripple Group Delay by MATLAB

Typically, the group delay results for satellite frequency up-converters are specified for three components.

► Linear group delay

► Parabolic group delay

► Ripple group delay

To extract these three quantities from the measured ZVA results (see Figure 31 and Figure 37, MATLAB is used. A few adjustments need to be made to the MATLAB code that does the calculations. The changes are explained in detail below.

To calculate these three quantities, first export the complex trace data from ZVA group delay measurement.

► Click **File** > Trace Data> Export complex Data (on the ZVA)

► Save the data as .csv file and make it available to the computer running MATLAB.

5.5.1 MATLAB code for group delay and corresponding plots:

```
1  x=data(:,1)
2  y=data(:,2)
3  plinear= polyfit(x,y,1)
4  flinear = polyval(plinear,x);
5  pparabolic= polyfit(x,y,2)
6  fparabolic = polyval(pparabolic,x);
7  
8  val = 4          %%%%%%%% change value here %%%%%%%%
9  
10 switch val
11 
12 case 1 %original plot
13 plot(x,y,'-')
14 
15 case 2 %linear group delay plot
16 plinear= polyfit(x,y,1)
17 flinear = polyval(plinear,x);
18 plot(x,flinear,'-')
19 l1=max(flinear)-min(flinear)
20 lnu=l1*1e+09
21 l=max(x)-min(x)
22 lden=l*1e-6
23 linear=lnu/lden          % in ns / MHz
24 
25 case 3 %parabolic group delay plot
26 pparabolic= polyfit(x,y,2)
27 fparabolic = polyval(pparabolic,x);
28 fparabolicplot=fparabolic-flinear
29 plot(x,fparabolicplot,'-')
30 pv=max(fparabolic)-min(fparabolic)
31 pnu=pv*1e+09
32 p=(max(x)-min(x))/2
33 pden=p*1e-6
34 parabolic=pnu/(pden.^2)      %in ns / MHz²
35 
36 case 4 %ripple group delay plot
37 fripple=y - fparabolic
38 plot(x,fripple,'-')
39 r1=max(fripple)-min(fripple)
40 rnu=r1*1e+09
41 ripple=rnu   %in ns peak-to-peak
42 
43 end
```

To calculate a specific Group Delay (ripple, parabolic or linear), change the value on line 7 accordingly:

- Val = 1 to see the trace plot as exported from the ZVA
- Val = 2 to see the linear group delay plot and linear group delay (on command window of MATLAB)
- Val = 3 to see the parabolic group delay plot and parabolic group delay (on command window of MATLAB)
- Val = 4 to see the ripple group delay plot and ripple group delay (on command window of MATLAB)
- After inputting the value of desired group delay, copy and paste the code on MATLAB command window.

5.5.1.1 MATLAB Plots and group delay values at 70MHz IF

Calculated values for linear, parabolic and ripple part of group delay as seen on the MATLAB command window:

- Linear = 0.0035 ns / MHz
- Parabolic = 0.0052 ns / MHz^2
- Ripple = 0.7428 ns peak to peak

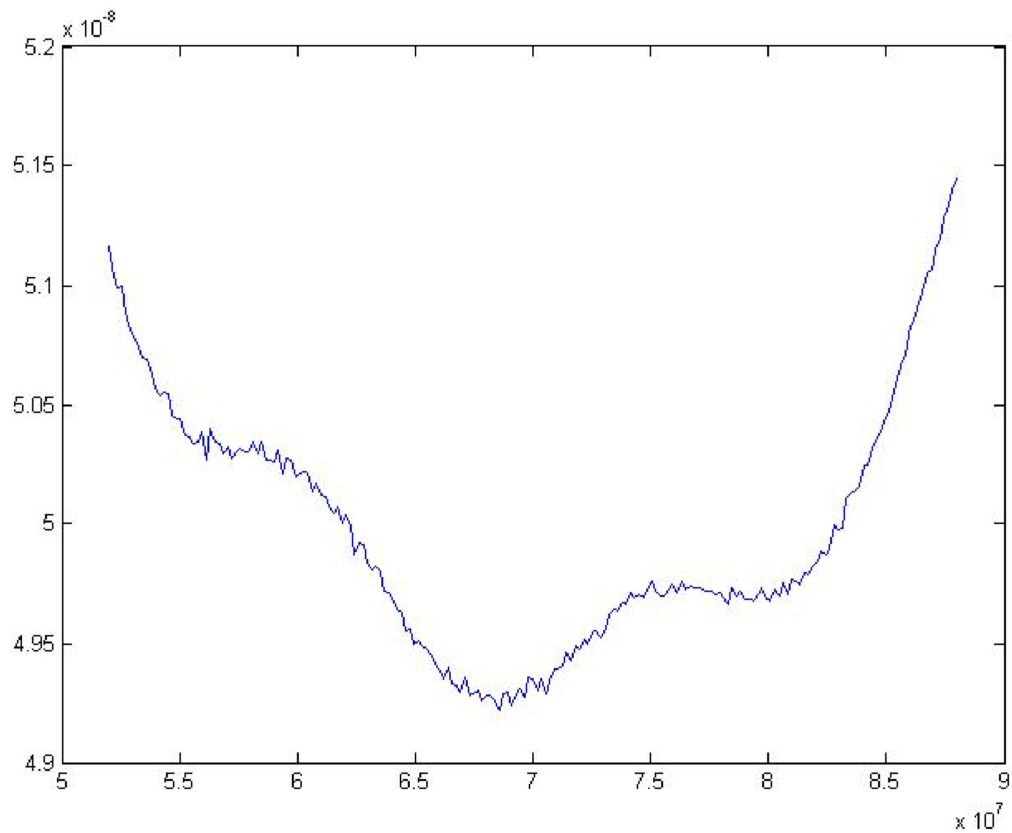


Figure 32: Original MATLAB plot of measured group delay (Val = 1)

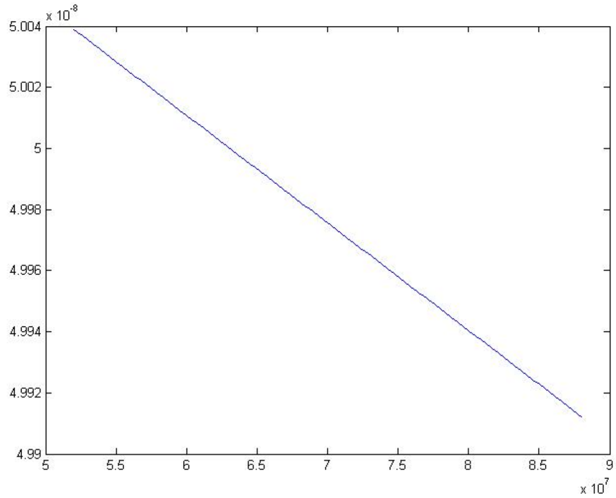


Figure 33: MATLAB plot of linear part of measured group delay (Val = 2)

