Pre-launch Testing of Satellite Payload

Application Note

Products:

- R&S®SMW200A
- R&S®FSW
- R&S®FSWP
- R&S®ZVA
- R&S®NRP
- R&S®NRP33SN-V
- R&S®RTO

Mission success in any satellite campaign greatly depends on test and measurement. At every stage of production, starting from the component design and eventually leading up to the final integration and launching phase, uncountable amount of tests are performed in order to ensure intended performance in all mission-critical aspects. Satellite test campaigns hence have a reputation of being time-consuming.

Rohde & Schwarz (R&S) provides very fast T&M equipment as one answer to reduce test time. Novel instrument functions decrease measurement time and calibration efforts dramatically. The industry-leading accuracy of R&S equipment described in this paper raises test yield and is a further means to make payload test more cost effective and reliable.

This application note addresses system- and manufacturing engineers. It focuses on CCR/CATR and TVAC RF tests of components and functional modules as well as complete satellite communication payloads at pre-launch level.

A parallel paper is available for after-launch RF tests and in-orbit maintenance measurements using R&S instruments.

Please find up to date document on our homepage
http://www.rohde-schwarz.com/appnote/1MA223
Application Note: On-Orbit Satellite RF Measurements
http://www.rohde-schwarz.com/appnote/1MA263

Application Note
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Abstract

As of June 2016, there are 1419 operational satellites in space. Half of which are serving as commercial communication satellites [1]. The worldwide satellite industry growth outpaces worldwide economic growth. Current growth is progressive and signifies the future placement of even more orders for development and manufacturing of new satellites [2]. Successful design of a satellite requires a lot of testing done at every stage of the development process.

Satellite links are indispensable in sound and TV broadcasting and in worldwide communications via telephone, internet, or mobile radio. Smooth, reliable and round-the-clock operation has to be ensured for commercial to the same extent as governmental systems.

A satellite is built in stages, and much effort is put into trying to correlate data drawn at various manufacturing stages. Tight requirements play heavily into permissible test margins; hence measurement uncertainty and repeatability are a prime concern throughout the manufacturing process. This leads people involved to demand the highest performance equipment and exactitude to calibration of the test environment right up to the device under test, making calibration another test time driver increasing cost of test.

After launch into space, fixing of a satellite may not be possible. Reliability and design margin considerations drive cost of test and demand high performance test equipment.

Following component and sub-system test, the Payload and Satellite Integration and Test (PSIT) includes the stages Near Field Range, Compact Range, Payload Integration, Integrated Payload Test, Payload Thermal Vacuum, Integrated Spacecraft Test, Vibe Testing & Spacecraft Thermal Vacuum Test (SCTV or "Shake & Bake"), Final Integrated Spacecraft Test (FIST), and Final Pre-Launch Test of the satellite after mating with the Launch Vehicle.

Addressing the RF-related aspects of the above manufacturing sequence, this paper, in addition to the test and measurement discussions, includes an in depth description of wide-band multi-tone test signal generation. Test signals of up to 2 GHz bandwidth are used to emulate a full spectrum of traffic and interference signals in order to determine a system's maximum linear operational range. Signal linearization and correction techniques allow achieving an amplitude flatness of ± 0.3 dB over a 2 GHz bandwidth.

Due to targeted scope of this application note, not all of the prevailing tests can be discussed here. In this paper, emphasis has been put on a number a critical pre-launch payload tests. In-orbit tests are described in a separate application note [3].

Abbreviations

The following abbreviations are used in this application note for Rohde & Schwarz products:

- The R&S®SMW200A vector signal generator is referred to as SMW
- The R&S®SGT100A SGMA vector RF source is referred to as SGT
- The R&S®SGS100A SGMA vector RF source is referred to as SGS
- The R&S®SGU100A SGMA up-converter is referred to as SGU
- The R&S®SGMA-GUI PC Software is referred to as SGMA-GUI
- The R&S®FSW signal and spectrum analyzer is referred to as FSW
- The R&S®FSWP Phase Noise Analyzer and VCO Tester is referred to as FSWP
- The R&S®ZNBT vector network analyzer is referred to as ZNBT
- The R&S®ZVT vector network analyzer is referred to as ZVT
- The R&S®ZVA vector network analyzer is referred to as ZVA
- The R&S®RTO digital oscilloscope is referred to as RTO
- The R&S®TS6710 automatic TRM test system is referred to as TS6710
- The R&S®TSMW universal radio network analyzer is referred to as TSMW
- The R&S®AFQ100B UWB Signal and I/Q Modulation Generator is referred to as AFQ
- The R&S®NRPxxS/SN Three-Path Diode Power Sensor is referred to as NRPxxS/SN
- The R&S®NRP2 Power Meter is referred to as NRP2
- The R&S®NRP-Zxx Three-Path Diode Power Sensor is referred to as NRP

1 Communication Satellite Structure

A communication satellite typically consists of two main function blocks:

1. The spacecraft bus or service module
2. The communication payload module

1. The service module consists of the following subsystems:

- The **structural subsystem** is the mechanical base of a satellite (SAT). This base enables the satellite to survive the stress and vibration during launching, withhold the structural integrity and stabilize the satellite in space. The structural subsystem also protects the satellite from extreme variations in temperature and damage from micro orbital debris and micrometeoroids.
- The **power subsystem** includes solar panels for converting the solar energy into electrical power. It performs power regulation and distribution functions. The power subsystem consists of batteries that store power, and ensures that power will be supplied to the satellite when it flies through the Earth's shadow region.
- The **thermal control subsystem** protects the electronic equipment installed on the satellite from the extreme temperature variations caused by travel from darkness into sun's exposure or temperature gradient caused by simultaneous intense sunlight on one and complete shade on the other side of the SAT body.
- The **telemetry subsystem** is responsible for monitoring the on-board equipment operations. In addition, it also transmits the equipment operational data to the earth control station and receives the commands from the earth control station in order to perform equipment operation adjustments.

  The **attitude and orbit control** subsystem mainly depends on sensors to measure the orientation of the vehicle in space. The inflight software has the ability to control the altitude of the satellite in flight by providing directional control signals to actuators and thrusters. This enables the satellite to stay in the correct orbital position. In addition, the satellite's antennas are adjusted to point in the correct directions.

2. Communication payload

Transponders are one of the major modules in the communication payload. A transponder is designed to:

- Receive uplink radio signals originating from earth satellite transmission stations.
- Amplify received radio frequency (RF) signals.
- Reorganize the input signals falling on the receive antenna of the satellite and direct the output signals through input/output signal multiplexers to the appropriate downlink antennas for retransmission to earth satellite receiving stations.

2 Satellite Payload Architectures

Most communication satellites operate as a radio relay containing multiple transponders having channel bandwidths of tens of Megahertz going up to multiple Gigahertz. The two general payload structures commonly used are described in this chapter.

1. Bent-Pipe Transponders

Most bent-pipe transponders follow the concept, where signals from the earth station are amplified in the satellite and the uplink frequency is converted to the downlink RF frequency and sent back to earth.

Fig. 2-1 shows the structure of the bent pipe transponder used in satellite payloads.

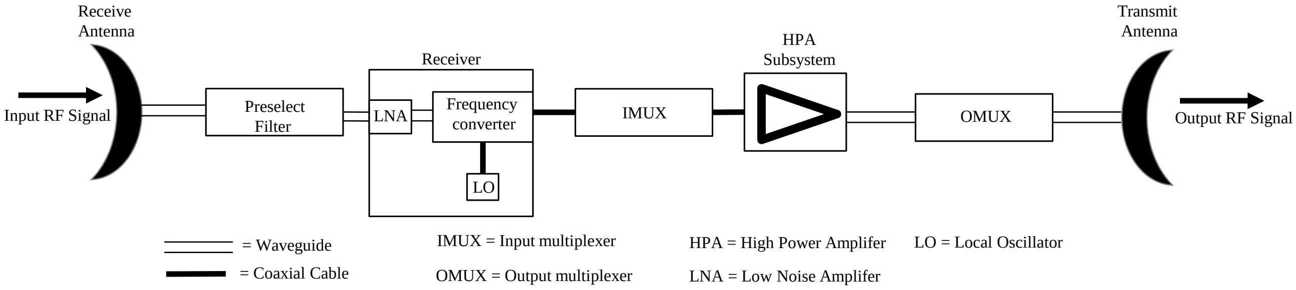


Fig. 2-1: Bent-Pipe satellite payload transponder structure (2)

2. Regenerative Transponders

Alternatively, to the bent-pipe payloads, regenerative satellites use the on-board processing concept. The received signal in the satellite is demodulated, decoded, in some cases error correction schemes applied, re-encoded, modulated and converted to downlink carrier frequency before transmitting the signal back to earth. These kind of transponders are called regenerative satellite payload transponders. These systems have many advantages but are typically more complex than the bent-pipe transponders.

Fig. 2-2 shows the structure of the complex regenerative satellite payload transponders used in modern satellites.

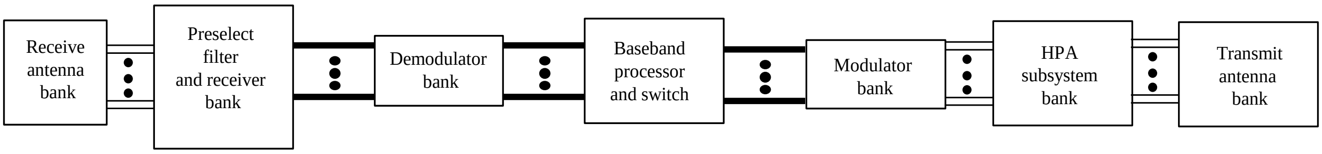
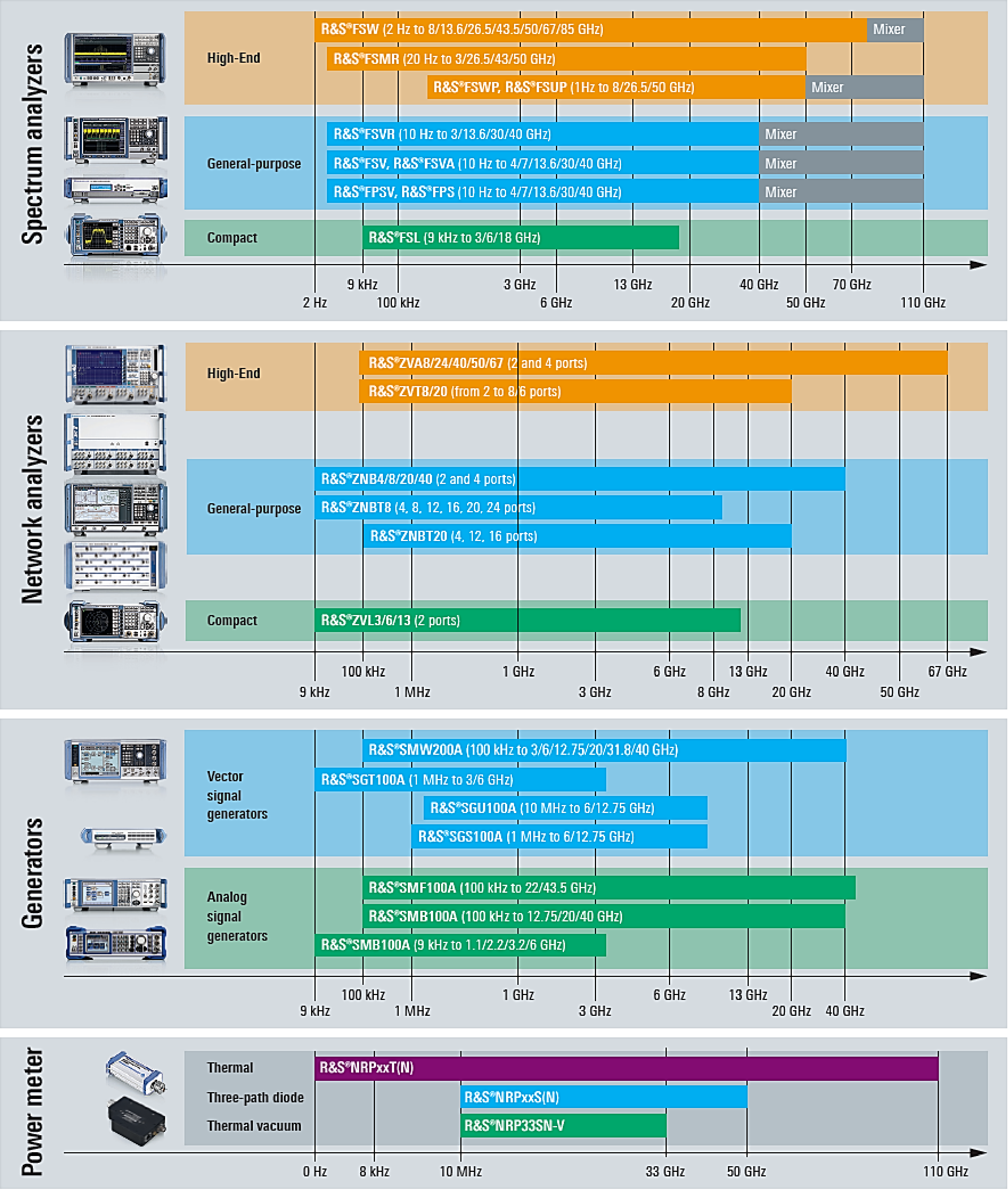