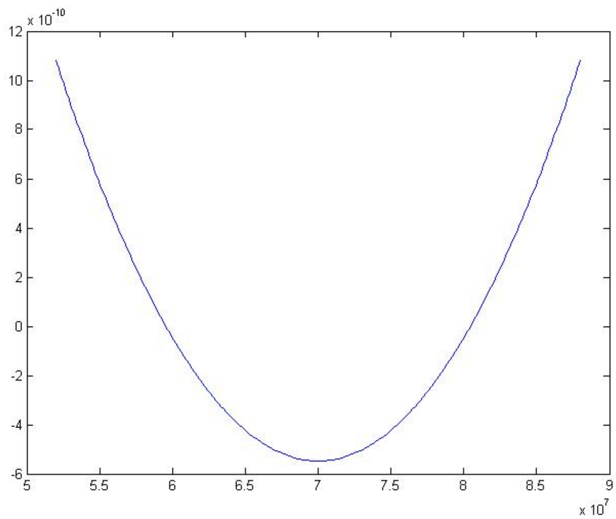


Figure 34: MATLAB plot of parabolic part of measured group delay (Val = 3)

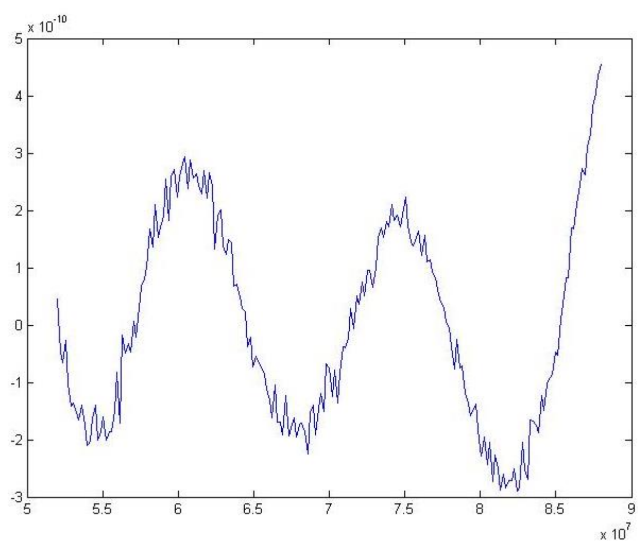


Figure 35: MATLAB plot of ripple part of measured group delay (Val = 4)

5.5.1.2 MATLAB Code for Calculating different parts of Group Delay (Group Delay Selection)

► Copy and paste the code to the MATLAB command window and change the val parameter to the wanted number (1, 2, 3 or 4 accordingly)

```
x=data(:,1)
y=data(:,2)
plinear= polyfit(x,y,1)
flinear = polyval(plinear,x);
pparabolic= polyfit(x,y,2)
fparabolic = polyval(pparabolic,x);

val = 4         %%%%%%%% change value here %%%%%%%%

switch val

case 1 % original plot
plot(x,y,'-')

case 2 %linear group delay plot
plinear= polyfit(x,y,1)
flinear = polyval(plinear,x);
plot(x,flinear,'-')
l1=max(flinear)-min(flinear)
lnu=l1*1e+09
l=max(x)-min(x)
lden=l*1e-6
linear=lnu/lden           % in ns / MHz

case 3 % parabolic group delay plot
pparabolic= polyfit(x,y,2)
fparabolic = polyval(pparabolic,x);
fparabolicplot=fparabolic-flinear
plot(x,fparabolicplot,'-')
pv=max(fparabolic)-min(fparabolic)
pnu=pv*1e+09
p=(max(x)-min(x))/2
pden=p*1e-6
parabolic=pnu/(pden.^2)   % in ns / MHz² max

case 4 % ripple group delay plot
fripple=y - fparabolic
plot(x,fripple,'-')
r1=max(fripple)-min(fripple)
rnu=r1*1e+09
ripple=rnu                              % in ns peak-to-peak

end
```

5.6 Conversion Gain Measurement

After having done the calibrations according to chapters 5.3.1 and 5.3.2 the conversion gain measurement is initiated with:

► Click **Trace** > Measure > Ratio > b2/a1

Below results for the measured converter under test for IF frequencies 70 MHz and 140 MHz.

Figure 36: Conversion gain or converter under test with IF 70 MHz

Figure 37: Conversion gain or converter under test with IF 140 MHz

5.7 Intermodulation measurements using the ZVA

Instead of the "classical" procedure of measuring intermodulation products by use of two signal generators (or a 2-channel signal generator like the R&S®SMW) and a spectrum analyzer like described later in chapter 0, the ZVA can do these measurements in many cases as well and without additional means beside a passive power combiner.

The test setup of Figure 30 is used again for the intermodulation measurement.

► *Click Channel: Mode: Intermod Distortion Meas: Define Intermod Dist Meas* and adjust the settings like shown in Figure 38:

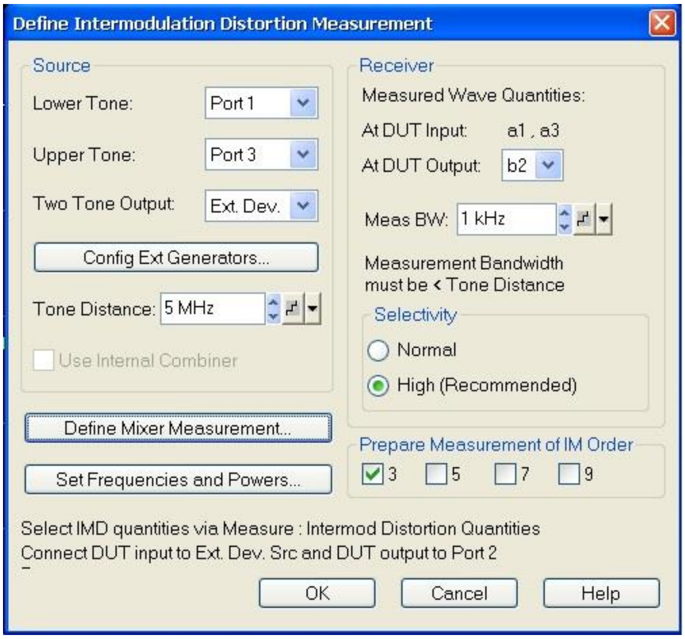


Figure 38: Instrument settings for ZVA Intermodulation measurements

► Click on *Define Mixer Measurement: Set Frequencies* and make the port and frequency adjustments as shown in Figure 39 and then Figure 40.