Fig. 2-2: Regenerative satellite payload transponder structure (2)

3 R&S Instruments for Satellite Testing

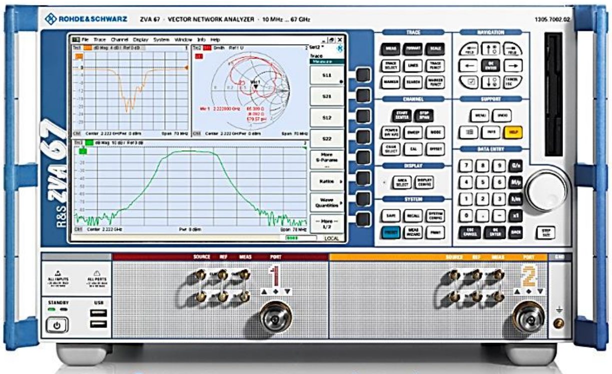


4 R&S Featured Products for Payload Testing

The following equipment has been used for this application note:

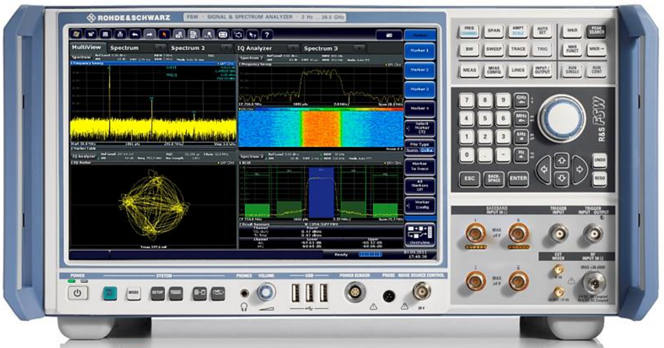
R&S®SMW200A Vector Signal Generator

- Frequency range from 100 kHz to 3 GHz, 6 GHz, 12.75 GHz, 20 GHz, 31.8 GHz or 40 GHz
- Optional second RF path with 100 kHz up to 3 GHz, 6 GHz, 12.75 GHz or 20 GHz
- Easy generation of complex signals
- I/Q modulator with up to 2 GHz RF modulation bandwidth
- Adaptive GUI for overview of both simple and complex scenarios
- SCPI macro recorder and code generator for generating executable remote control code from manual operating steps (for MATLAB®, CVI, etc.)
- Customizing of instrument to accommodate virtually every application
- Software upgrades possible at any time, simple and quick activation via key codes



R&S®ZVA Vector Network Analyzer

- Frequency Range 300 kHz to 8 GHz (R&S®ZVA8), 10 MHz to 24/40/50/67/110 GHz (R&S®ZVA24/40/50/67/110
- Phase and group delay measurements on mixers with and without LO access
- Long Distance Group Delay Measurement
- Linear and nonlinear amplifier and mixer measurements
- Noise figure measurements
- Pulse profile measurements with 12.5 ns resolution
- True differential measurements for reliable characterization of active devices with balanced ports
- Short measurement times due to fast synthesizers, wide IF bandwidths and high dynamic range
- Direct access to the generators and receivers for 30 dBm output power and 150 dB dynamic range
- First VNA with IF bandwidths up to 30 MHz for pulsed measurements on amplifiers and mixers



R&S®FSW Signal and Spectrum Analyzer

- Frequency range from 2 Hz to 8/13.6/26.5/43.5/50/67/85 GHz
- Low phase noise of –137 dBc (1 Hz) at 10 kHz offset (1 GHz carrier)
- –88 dBc dynamic range (with noise cancellation)
- Up to 2 GHz analysis bandwidth
- Real-time analysis up to 160 MHz bandwidth
- Multiple measurement applications can be run and displayed in parallel
- Resolution bandwidth from 1 Hz to 10 MHz, 80 MHz

R&S®NRP33S/SN

Frequency Range from 10MHz to 50GHz

- 10 000 triggered measurements/s
- More than 50 000 readings/s
- Remote monitoring via LAN over any distance
- 93 dB dynamic range
- Built-in trigger I/O port
- Intelligent averaging function minimizes measurement time
- Minimizing measurement uncertainty
- Three-path diode power sensors

R&S®NRP33SN-V

- Frequency Range from 10MHz to 33GHz
- Specially designed for TVAC applications
- Measurement range: 100 pW to 200 mW
- Frequency range: 10 MHz to 33 GHz
- 3.5 mm (m) connector

5 Environmental Testing

Most of the satellite characterization testing is initially performed at the component and sub-system level. As a hard requirement for ensuring mission success, a satellite is required to go through a series of different environmental stress testing. These environmental testing also known as test-like-you-fly, and a serves a crucial part of the satellite integration and assembly process.

The whole spacecraft, including the launch vehicle and the payload, has to undergo thermal stress testing. The satellite is placed inside the Thermal Vacuum Chamber (TVAC) in one part of test cycle and tested for multiple weeks in emulated extreme conditions. This helps to demonstrate the activation and performance of the satellite when in space.

Prior to launch, the Compensated Compact Range (CCR) or Compact Antenna Test Range (CATR) testing is carried out. The CCR/CATR testing is the primary reference or benchmark for the end-to-end link margin test. Obviously, the importance of the other environmental testing (i.e. acoustic testing, vibration testing and shock testing) cannot be stressed enough. However, the scope of this application does not extend to non-RF topics.

5.1 Compact Range Testing

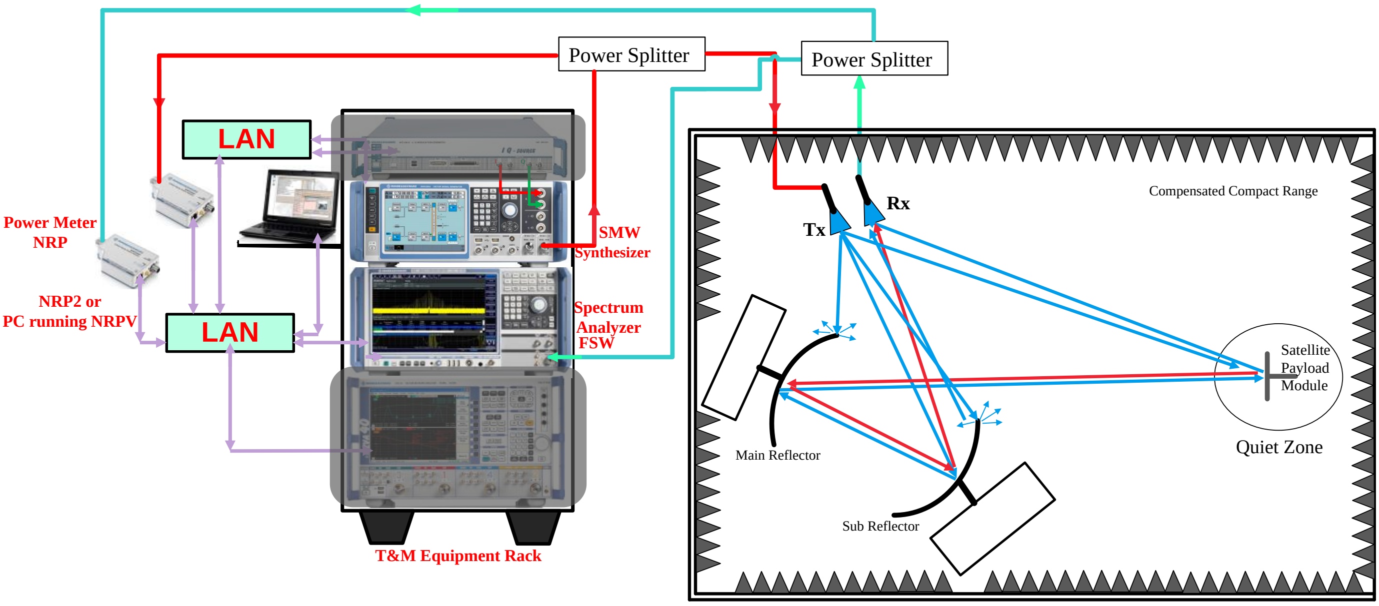


Fig. 5-1: CCR/CATR Compact Range Test for radiated test of payload module; based on exact application requirements, a Vector Network Analyzer may alternatively be used. The reflectors serve to fully illuminate the satellite receive antenna in the short distances. Greyed out equipment is used in only some of the required CCR/CATR tests

Tests performed are Antenna Patterns, EIRP (Equivalent Isotropic Radiated Power), PIM (Passive Intermodulation, to verify the waveguide connection to the antenna), Gain Transfer, NPR (Noise Power Ratio), Carrier to Noise or Noise Temperature, Amplitude Frequency Response, Group Delay.

Test and measurement (T&M) equipment for space industry applications are usually driven to the limit. Large spatial layout and the complexity of test setups used eats away on test margins, hence leaving only very little permissible uncertainty to the T&M gear. CCR/CATR testing sets the industry standard for over-the-air testing of communication satellites because of the fact that only compact ranges are able to facilitate real-time closed loop testing. In addition, CCR/CATR provides great accuracy for T&M, especially for the state-of-art multi-beam and multi-feed satellites. The modern ranges are designed to provide a large quiet zone diameter and depth.

Fig. 5-1 shows a possible setup of the radiated satellite payload testing inside a CCR/CATR. The test range consists of a main reflector, a sub reflector, a transmit (Tx) range feed antenna and a receive (Rx) range antenna. Generation of stimulus signals and analysis of received signals is generally performed outside the chamber. Depending on individual test requirements, a VNA, or as shown here, a combination of VSG and Signal Analyzer may be used.

5.2 Thermal Vacuum Chamber (TVAC) Measurement

Satellites in outer space and spacecraft with payloads that are travelling to space must survive in that environment. This determines the qualification and verification process for components and subsystems used in the satellite. In-space conditions (open space and sun exposure) can be re-created inside a Thermal Vacuum Chamber (TVAC). The chambers are designed to simulate customized atmospheric conditions for altitude (temperature and pressure) testing.