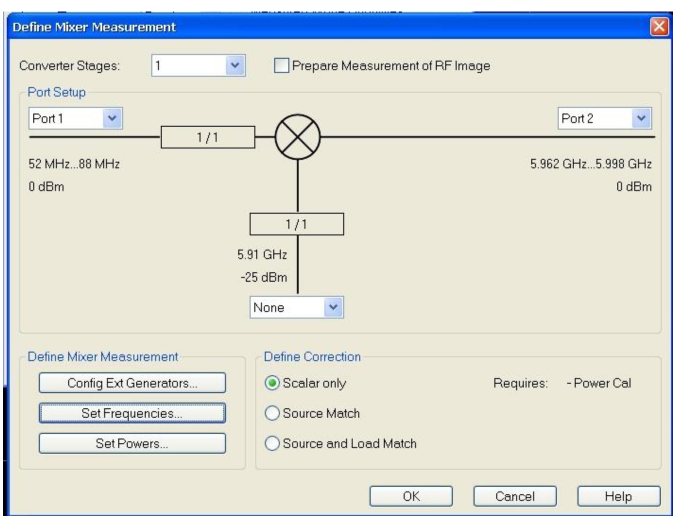


Figure 39: Instrument settings for ZVA Intermodulation measurements

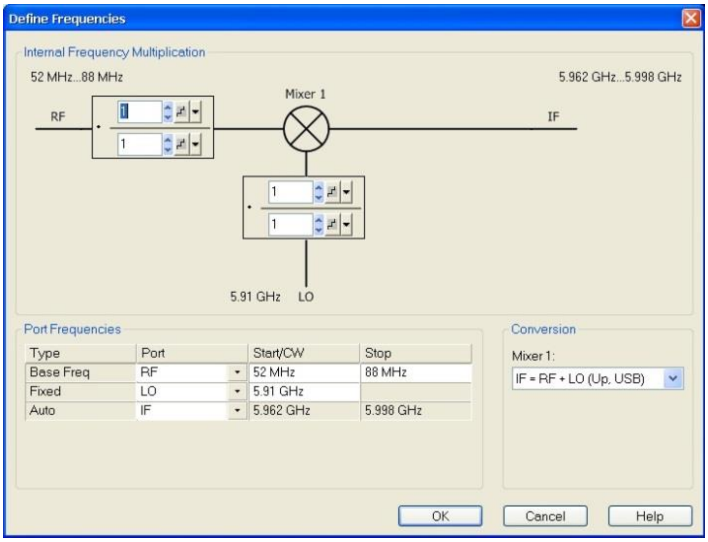


Figure 40: Frequency settings for ZVA Intermodulation measurements

► Click to *Channel: Mode: Intermod Distortion Meas: CW Mode Intermod Spectr*um and make adjustments as shown in Figure 41 below**.**

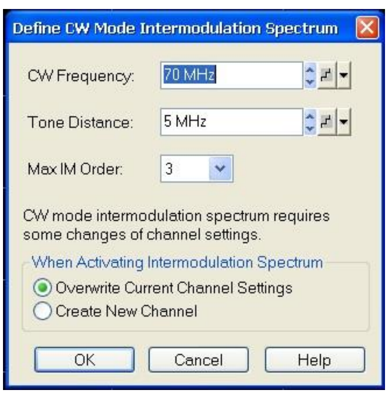


Figure 41: Settings of Define CW Mode Intermodulation Spectrum

► Click *Channel: Mode: Port Config* and make the adjustments as shown in Figure 42 (Cal Power Offset: Sum of attenuation of resistive power combiner + attenuation of 6 dB Attenuator about 12 dB. A Power Result of -25 dBm gives an output power of the converter under test of approximately 0 dBm, which is the specified power for intermodulation product)

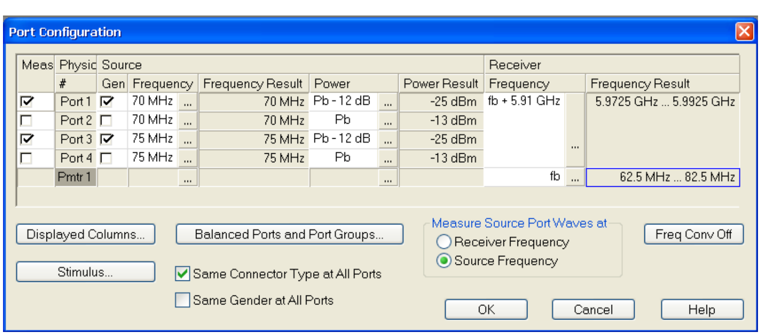


Figure 42: Port Configurations Settings

► Click on *Stimulus* and make adjustments as in Figure 43

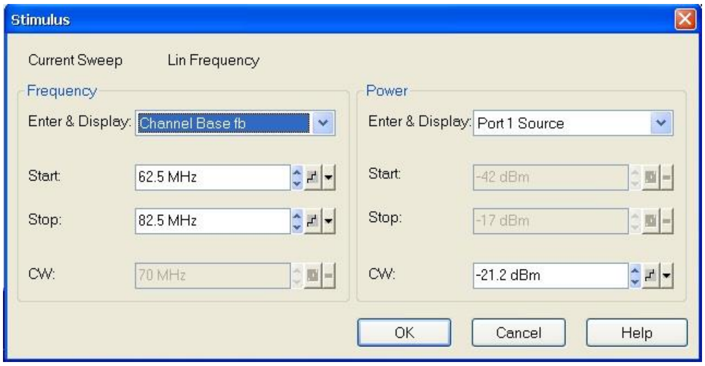


Figure 43: Stimulus Settings

► *Sweep: Number of points 201*

► *Power BW AVG*

► *Deselect Average On*

5.7.1 Measurement Results

Figure 44 shows the intermodulation measurement results of the converter under test at IF 70 MHz using the two tone method. The tone spacing used is 5MHz, the frequency span is 20 MHz.

► Adjust level of 2-tone signal for exactly 0 dBm per tone with *Power BW AVG: Power* using the rotary knob.