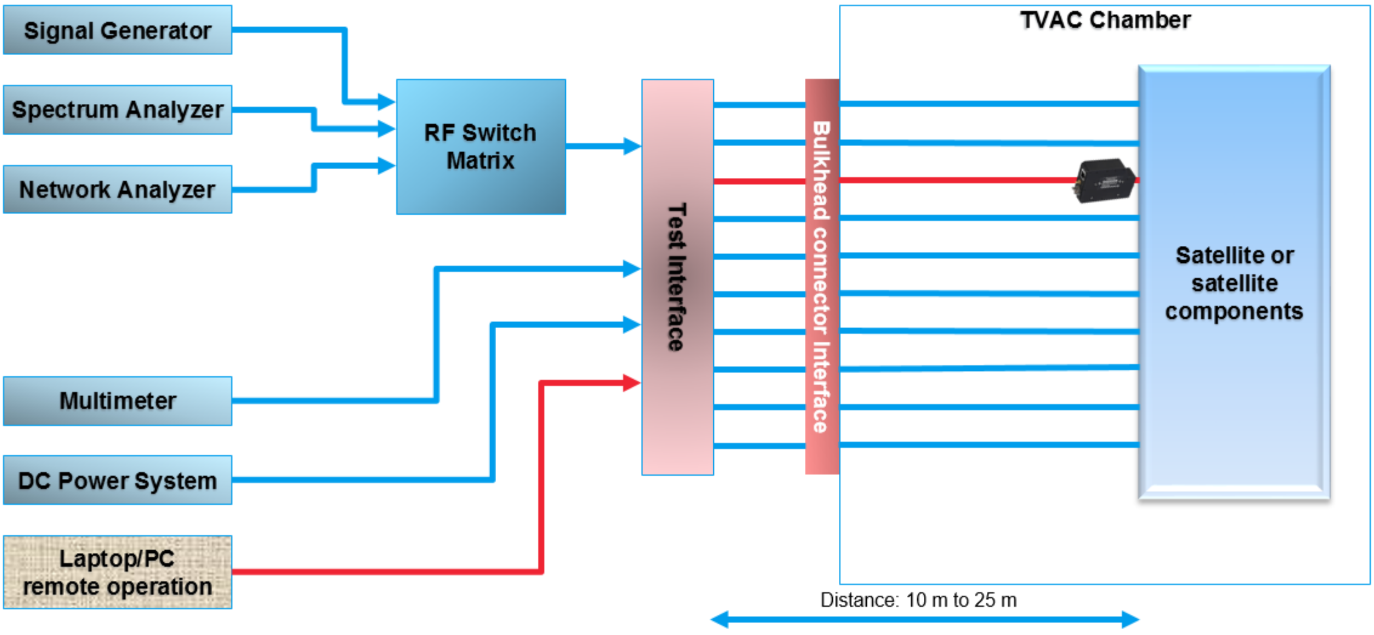


Fig. 5-2: Possible TVAC test configuration with NRP33SN-V power sensor connected directly to the test object inside the Chamber

Satellites undergo continual temperature variations because of their spin and path in earth's orbit. Temperature variation of satellite components in space between approx. -170°C to +123°C per temperature cycle has been observed in the Low Earth Orbit (LEO) [12]. Thermal cycling tests performed in the TVAC are important to verify choice of materials and processes.

Thermal cycling tests ("test like you fly") are performed to mimic the real conditions a payload will be facing during its launch, cruise, and mission. Temperature is not altered continuously. Typically, discrete steps are used; the dwell times are in the range of several hours. A total of 100 cycles are not uncommon. This means a DUT may spend several weeks within a TVAC to guarantee optimal performance.

The thermal test objective specifies requirements on the type of thermal testing (typically involves thermal cycling, thermal vacuum testing, thermal balance testing or thermal burn-in testing) that would be suitable for thermal characterization of the test object.

Until now power sensors could not be operated inside the chamber and long RF cables were required to measure RF power at the outside of the chamber. The increasing demand for highly accurate and reliable power measurements directly on the DUT, i.e. inside the TVAC chamber, requires a new approach. The power sensors must therefore not only function in a high vacuum but also be able to withstand certain temperature fluctuations.

The NRP33SN-V TVAC-compliant power sensor is specially designed for the operation in TVAC chambers. Since all the components of the power sensor are already baked in a vacuum chamber during the production process, so outgassing of volatile organic compounds (VOC) is reduced to a minimum. In addition, venting holes in the housing of the sensor ensure pressure equalization between the inside of the sensor and the environment.

6 R&S Equipment for Satellite Payload Characterization

Since the start of the space age in 1957, there have been many different types of satellite and perhaps as many manufacturing campaigns. Over the years, test and measurement strategies and techniques have evolved a great deal. Given the high (opportunity) cost of a mission, T&M techniques and gear were mostly allowed to be state of the art or even cutting edge. Despite this, certain "house practices" mark and differentiate every player in the space business. Obviously, there are multiple ways how each of the measurements can be performed and most satellite manufacturers have developed specialized T&M methods that fits their need best. This section does not aim to compete, but rather describes the most common T&M setups using Rohde & Schwarz test equipment, and shows operational advantages of the equipment offered by Rohde & Schwarz for satellite payload testing. Please contact your representative for advice on integration into your individual test environment.

6.1 Accessory Characterization

Accessories that need to be evaluated for their influence of the test setup are i.e. multiple uplink and downlink cables (so-called "pig tails" that go from the TVAC chamber bulk head to the space craft test coupler), and space craft test coupler characterization for insertion loss, coupling loss, directivity and port match.

These tests are commonly performed using a VNA with best uncertainty and repeatability. That said, these cable calibrations could also be done with a signal Generator/ Spectrum Analyzer referenced to a power meter,

Cable loss characterization is quite a fundamental part of the test and measurement of satellite payloads. In order to characterize very long (~30 m) high frequency cables that connect the test equipment with the payload placed inside the TVAC, a system error correction (SEC) needs to be performed first.

Prerequisites
• Three hours storage at ambient temperature followed by 30 minutes warm-up operation
• Specified environmental conditions met
• Recommended calibration interval adhered to
• All internal automatic adjustments performed on all related instruments, if applicable

Fig. 6-1: 4-Port ZVA goes from 10 MHz up to 110 GHz

In particular, for multi-port measurements with a higher number of ports, it is highly recommended to use a calibration unit instead of single calibration standards to reduce the time and to avoid mistakes. To perform a full n-port calibration by a calibration unit with a lower number of ports, it is obvious that the calibration unit has to be connected to each physical port of the VNA. The vector network analyzer provides an optimized connection proposal to reduce the number of THRU connections. Hence, the required number of reconnections will also be reduced. Instead of measuring the THRU connection between each individual port, the error correction data of the missing transmissions are calculated based on the available system error correction data.

The total number of connections is related to the used ports of the vector network analyzer, the ports of the calibration unit and the selected calibration type. For a segmented sweep, the n-port calibration procedure includes each segment. It is not necessary to calibrate the segments individually. The number of ports which can be calibrated e.g. by a two port calibration unit is only limited by the physical ports of the vector network analyzer or the connected switch matrix. A detailed systematic calibration procedure is described in the Application Note 1EZ70 (Multi-Port calibration by using a two-port calibration unit) [8].

6.2 Signal Generation Setup

Signal generation is one of the most important part of satellite payload testing. Complex modulation schemes are used for today's satellite signals. Bandwidth (BW) requirements of these modulated IQ signals normally range from 40 MHz, 80 MHz, 160 MHz, 320 MHz, 500 MHz, 1 GHz and 2 GHz at center frequencies up to 40 GHz.

Bandwidths up to 2 GHz can be addressed with the internal ARB of the SMW200A VSG as shown in Fig. 6-2 . SMW-internal functions allow easy multicarrier signal generation and include a function to generate a stimulus with minimal crest factor.

However, external Arbitrary Waveform generators are typically used for generating signals exceeding bandwidths of 160 MHz, i.e. the AFQ100B can generate IQ signals with up to 528 MHz. Such a setup requires an external software for correction of the stimulus. In Fig. 6-3 the FSW is used for amplitude compensation of such a signal.

Fig. 6-2: One RF path 40 GHz SMW200A. The VSG is fully compensated and does not need further amplitude correction.

Using the SMW as VSG with the combination of an external Arbitrary Waveform Generator (ARB) and NPR software, wideband vector modulated signals (up to 2 GHz BW) can be generated at frequencies up to K_a band limits. The SMW is also capable of generating up to 2GHz bandwidth wide vector modulated signals using its internal Arbitrary Waveform Generator. However, please note that throughout this application note the arrangement of Fig. 6-3 is used, even when a CW signal is generated for certain measurements. This is intended for consistency purpose. In case a CW signal is used, the analog IQ input of the SMW needs to be switched off.

The ARB is connected via LAN to a PC that is running the NPR software in the background. The RF output of the SMW can feed either to the FSW for signal correction and calibration of the generated signal or to the DUT for testing.

Please note that test signal generation using the NPR is only shown for demonstration purposes. The intention is to show the functionality of Rohde & Schwarz equipment for such high-end applications. NPR is not intended as a replacement for a project's specific signal generation software.

Prerequisites

The cables from the IQ output of an external ARB to the IQ input of the vector signal generator (SMW) must be of the same length and the length of the cables should be as short as possible. In case of differential IQ being used, all four cables must be the same length. If the BW of the generated signal is more than 1 GHz, then the differential IQ is no longer an option, so the unused I- and the Q- outputs of the external ARB must be properly terminated using 50 Ω terminations.

The SMW supports different types of signal for various measurement cases:

- Multi-carrier CW - out of band distortion, C3IM, group delay measurements, and payload channel loading
- Noise Power Ratio - in band distortion for system level
- Ramp Sweep - Gain Transfer, AM/AM, AM/PM vs drive
- User-defined Custom Modulation - QPSK, PSK and FSK to simulate channel loading

6.2.1 Wideband signal generation using External Arbitrary Waveform Generator

In order to achieve a high degree of amplitude flatness of the generated 1 GHz or 2 GHz bandwidth (BW) signal over the full spectrum at 40 GHz RF, the signal needs to be corrected. Even though the flatness of the signal depends on the performance of the external ARB. Fig. 6-3 shows setup for the 2 GHz signal generation and correction.

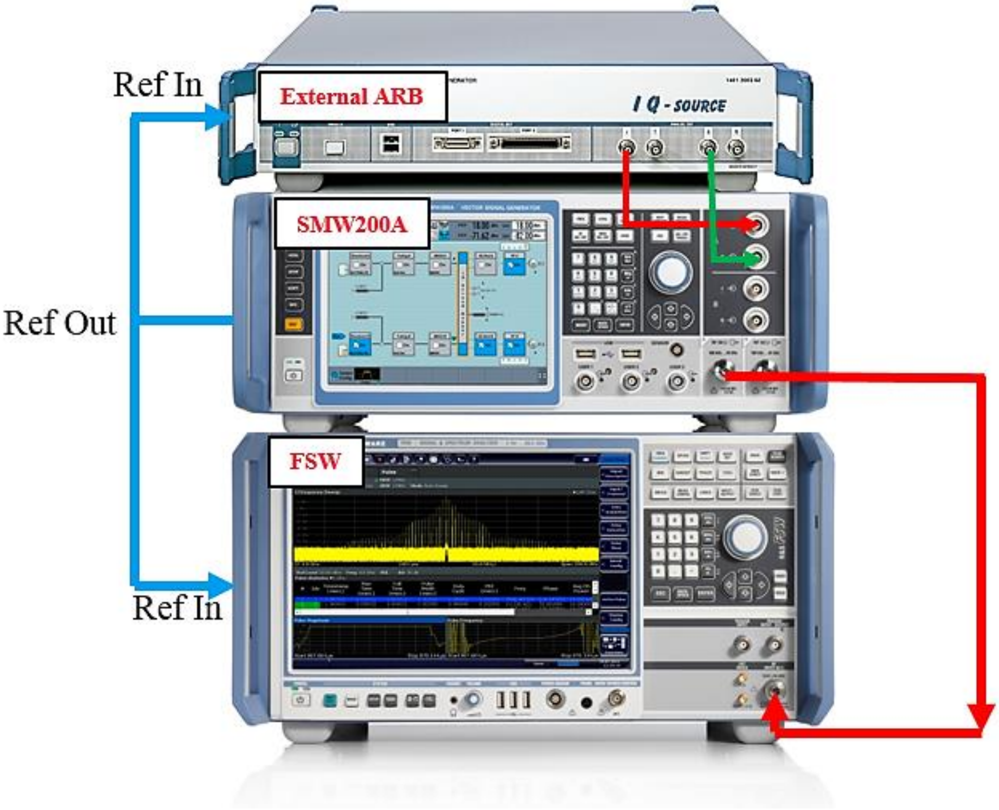
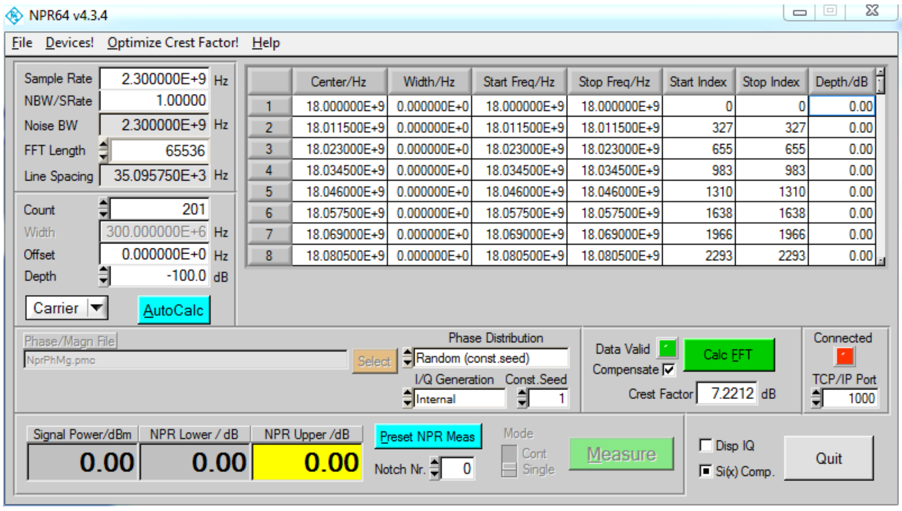


Fig. 6-3: Instrument connection for signal correction of the test stimulus. The ARB is set to differential IQ signal output in this example.

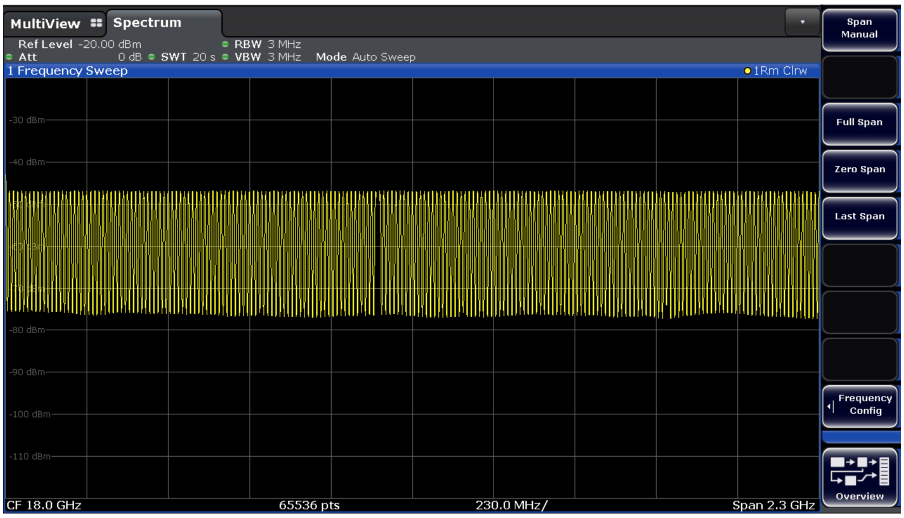


Sample Rate 2.300000E+9 Hz
NBW/SRate 1.00000
Noise BW 2.300000E+9 Hz
FFT Length 65536
Line Spacing 35.095750E+3 Hz
Count 201
Width 300.000000E+6 Hz
Offset 0.000000E+0 Hz
Depth -100.0 dB

	Center/Hz	Width/Hz	Start Freq/Hz	Stop Freq/Hz	Start Index	Stop Index	Depth/dB
1	18.000000E+9	0.000000E+0	18.000000E+9	18.000000E+9	0	0	0.00
2	18.011500E+9	0.000000E+0	18.011500E+9	18.011500E+9	327	327	0.00
3	18.023000E+9	0.000000E+0	18.023000E+9	18.023000E+9	655	655	0.00
4	18.034500E+9	0.000000E+0	18.034500E+9	18.034500E+9	983	983	0.00
5	18.046000E+9	0.000000E+0	18.046000E+9	18.046000E+9	1310	1310	0.00
6	18.057500E+9	0.000000E+0	18.057500E+9	18.057500E+9	1638	1638	0.00
7	18.069000E+9	0.000000E+0	18.069000E+9	18.069000E+9	1966	1966	0.00
8	18.080500E+9	0.000000E+0	18.080500E+9	18.080500E+9	2293	2293	0.00

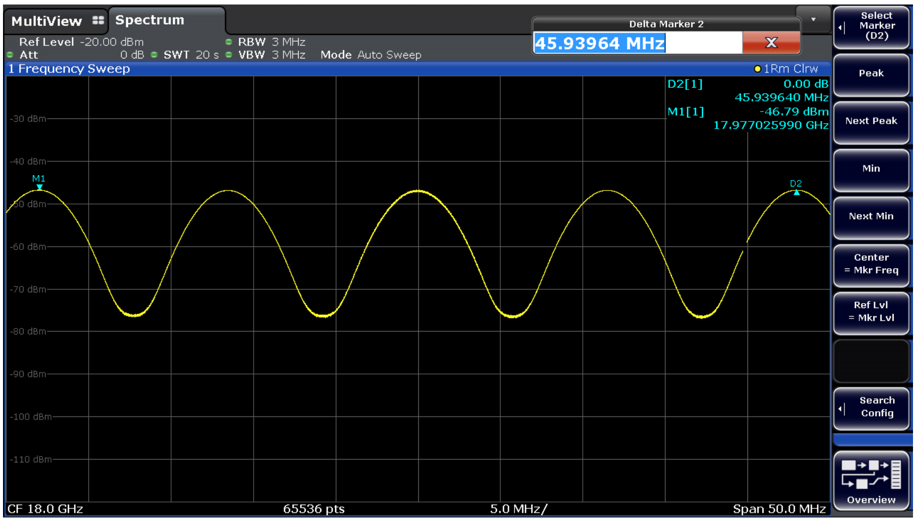
Phase/Magn File NprPhMg.pmc
Phase Distribution Random (const.seed)
I/Q Generation Internal
Const.Seed 1
Data Valid
Compensate ☑
Crest Factor 7.2212 dB
Connected
TCP/IP Port 1000
Signal Power/dBm 0.00
NPR Lower / dB 0.00
NPR Upper /dB 0.00
Notch Nr. 0
Mode Cont Single
☐ Disp IQ
☒ Si(x) Comp.

Fig. 6-4: Parameter configuration with NPR demo software



Ref Level -20.00 dBm
Att 0 dB
SWT 20 s
RBW 3 MHz
VBW 3 MHz
Mode Auto Sweep

Fig. 6-5: 2 GHz wide multi-carrier signal with 201 tones after magnitude correction at 18 GHz



Ref Level -20.00 dBm
Att 0 dB
SWT 20 s
RBW 3 MHz
VBW 3 MHz
Mode Auto Sweep

Delta Marker 2: 45.93964 MHz

D2[1] 0.00 dB
45.939640 MHz
M1[1] -46.79 dBm
17.977025990 GHz

Fig. 6-6: 2 GHz wide multi-carrier signal with 201 tones after magnitude correction (Span 50 MHz). For small spans, there is practically no amplitude variations between carriers (see D2[1] marker).

6.2.2 Signal generation using internal ARB of R&S®SMW200A

- The generation a two-tone signal can be done using the internal ARB of the SMW from the baseband multicarrier option as shown in Fig. 6-8. Adjust the RF frequency of path A to 33 GHz and the power level to 0 dBm.

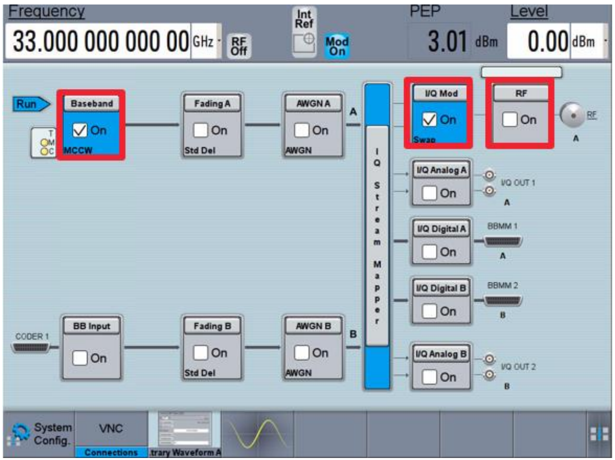
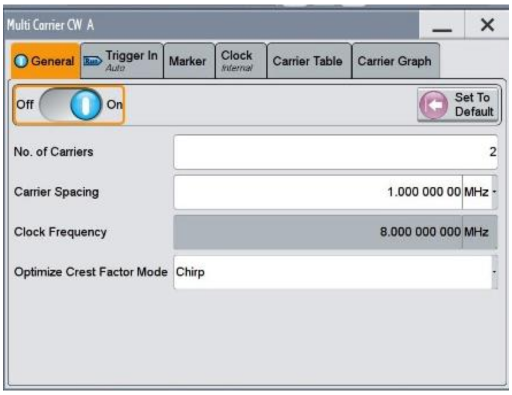


Fig. 6-7: Two tone signal generation on the R&S®SMW200A

- Next, make the adjustments as shown in Fig. 6-8.



No. of Carriers: 2

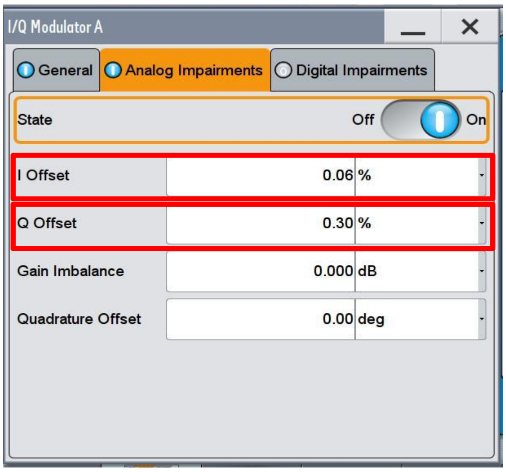
Carrier Spacing: 1.000 000 00 MHz

Clock Frequency: 8.000 000 000 MHz

Optimize Crest Factor Mode: Chirp

Fig. 6-8: Two tone signal configuration on the R&S®SMW200A

- After the signal is generated, the carrier feed through at the center frequency is compensated. The carrier feed through is introduced when the I and Q signals are not perfectly orthogonal to each other. This issue can easily be compensated by adjusting the I offset and Q offset in the analog impairment menu as shown in Fig. 6-9.



State Off ● On

I Offset 0.06 %

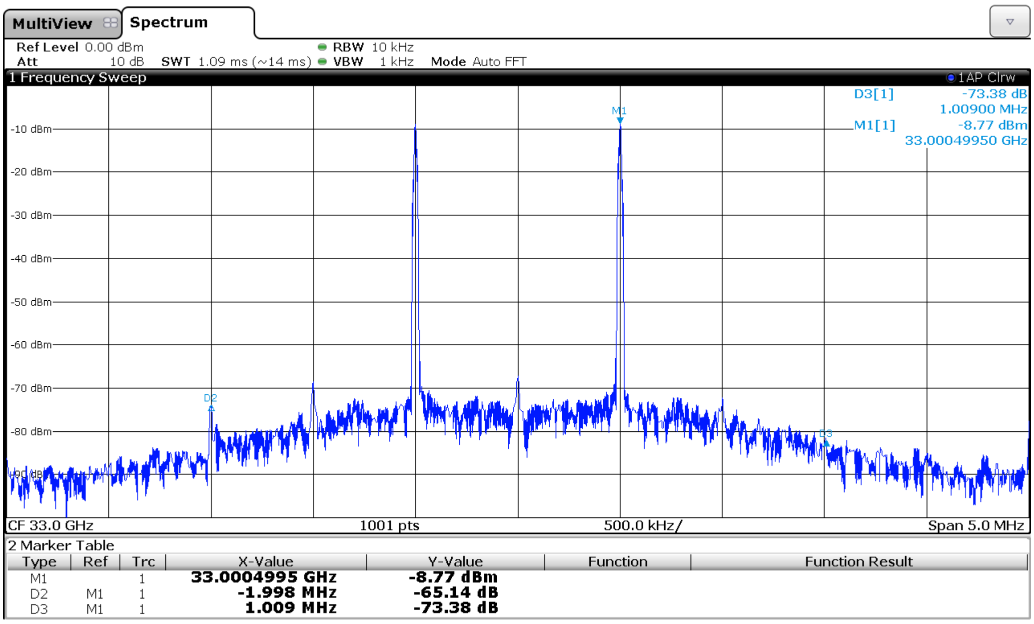
Q Offset 0.30 %

Gain Imbalance 0.000 dB

Quadrature Offset 0.00 deg

Fig. 6-9: Analog impairment to compensate for the carrier feed through

- Press RF ON (Fig. 6-7)



Ref Level 0.00 dBm
Att 10 dB SWT 1.09 ms (~14 ms) RBW 10 kHz VBW 1 kHz Mode Auto FFT

D3[1] -73.38 dB
1.00900 MHz
M1[1] -8.77 dBm
33.00049950 GHz

2 Marker Table

Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
M1		1	**33.0004995 GHz**	**-8.77 dBm**		
D2	M1	1	**-1.998 MHz**	**-65.14 dB**		
D3	M1	1	**1.009 MHz**	**-73.38 dB**		

Fig. 6-10: Two-tone signal generation at 33 GHz using the SMW

Fig. 6-10 shows a two-tone signal generated by the internal ARB of SMW and its intermodulation products.