Marker Settings:

► Marker: Ref Marker 70 MHz

► Marker 1: Delta Mode: -5 MHz

► Marker 2: 75 MHz

► Marker 3: Delta Mode: 10 MHz

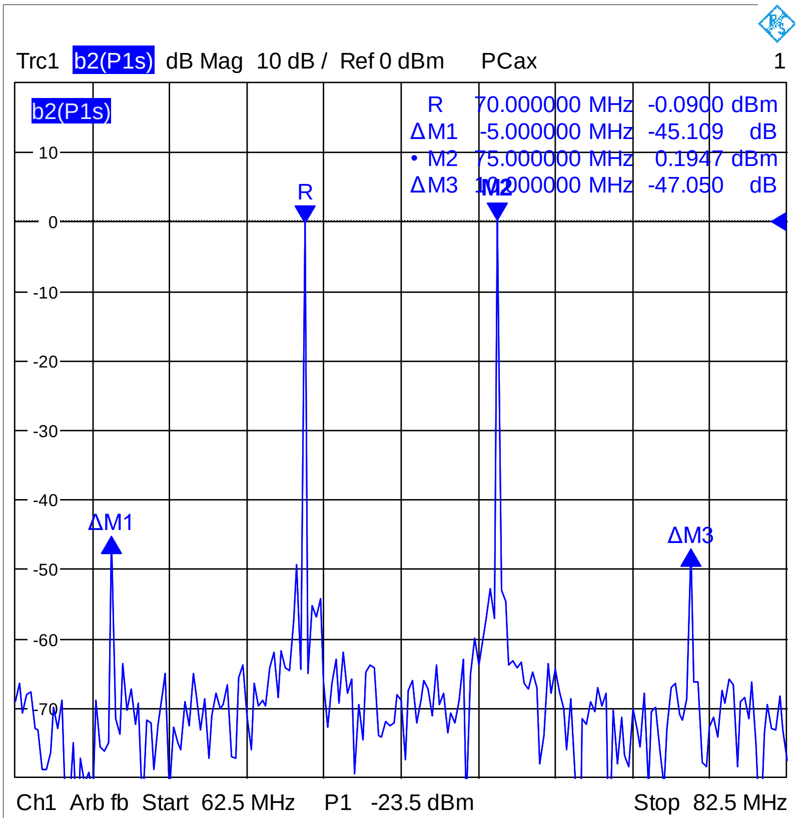


Figure 44: Intermodulation measurement at IF 70MHz using the ZVA. d3 products are -45 dB and -47 dB referred to 0 dBm of 70 MHz signal

5.8 1 dB-Compression point measurement with the ZVA

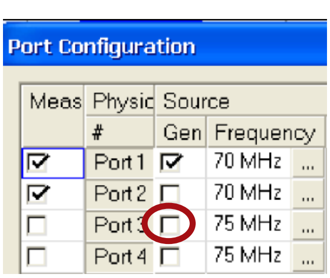
The test setup shown in Figure 30 is used again for the 1 dB compression point measurement (only the Port 3 Source output is switched off)

Instrument settings for the 1dB compression point measurement (starting from the former intermodulation distortion measurement described in chapter 5.4)

- ► *SWEEP:Sweep Type: Power: Channel Base Frequency 70 MHz*
- ► *MEAS: Rations: b2/a1 Src Port 1*
- ► *START: -20 dBm (default)*
- ► *STOP: 0 dBm (default)*

Mode: Port config

Switch off port 3: Source Gen:



► *SCALE: Ref Position 0: Close*

► *SCALE:Scale/Div 5 dB*

► *Trace Funct: Trace Statistics: Compression Point*

Figure 45 shows the result of the compression point measurement at input and output of the converter under test (-9 dBm at the input and + 14.8 dBm at the output). The gain of the converter under test is approximately 25 dB (about 24 dB at the 1-dB compression point).

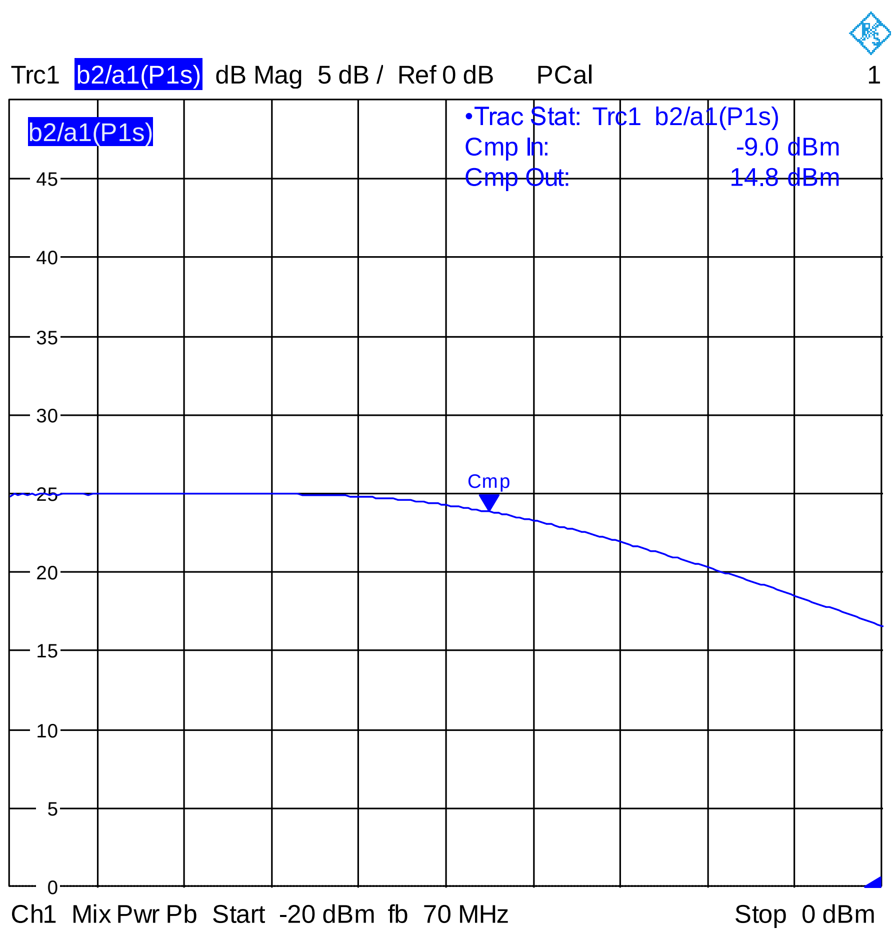


Figure 45: Compression point measurement result of the ZVA at the converter under test.

5.9 Intermodulation test setup using the Signal and Spectrum Analyzer FSW and two Signal Generators SMB

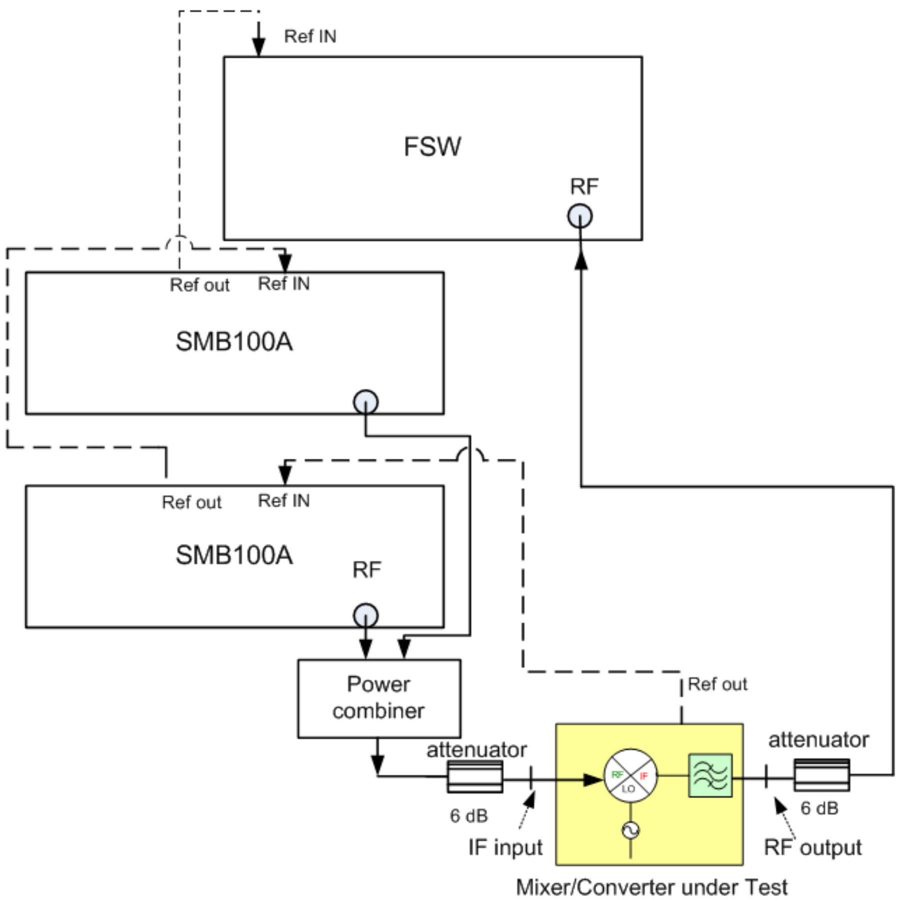


Figure 46: Test setup using an FSW and two SMB for intermodulation measurement

To perform intermodulation measurements using the FSW and two SMB, the test setup is implemented as shown in Figure 46. Tests are to be performed at both IF 70 MHz and IF 140 MHz; setup the converter under test respectively. Synchronizing the R&S test instruments to the reference output of the converter under test is optional.

IF 70MHz:

SMB configuration:

PRESET

SMB 1: *Frequency: 67.5MHz; Level: -15dBm,*

SMB 2: *Frequency: 72.5MHz; Level: -15 dBm*

RF ON

FSW configuration:

PRESET

Frequency: 5.98GHz

Span: 36MHz

RBW: 10KHz

VBW: 10KHz

Attenuation: 4dB

A typical test result is shown in Figure 47. With 5 MHz aperture (which means frequency distance of the 2-tone signal) d3 intermodulation products are – 44.3 dB and -46.9 dB down.

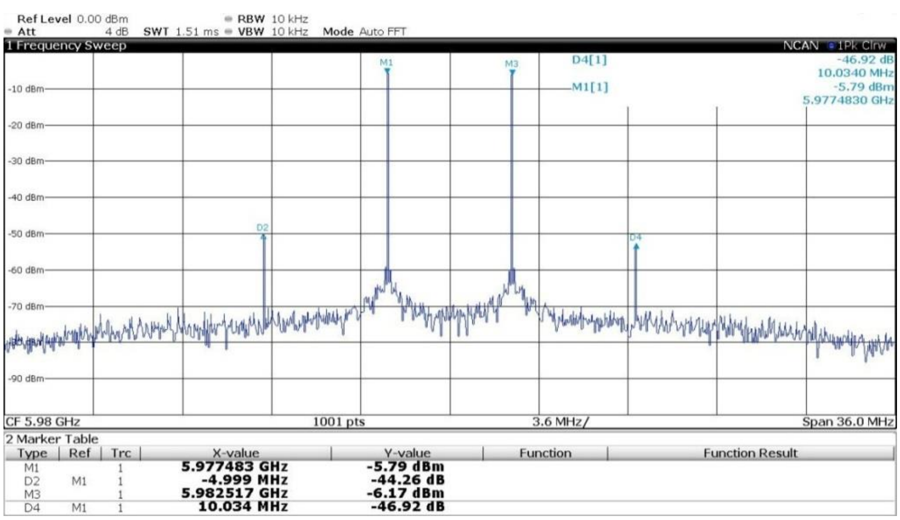


Figure 47: FSW result of Intermodulation measurement at 70MHz IF (5MHz aperture)

5.10 Phase Noise measurement using FSW

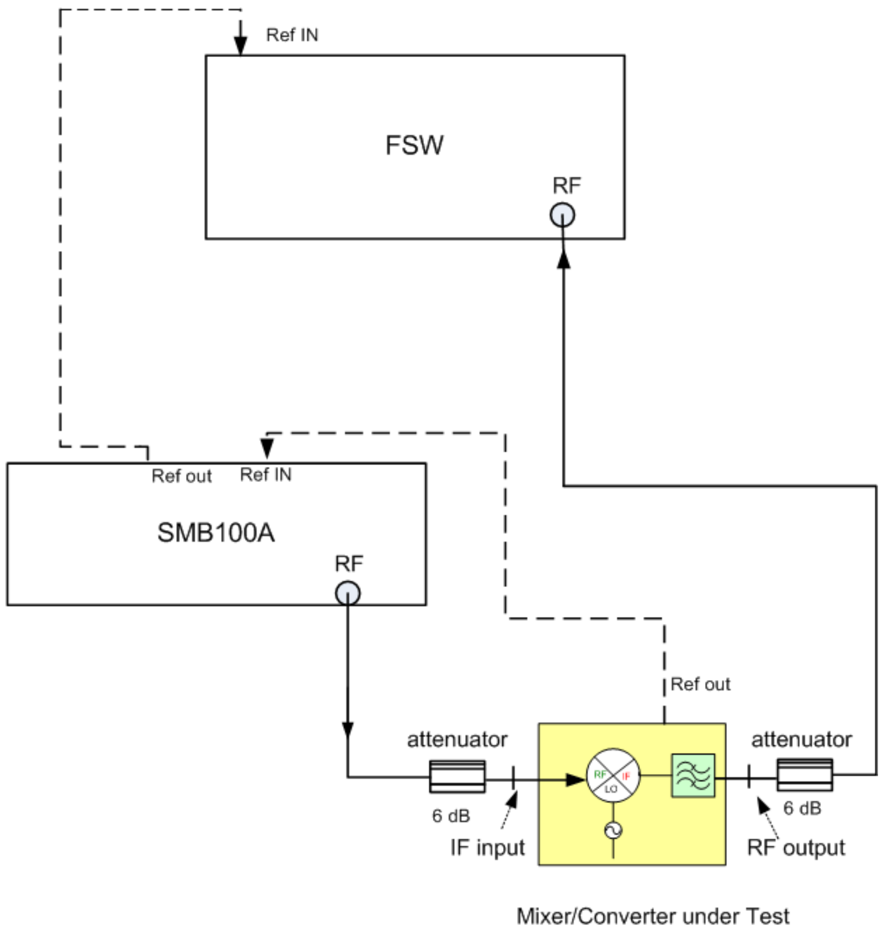


Figure 48: Test setup for phase noise measurement using FSW and SMB

The test setup as shown in Figure 48 is used for phase noise measurements. Setup the instruments like shown below. The measurement is done at IF 70 MHz. Synchronizing the R&S test instruments to the reference output of the converter under test is optional.