6.3 Satellite Antenna Characterization

6.3.1 Equivalent Isotropic Radiated Power (EIRP)

EIRP is the product of the gain (G_T) of the transmit antenna in the direction of maximum gain and the Input Transmitted Power (P_T) [14]. To define this parameter, we need to refer to the Friis transmission equation.

$$EIRP = P_T G_T$$

The equation can be re-written as:

$$EIRP = \left(\frac{4\,\pi\,R}{\lambda}\right)^2 \left(\frac{P_R}{G_R}\right)$$

Where,

P_R= power observed at the receiver antenna
G_R = gain of the receive antenna
R = distance between the transmit and receive antennas
λ = wavelength of the radiated signal
The unit of EIRP is typically dBW.

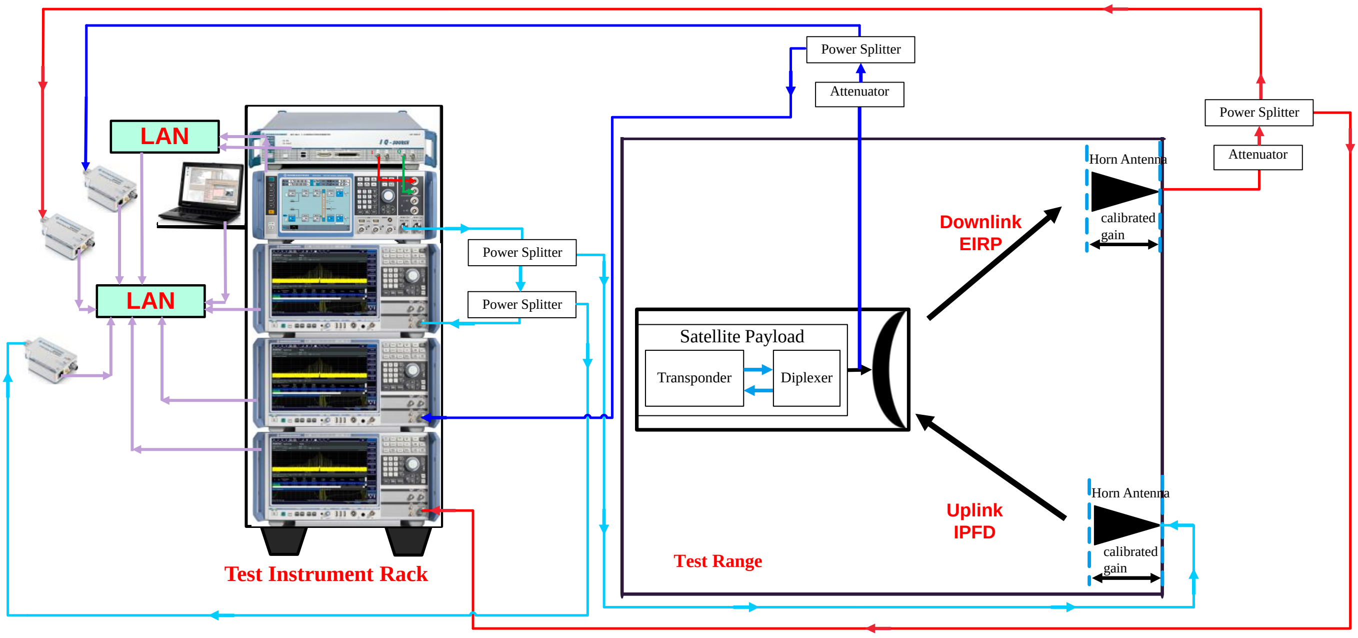


Fig. 6-11: EIRP and IPFD measurement test setup

Fig. 6-11 shows the test setup for EIRP measurement. The transmit antenna of the satellite is pointed towards the test antenna in direction of antenna boresight. A synthesized AM-modulated signal is transmitted from the Tx antenna of the satellite. The power level of this signal needs to be high enough to cause the transponder to saturate. Each individual channel of the transponder as well as the Channel Output Amplifier of the payload is driven to its saturation point. This saturation point needs to be individually determined, because this parameter is variable for every channel. The best method is to find for each channel that power level, at which the first two sidebands of an AM modulated signal undergo maximum AM suppression.

The gain of the range's RX feed and the range distance R needs to be pre-defined in order to calculate the EIRP. The received signal is monitored using FSW. The power level at the Tx feed of the CCR/CATR is increased at i.e. 0.5 dB increments from SMW until the sideband of the received signal undergoes maximum AM suppression. The power level of the received signal can be measured by using NRP family power heads with the free download NRPV Virtual Power Meter installed on a PC, or connected to NRP2 power meter. The power level at the satellite is also monitored by using the FSW and NRP power head connected at the satellite payload.

The NRPxxS/SN power sensors cover the frequency range up to 33 GHz. They are especially suitable for multiple applications in the satellite industry. For applications between 33 GHz up to 67 GHz, the NRP- Z55, NRP- Z56 and NRP- Z57 are recommended.

All NRPxxS/SN sensors offer the same measurement modes: Continuous Average, Burst Average, Time Slot, Trace Mode, as the existing three-path diode sensors but with a significantly improved performance:

- Dynamic range: -70 dBm to +23 dBm
- Frequency range: 10 MHz to 8 GHz, 18 GHz and 33 GHz
- Measurement speed (triggered): 10,000 readings/s
- Measurement speed (free run): 50,000 readings/s
- Extremely fast and accurate measurements at low power levels
- LAN capability with web client (for NRPxxSN models)
- Remote control via USB

6.3.2 Input Power Flux Density (IPFD)

The input power level required in order to saturate the transponder is known as the IPFD. It is directly proportional to the EIRP.

$$IPFD = EIRP\left(\frac{1}{4\pi R^2}\right)$$

IPFD is normally measured at the point when a high power amplifier of the satellite transponder goes into saturation. When a satellite is on orbit, the EIRP of the uplink antenna in the Earth Station needs to be adjusted to resemble an accepted IPFD at the satellite. The unit of IPFD is in dBW/m^2.

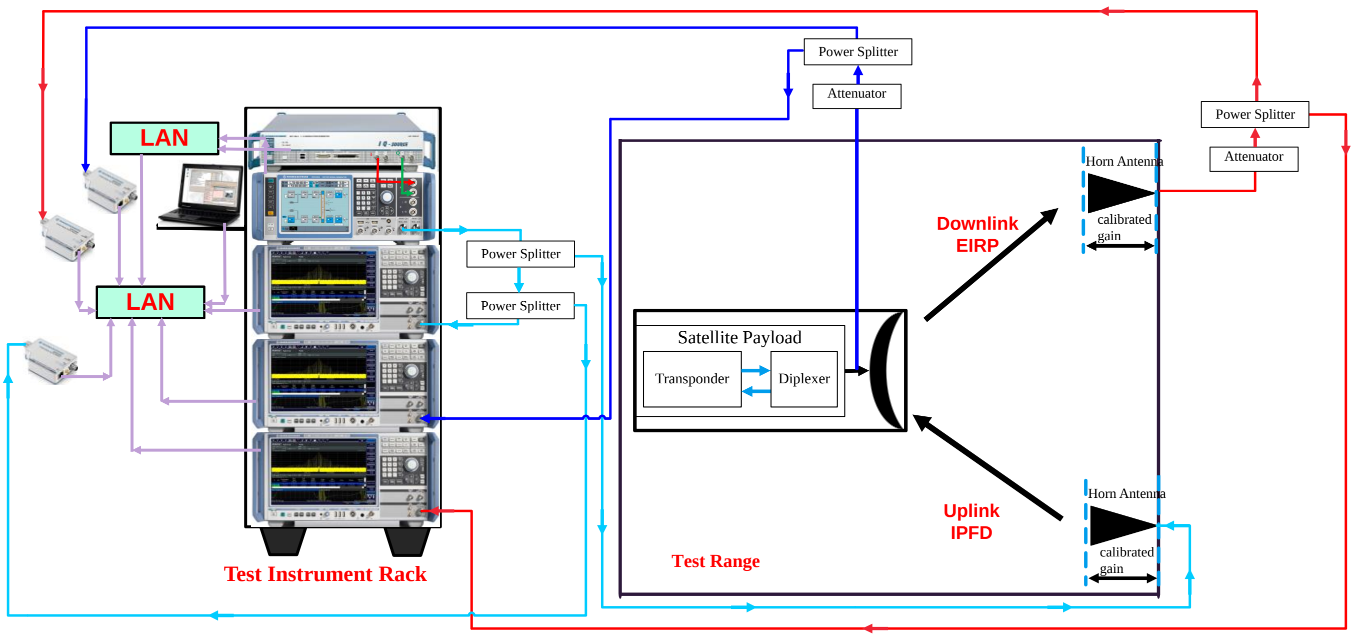


Fig. 6-12: IPFD measurement test setup

The input power flux density (IPFD) parameter is also measured the same way as the EIRP. The transponder of the payload needs to be driven to the point of saturation. The transmit power of the range Tx antenna is incremented at small steps until the transponder reaches the point of saturation. IPFD is calculated using the equation provided above. In addition to the NRPxxS/SN power sensors, the NRP-Zxx power sensors are also suitable for the measurement of IPFD.

The advantages of NRP-Zxx power sensors over conventional technology are obvious: high signal/noise ratio throughout, low modulation effect, negligible delays and discontinuities when switching signal paths, and the ability to perform a time-domain analysis of the test signal within the available video bandwidth. These sensors not only compete with peak power meters, they are even superior in two respects:

- No restrictions on the RF bandwidth of the test signal
- Larger dynamic range

Thus, it is now already possible to analyze extremely broadband signals.

6.4 Satellite Payload Characterization

6.4.1 Amplitude Frequency Response (AFR)

The amplitude frequency response is a key parameter for characterizing the communication channels that are realized after a signal passes through a chain amplifier and bandpass filter chain. Amplifiers and bandpass filters are used in every transponder, transmitting earth station and receiving earth station. Thus, the influence of these components on the communication channel is an important aspect that needs to be investigated in order to achieve desired performance from a particular communication link. Ideally, the AFR needs to be flat throughout the operational bandwidth.

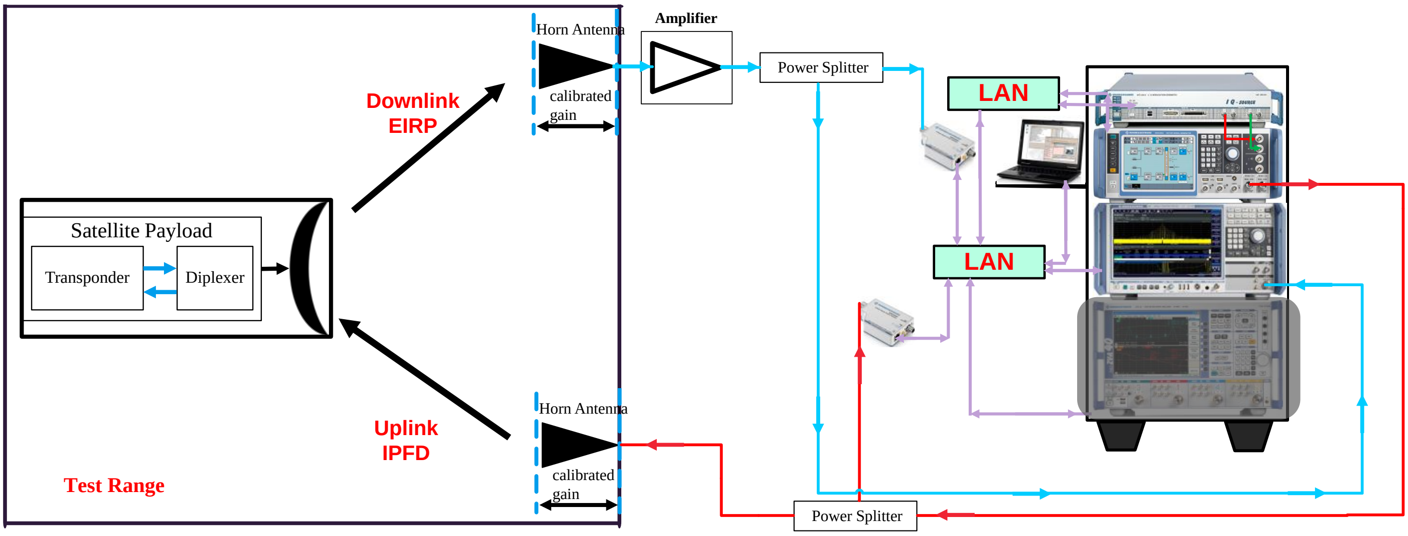


Fig. 6-13: AFR measurement test setup. Greyed-out equipment in the stack is not used for this measurement, but may be used for calibration of the setup.

Fig. 6-13 shows the test setup for the measurement of the amplitude vs frequency response. *For RF signal bandwidths of up to 160 MHz, the internal ARB option of SMW allows to omit a separate arbitrary waveform generator*

1. Single Tone Stepped AFR Measurement

In order to make this measurement, the transponder of the payload needs to be operated in its linear region. The transmitted signal from the Tx feed of the CCR/CATR is swept from the start frequency to the stop frequency of the channel BW in 5 MHz steps. The signal power level is measured for every frequency step via the power head. The spectrum is monitored using the FSW and the uplink feed power level compensation is done simultaneously.

2. Multi-Tone AFR Measurement

When a wideband multi-tone signal is used for the Tx feed, the compensation of the uplink and downlink signal in order to achieve a flat amplitude vs frequency spectrum is done before testing. In our example from Section 6.2.1, we used the software NPR to do an automatic amplitude correction across the used bandwidth. The flatness of the AFR using the SMW at 33 GHz achieved this way is about ± 0.3 dB. Satellite manufacturers use procedures integrated to their production software that will yield similar results.

6.4.2 Group Delay Measurement

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:

Equation 6-1:

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

For practical reasons, Vector Network Analyzers measure a difference coefficient of the transmission parameter S_{21} instead of the differential coefficient. This 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.

Equation 6-2:

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

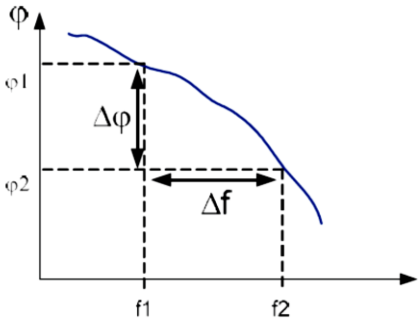


Fig. 6-14: Definition of phase shift $\Delta\varphi = \varphi 2 - \varphi 1$ and aperture $\Delta f = f2 - f1$

Fig. 6-14 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.

The most widely used group delay measurements are relative and absolute group delay. Relative group delay measurements ignore the constant delay caused by the DUT. This delay affects all frequency components in the same way and does not lead to a change in the signal shape. However, the absolute group delay is significant in certain cases, e.g. if the signal delays of two transmission channels are to be adjusted with respect to each other.

6.4.2.1 Group Delay Measurement using the R&S®FSW

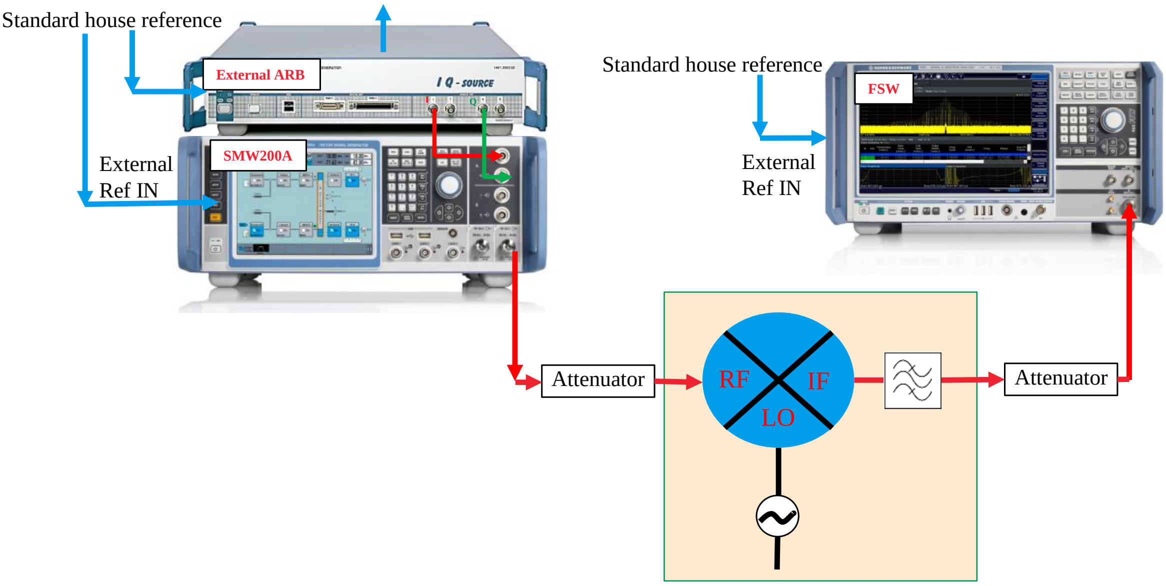
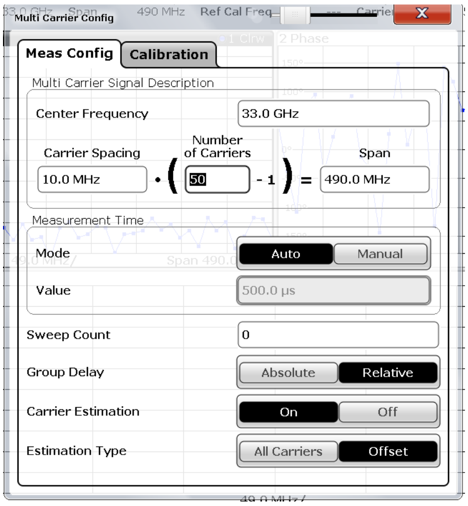


Fig. 6-15: Test setup for Group Delay measurement

Fig. 6-15 shows the test setup for measuring the group delay of a satellite mixer. Using the combination of FSW option K17 (Multicarrier Group Delay Measurements) and B500, group delay of up to 500 MHz BW can easily be calibrated and measured using the FSW signal and spectrum analyzer.

The FSW-K17 performs multi-carrier group delay measurements on amplifiers and frequency converting devices. The option FSW-K17 is primarily of interest for measurement scenarios when there is no physical access to the LO of the DUT.

Using this test setup, a signal of total 500 MHz bandwidth (50 carriers with carrier spacing of 10 MHz) is generated using SMW with an external ARB, i.e. AFQ100B. The calibration of FSW is performed in the first step. Select FSW multicarrier group delay mode and configure the parameters as shown in Fig. 6-16 for this example:



Multi Carrier Signal Description

Center Frequency: 33.0 GHz

Carrier Spacing · (Number of Carriers - 1) = Span: 10.0 MHz · (50 - 1) = 490.0 MHz

Measurement Time

Mode: ● Auto ○ Manual

Value: 500.0 µs

Sweep Count: 0

Group Delay: ○ Absolute ● Relative

Carrier Estimation: ● On ○ Off

Estimation Type: ○ All Carriers ● Offset

Fig. 6-16: Multi-carrier mode configuration

After the analyzer is properly configured, remove the MUT and make a THROUGH connection between the RF port of the SMW and the FSW. The calibration is performed by simply selecting the CALIBTATION button on the FSW touch screen. Next, connect the MUT as shown in Fig. 6-16 and perform the group delay measurements.

Measurement speed plays an important part in payload tests. Here too, the R&S®FSW along with the K17 option shows its strengths. For a wideband, relative, group delay analysis over a span of 160 MHz with a carrier spacing of 200 kHz (800 carriers), the option only needs 350 ms, and a mere 80 ms with a carrier spacing of 1 MHz (160 carriers). Because the phase relation between the reference calibration and the measurement is the only thing that is important for analysis, it is possible to work with crest factor optimization on the generator. A multicarrier signal with a low crest factor improves the SNR for the group delay analysis and helps to protect the DUT at higher avg. power levels.

Despite the ease of calibration, an important strength of this setup is the measurement uncertainty. For example, at center frequencies between 100 MHz and 6 GHz, the group delay measurement uncertainty for a signal with a carrier spacing of 100 kHz and 601 carriers (i.e. 60 MHz bandwidth) is just ±300 ps.

The maximum BW for the group delay measurement using FSW is 500 MHz. In case the required BW for the group delay measurement is greater than 500 MHz, this measurement can be performed using the ZVA vector network analyzer, as explained in the following section.

6.4.2.2 Group Delay Measurement using the R&S®ZVA

For even more accurate group delay measurements with the two-tone method 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.

A side benefit compared to the multitone measurement described in section 6.4.2.1 above, is the reduced crest factor of the two-tone test stimulus. This allows slightly higher stimulus level to be used and yields a corresponding SNR benefit.

The two signals are combined by using an external combiner or using one of the ZVA's internal couplers as the RF 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 various ZVA models. Connected 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 the IF and RF frequencies used are above 700 MHz.

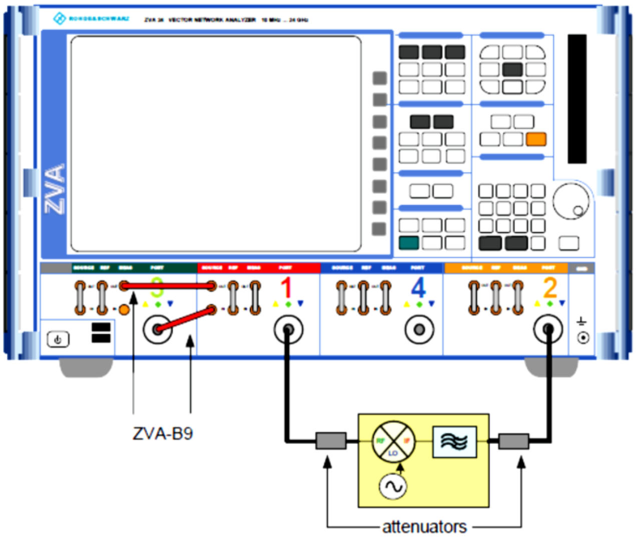


Fig. 6-17: Test setup using ZVA-B9

If a VNA type ZVA8, ZVA24, ZVA40 or ZVA50 is used at lower frequencies than 700 MHz, like for measurements on a Satellite Up-Converter with a 70 or 140 MHz IF input frequency, the attenuation of the internal coupler may lead to increased trace noise.