IF 70 MHz:

- ► **SMB:**
- ► *PRESET*
- ► *Frequency: 70 MHz; Level: -19dBm*
- ► *RF ON*

FSW:

- ► *MODE: Phase Noise* (Note: option Phase Noise R&S®FSW-K40 is needed)
- ► *Frequency: 5.98 GHz*
- ► On the right side of the FSW screen press *Phase Noise* and make the adjustments as shown in Figure 49:

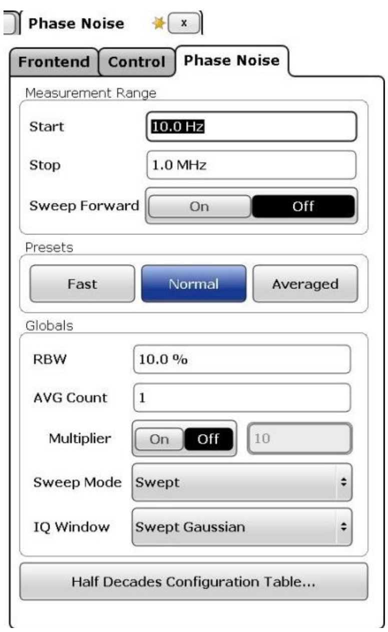


Figure 49: Settings for performing phase noise measurements

A typical phase noise plot of the FSW measured at the RF output of the converter under test at IF 70 MHz is shown in Figure 50:

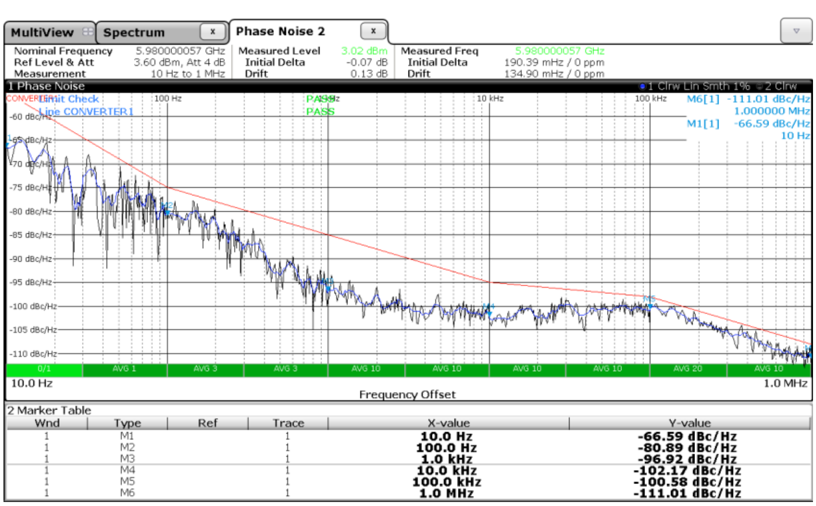


Figure 50: FSW Phase noise plot of converter under test at 70MHz IF

A limit line “converter1” is activated to get a pass/fail information. The marker table shows at the lower screen shows phase noise values at several frequency offsets.

Note: The specified phase noise values of both SMB and FSW are much lower than the measured values of the converter under test and therefore can be neglected. Below typical phase noise plots of an FSW for different RF frequencies:

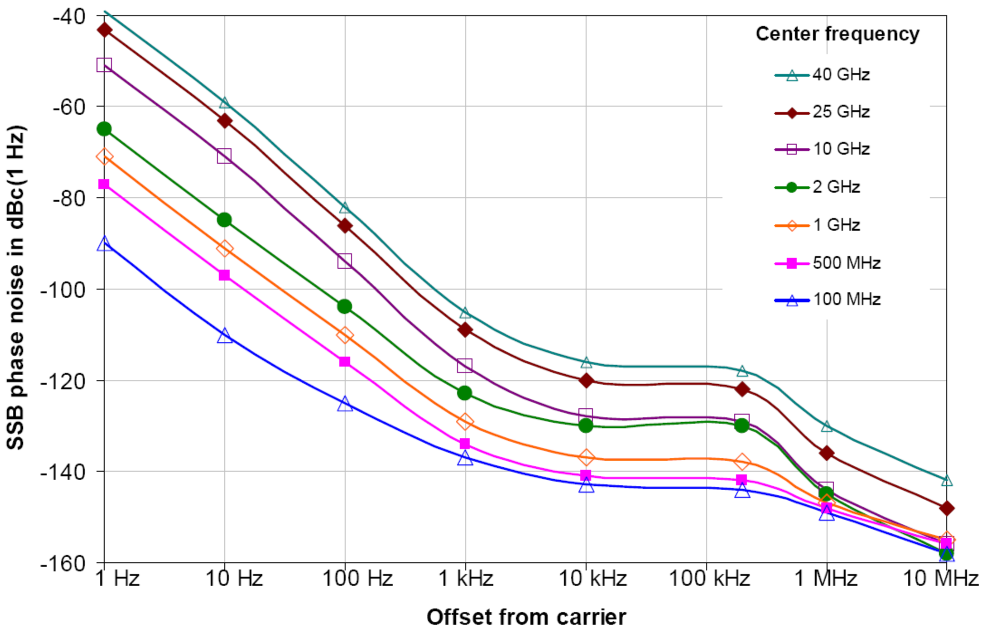


Figure 51: Typical phase noise plots of a FSW for different RF frequencies

5.11 Spurious Outputs Measurements

For measuring spurious outputs, the test setup in Figure 48 is used (same test setup as for phase noise measurements). Normally there are two types of spurious output signals defined for frequency up-converters:

- Signal related spurious signals specified in dBc (referred to level of output signal).
  For the measurement, a spurious free input signal at nominal power is input into the up-converter in this case.
- Signal independent spurious specified in dBm (absolute level). For the measurement, the input signal is switched off.

For the converter under test the signal related spurious are specified to -60 dBc for frequency offsets < 1MHz and -70 dBc for frequency offsets >= 1MHz. The signal independent spurious are specified to < - 70 dBm. A maximum offset of +-500 MHz is defined for the spurious measurement.