To overcome this, an alternative method is described below. Well-matched 6 dB attenuators are recommended to be used at both ports in order to increase the accuracy; ideally, they are directly attached to the measurement plane.

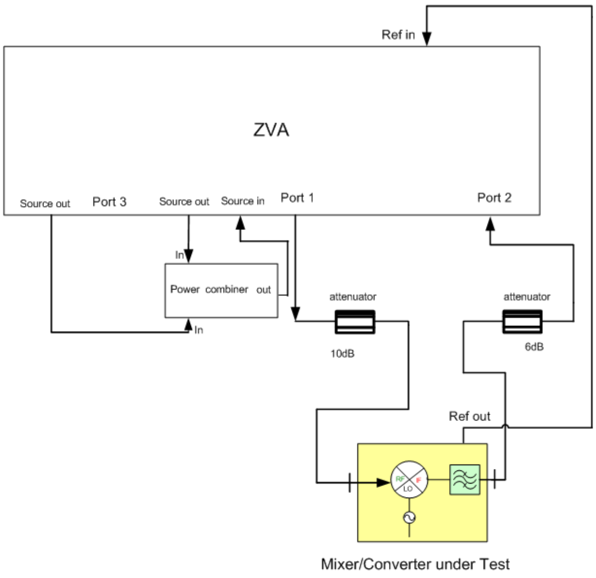


Fig. 6-18: Converter Test setup using the ZVA

A two-tone signal is generated using ZVA port 3 and port 1 Source out signals combined by an RF combiner (e.g. Resistive Power Divider). The output of the sum port of the power combiner connects to "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 fed 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, i.e. synchronizing the converter under test to an external reference could possibly cause problems because of strain on the loop design).

If a converter under test does **not** provide access to the internal time base (reference frequency), drift of the internal LO and a potential constant offset of the internal LO signal must be taken into account. Using option ZVA-K9, which focusses especially on such devices, a reliable solution is provided to overcome the challenges arising from DUT LO drift. A constant offset of the internal LO of the DUT 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, easily yields this LO offset.

Prerequisites

The following measurement requires that RF offset of the DUT's LO remains within the used measurement bandwidth (e.g. 1 kHz) during time of evaluation.

The test setup shown in Fig. 6-18 can be used for

- group delay measurements
- conversion loss measurement
- intermodulation measurement and
- 1-dB compression point measurement

A more systematic description of performing frequency converter group delay measurements can be found in the application note 1MA224 (Characterization of Satellite Frequency Up-Converters) [6].

6.4.3 Gain vs noise temperature (G/T)

G/T is also known as the receiver sensitivity and hence one of the most important parameters in satellite payload test. It is a figure of merit to characterize the performance of a satellite system. G/T defines the performance of the whole receiver subsystem i.e. both the antenna and the receiver.

The G/T measurement provides the widely accepted central Figure-of-Merit for satellite receivers.

Equation 6-3:

$$\left.\frac{G}{T}\right|_{SAT} = \frac{kBLP_L}{P_T G_T}\frac{P_3-P_2}{P_2-P_1}$$

Where:
k = Boltzmann constant
B = Noise bandwidth (BW)
LP_L = Path loss of uplink signal
P_1 = noise power level of RF equipment
P_2 = noise power level (Satellite noise + noise of RF equipment)
P_3 = power level when the uplink level is switched on

This Figure-of-Merit is derived in a three-step power level measurement. The total link budget for the G/T measurement needs to be calculated for the equivalent far field distance of the particular CCR where the measurement is being carried out. Also the satellite C/N_o and EIRP needs to be known.

The setup of this measurement is presented in Fig. 6-19.

Arrange the receive antenna beam so that it is directed along the antenna bore sight. Antenna bore sight of a directional antenna is defined as the axis along which maximum RF power is radiated (maximum gain) for a given frequency.

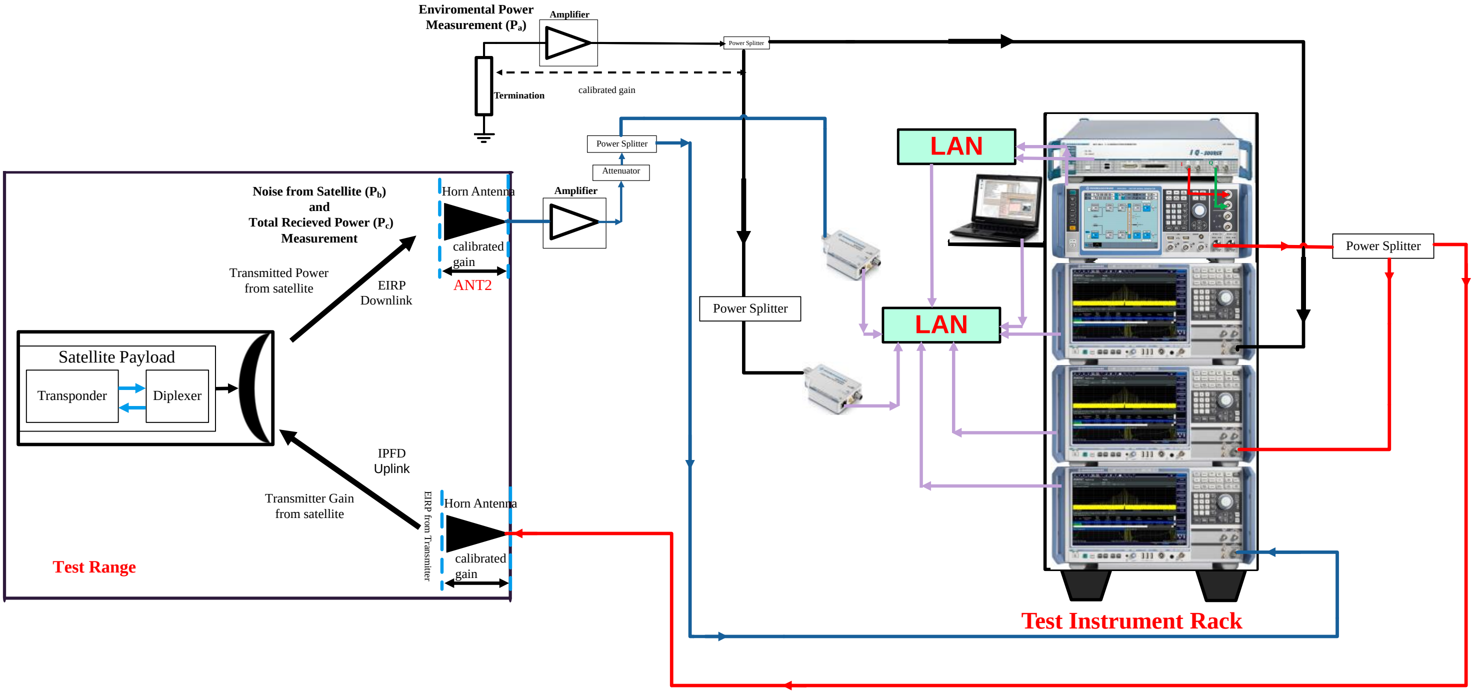


Fig. 6-19: Receiver Figure-of-Merit (G/T) measurement test setup

For noise figure measurements, an FSW with option K30 (Noise Figure Measurements) measures the noise characteristics of the device to be tested at different noise levels at the input and calculates from the known noise behavior of the sources at the input the noise figure, the gain of the device, and the quality of the tolerances and uncertainties

By using the R&S®FSW-K30 option in the FSW, it is possible to perform the G/T measurement conveniently.

- Step 1: at the Receiver Station
  - First, direct the antenna Ant2 away from the satellite and measure the Receive-station + P_a over the entire bandwidth
  - Second, direct the antenna towards the satellite and measure, over the entire BW, the total noise power; this also includes the noise contribution from the satellite (P_b)

- Step 2: at the Transmitter Station
  - A continuous wave (CW) signal is transmitted in this case. Then increase transmit power level / gain up to the point where the ratio between total received power (P_c) and total satellite noise contribution (P_b) is better than or equal to 2 (+3 dB)
  - At this point measure the EIRP of the transmitter

- Step 3: at the Receiver Station

- Measure the total received power (P_c) with the same setting as before over the entire BW, but this time including the noise from the Rx station + noise from the satellite + CW signal

The measured values from this stage are used to calculate the G/T, using the Equation 6-3.

6.4.4 Passive Intermodulation (PIM)

Passive intermodulation (PIM) occurs at high power levels in devices such as cables, connectors, waveguide flanges, output multiplexers and (duplex) filters. In modern satellite communication transponders, access to more efficient sources of energy has enabled increasing RF transmission levels and PIM effects have grown to be a major concern where PIM signal frequencies coincide with the receiver path frequency in the duplex filter. The outcome of the PIM effect is a degrading of the receiver RF sensitivity.

PIM testing of duplex filters during production is therefore essential.

For measurement on a complete payload, two tones are applied to the satellite under test (SUT), ideally swept in frequency and power.

The two-tone signal is generated and transmitted over the uplink on all applicable different receive channels of the satellite transponder. The amplitude of the two uplink carriers F1 and F2 need to be adjusted so that the regenerated downlink signal from the satellite transponder F1* and F2* have the same EIRP. The carrier spacing between the two tones is chosen, keeping in mind the operating frequency plan to the satellite so that the worst-case situation can be investigated. This worst-case situation is better explained by

$$F_{PIM} - frequency = \pm M * (F1^{*}) \pm N * (F2^{*})$$

(M, N are the harmonic order and the sum M+N is an odd number)

Prerequisites

- The doors of the testing chamber must be closed to avoid outside EM influence from the environment
- Remove all ferromagnetic material from the surrounding
- The Tx feed polarization of the chamber and Rx feed polarization of the chamber are orthogonal to each other. (Example, Tx feed = Horizontally polarized and Rx feed= Vertically polarized)

R&S®SMW*

- Depending on frequency range, i.e. up to 20 GHz, a single two path R&S®SMW is sufficient for two tone generation
- For carrier frequencies over 20 GHz up to 40 GHz, two R&S®SMW are required for two tone signal generation
- The multi-tone internal signal generation option of the R&S®SMW **must** not be used for PIM testing

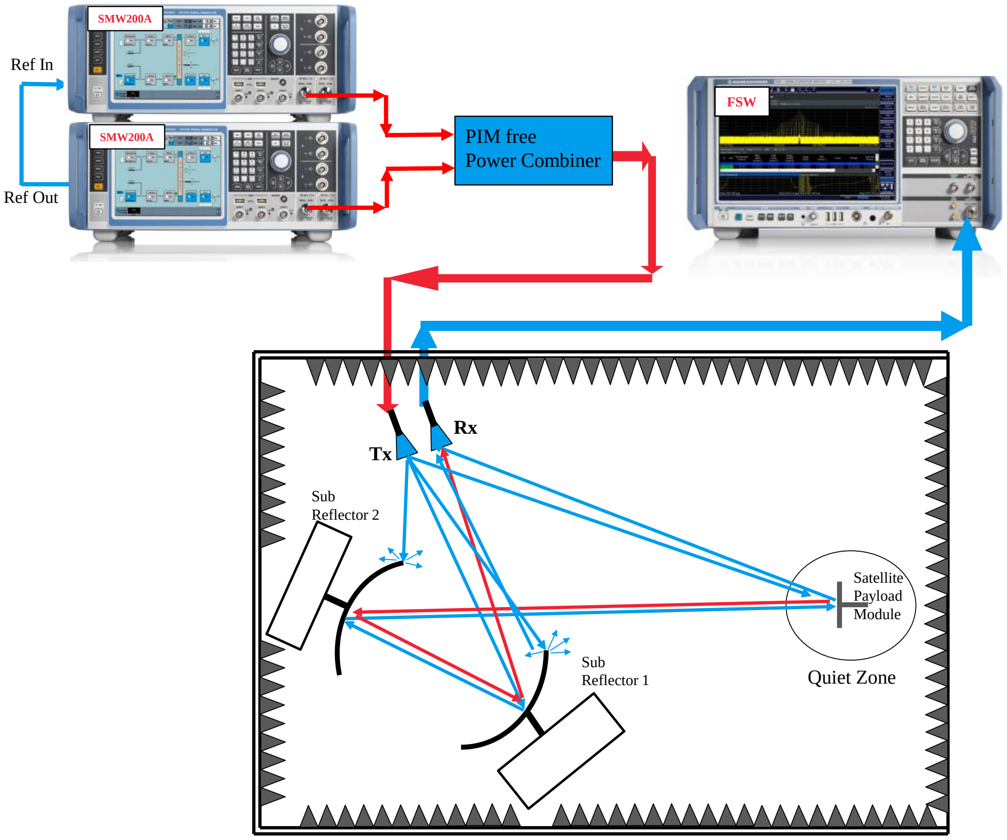


Fig. 6-20: Test setup for PIM measurement

The measurement setup for the PIM testing at satellite level is shown in Fig. 6-20. PIM occurs primarily in the transmit path of the satellite.