For the spurious measurement according to the converter specification, the spectrum emission mask function of the FSW is recommended which can handle both absolute and relative limits.

SMB configuration (for signal related spurious outputs)

- *Frequency: 70 MHz; Level: -19dBm*
- *RF ON*

FSW configuration:

- *Frequency: 5.98GHz*
- *Span: 1 GHz*
- *Ref Level Offset: 6 dB (6 dB attenuator in front of the FSW RF input)*
- *Adjust SMB level for indication of 0 dBm at the FSW*
- *MEAS: Spectrum Emission Mask*
- *TRACE:Trace1: Detector Type: Positive Peak*
- *Reference Range: Power Reference Typ Peak Power*
- *MEAS CONFIG: Sweep List*
- Edit a sweep list according to that of Figure 52 (insert 2 ranges, change start and stop frequencies of ranges, change bandwidths and set relative limits)

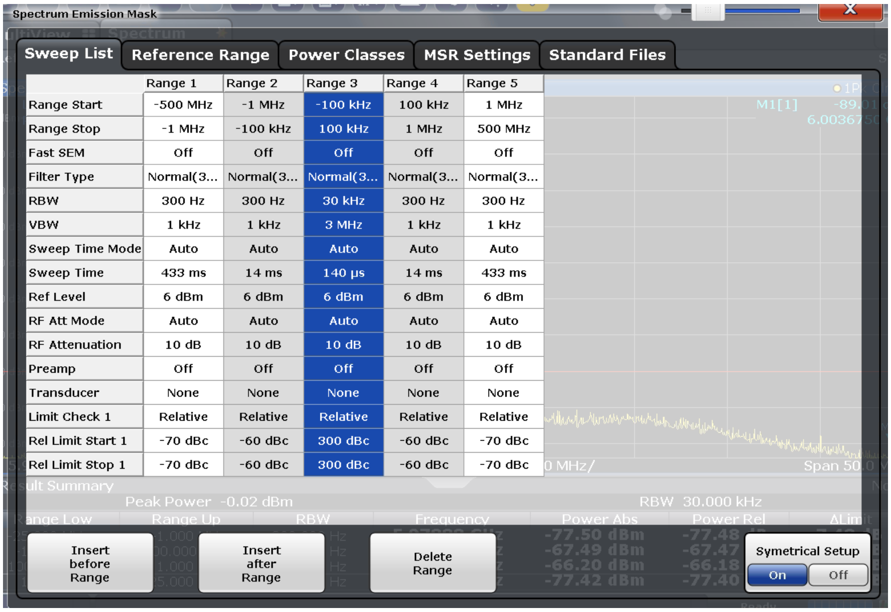


Figure 52: Sweep list for the spectrum emission mask for signal dependent spurious according to the converter specification.

► *Span: 50 MHz*

The FSW sweeps with 50 MHz span at a center frequency of 5.98 GHz and checks the peak spurious closer to the carrier according to the frequency dependent relative limits -60 dBc respectively -70 dBc, see Figure 53. The highest spurious levels in each range are displayed in the result summary. Additionally, spurious can be assigned by means of the markers.

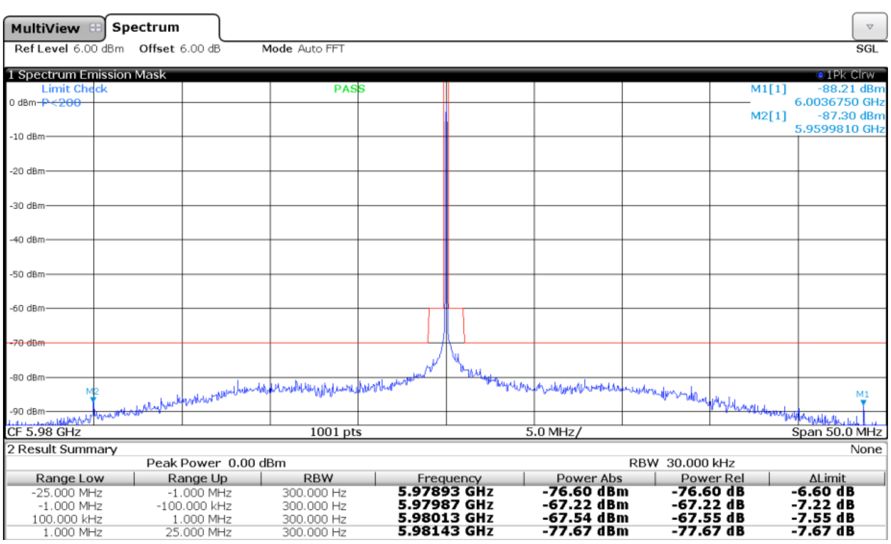


Figure 53: Signal dependent spurious measurement using the spectrum emission mask function of the FSW according to the converter specification (span = 50 MHz)

► Span: 1 GHz

The FSW sweeps now with 1 GHz span and checks also the spurious farer away from the carrier, see Figure 54.

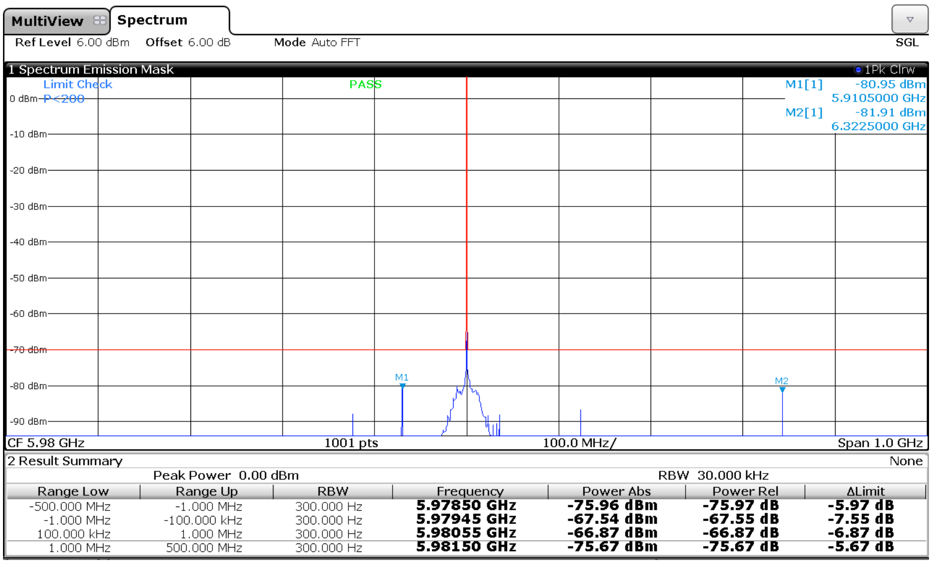


Figure 54: Signal dependent spurious measurement using the spectrum emission mask function of the FSW according to the converter specification (span = 1000 MHz).

To measure the signal independent spurious outputs, make the following settings on the instruments:

SMB:

► *RF OFF*

FSW:

► *MEAS CONFIG: Sweep List*

► *Edit the sweep list according to* Figure 55 (delete ranges, change limits to absolute values)

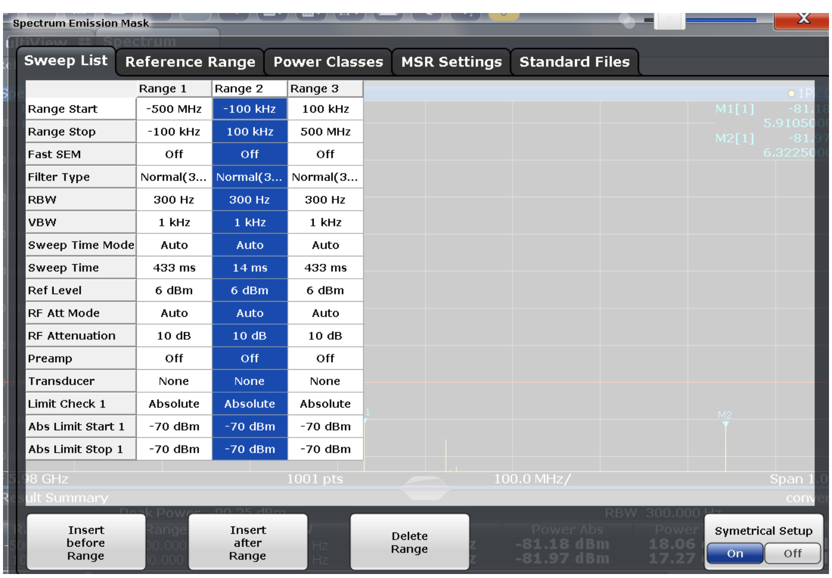


Figure 55: Sweep list for the spectrum emission mask for signal independent spurious according to the converter specification

Figure 56 shows the signal independent spurious of the converter under test measured and checked to the absolute limit -70 dBm. The markers were used to assign the highest spurious signal in the 1 GHz span.

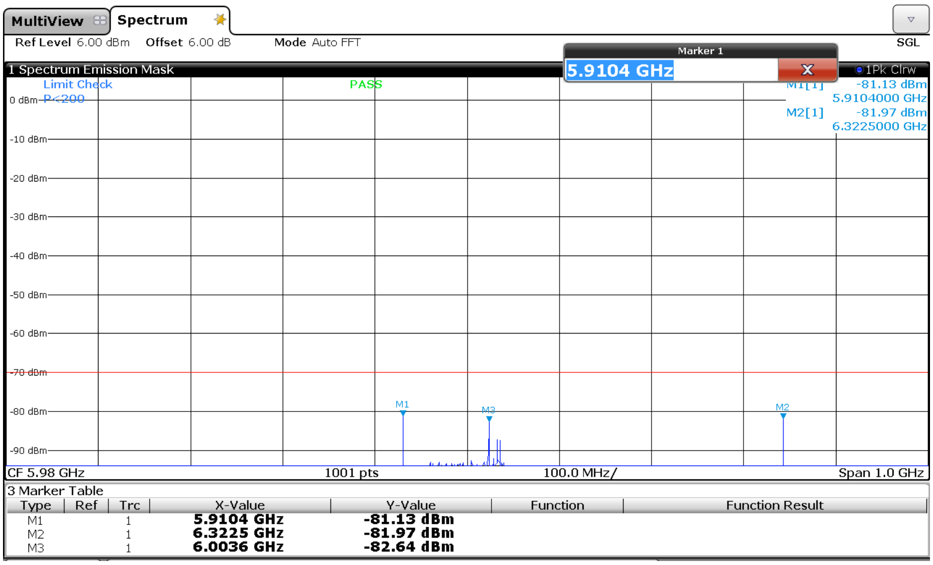


Figure 56: Signal independent spurious measurement of the converter under test using the spectrum emission mask function of the FSW.

6 Literature

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[8] W. M. GmbH, *Satellite Upconverter Type SCU/HCU User Manual.*

[9] ITU-R, *SM.1541-4 “Unwanted emissions in the out-of-band domain”.*

[10] ITU-R, *SM.329-12 “Unwanted emissions in the spurious domain”.*

7 Ordering Information

Vector Network Analyzer

Designation	Type	Order No.
Vector Network Analyzer, 300 KHz..8GHz, 4 Port	R&S®ZVA 8*	1145.1110.10
Embedded LO Mixer delay measurement	R&S®ZVA-K9	1311.3128.02
Frequency Conversion	R&S®ZVA-K4	1164.1863.02
Direct Generator/Receiver Access for the R&S® ZVA 8.	R&S®ZVA8-B16	1164.0209.08
Generator Step Attenuator Port 1	R&S®ZVA8-B21	1164.0009.02
Generator Step Attenuator Port 2	R&S®ZVA8-B22	1164.0015.02
Generator Step Attenuator Port 3	R&S®ZVA8-B23	1164.0021.02
Generator Step Attenuator Port 4	R&S®ZVA8-B24	1164.0038.02
Receiver Step Attenuator Port 1	R&S®ZVA8-B31	1164.0044.02
Receiver Step Attenuator Port 2	R&S®ZVA8-B32	1164.0050.02
Receiver Step Attenuator Port 3	R&S®ZVA8-B33	1164.0067.02
Receiver Step Attenuator Port 4	R&S®ZVA8-B34	1164.0073.02

Power Sensor

Designation	Type	Order No.
Three-Path Diode Sensor, 200 pW to 200 mW, 10 MHz to 18 GHz	R&S®NRP-Z21*	1137.6000.02
USB Adapter(Passive)	R&S®NRP-Z4	1146.8001.02

Signal Generator

Designation	Type	Order No.
RF and Microwave Signal Generator	R&S®SMB100A*	1406.6000.02
RF Path/Frequency Option 9 kHz to 1.1 GHz	R&S®SMB-B101	1407.2509.02
RF Path/Frequency Option 9 kHz to 6 GHz	R&S®SMB-B106	1407.2909.02

Signal and Spectrum Analyzer

Designation	Type	Order No.
Signal and spectrum analyzer 2 Hz to 8 GHz	R&S®FSW8*	1312.8000.08
Phase Noise Measurements	R&S®FSW-K40	1313.1397.02

* Other ZVA models, Power Sensors, Signal Generators and Signal and Spectrum Analyzers are suitable as well. More options are available. The instrument minimum configuration for this application is shown in the table. Please ask your local representative for a suitable configuration according to all your needs.

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