The PIM measurement is performed in two steps. For the first step, the PIM level of the chamber at the desired frequencies are measured and documented. These values are later taken into account at the final PIM level calculation.

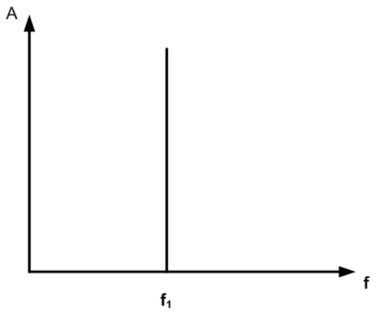
The second step involves generating two CW signals, using the SMW, with required carrier spacing. The two signals are combined using a PIM free power combiner and then feeding it to the range horn antenna. The Tx range feed is pointed towards the sub reflector and a radiated signal is illuminated towards the satellite payload. The two carrier signal (f1 and f2) power levels are adjusted so that the satellite transponder is saturated. The EIRP of the transmitted signal (f1 and f2) and the EIRP of the regenerated signals from the satellite (f1* and f2*) also needs to be equal in magnitude. The generated PIM products (typically the 3rd, 5th and 7th order) is monitored in the downlink from the satellite using the FSW. Due to the excellent dynamic range of FSW, the arrangement of phase shifter and level adjustment for stimulus suppression can be omitted in some cases.

6.4.5 Phase Noise

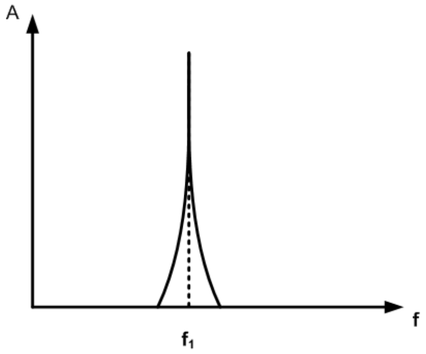
Phase noise can be considered as a random phase modulation around an “ideal” carrier. The following equation describes an ideal carrier:

Equation 6-4:

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



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

1. Noise Power Density

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

Equation 6-5:

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

2. 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.

Equation 6-6:

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

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

Equation 6-7:

$$L(f_m) = \frac{1}{2} S_{\Delta\phi}(f_m)$$

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

Equation 6-8:

$$L_c(f_m) = 10\log(L(f_m))$$

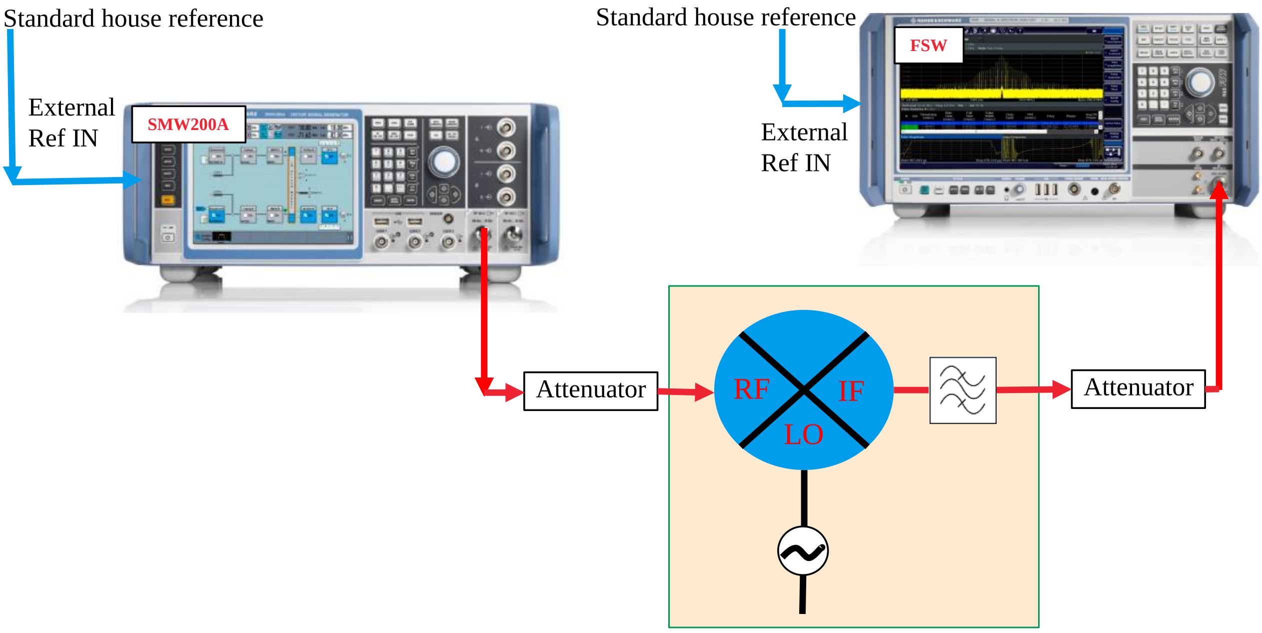


Fig. 6-21: Test setup for phase noise measurement

The measurement is performed at IF, for this example at 70 MHz. FSW with option K40 (Phase Noise Measurement) allows to achieve results conveniently inside the signal analyzer.

If highest precision is desired in characterizing LOs, reference oscillators and sampling clocks, the dedicated phase noise tester FSWP can be used. Personalities available for FSWP allow it to substitute the signal analyzer FSW in most applications where FSW is shown in this paper and help to reduce the instrument count in payload test rigs.

Connect the instruments as shown in Fig. 6-21.

Synchronizing the R&S test instruments to the reference output of the converter under test is optional. Option SMW-B22 enhances the generator's inherent phase noise performance. Depending on the payload under test, this option may be desirable.

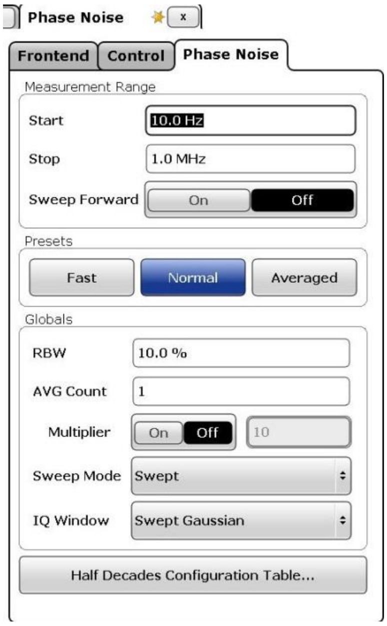
Example for an IF of 70 MHz:

- **SMW** (Note: option SMW-B22 may be desirable)**:**
- *PRESET*
- *Frequency: 70 MHz; Level: -19dBm (CW signal is being used)*
- *RF ON*

FSW (Note: option FSW-K40 is needed)**:**

- *MODE: Phase Noise*
- *Frequency: 5.98 GHz*

On the right side of the FSW screen press *Phase Noise* and make the adjustments as shown in Fig. 6-22.



Start: 10.0 Hz
Stop: 1.0 MHz
Sweep Forward: On / Off (Off)
RBW: 10.0 %
AVG Count: 1
Multiplier: On / Off (Off), 10
Sweep Mode: Swept
IQ Window: Swept Gaussian

Fig. 6-22: 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 Fig. 6-23:

Nominal Frequency 5.980000057 GHz
Ref Level & Att 3.60 dBm, Att 4 dB
Measurement 10 Hz to 1 MHz

Measured Level 3.02 dBm
Initial Delta -0.07 dB
Drift 0.13 dB

Measured Freq 5.980000057 GHz
Initial Delta 190.39 mHz / 0 ppm
Drift 134.90 mHz / 0 ppm

M6[1] -111.01 dBc/Hz
1.000000 MHz
M1[1] -66.59 dBc/Hz
10 Hz

2 Marker Table

Wnd	Type	Ref	Trace	X-value	Y-value
1	M1		1	10.0 Hz	-66.59 dBc/Hz
1	M2		1	100.0 Hz	-80.89 dBc/Hz
1	M3		1	1.0 kHz	-96.92 dBc/Hz
1	M4		1	10.0 kHz	-102.17 dBc/Hz
1	M5		1	100.0 kHz	-100.58 dBc/Hz
1	M6		1	1.0 MHz	-111.01 dBc/Hz

Date: 29.AUG.2013 18:48:28

Fig. 6-23: FSW Phase Noise plot of converter under test at 70MHz IF

A user-definable limit line labelled “CONVERTER1” is activated to get pass/fail information. The marker table shown in the lower screen shows numeric phase noise values at several common frequency offsets.

Note: The specified phase noise values of both SMW and FSW are much lower than the measured values of the converter under test and therefore can be neglected. Fig. 6-24 shows typical Inherent SSB phase noise plots of the FSW signal and spectrum analyzer for a range of different RF frequencies. Inherent SSB phase noise of the analyzer should be ca. 10dB better than phase noise of the DUT to be characterized:

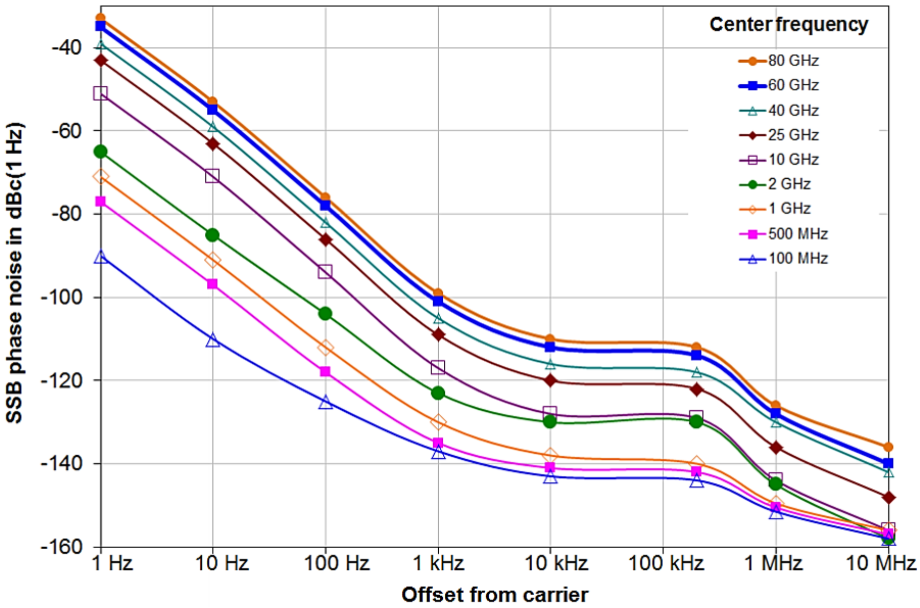


Fig. 6-24: Typical phase noise of a FSW for various RF carrier frequencies (with the FSW-B4 option for offsets ≤ 10 Hz)

If the performance highlighted above does not fulfil requirements, the FSWP phase noise analyzer meets the most demanding phase noise measurement needs [13].

Fig. 6-25: The FSWP Phase Noise Analyzer and VCO Tester

In this application note, high-end phase noise measurement has been explained using external signal generators as reference sources. The quality of such a generator or external source limits the sensitivity of phase noise measurement. The FSWP does not require external reference sources. The internal local oscillator surpasses almost any generator available on the market when it comes to phase noise performance.

In order to measure sources with extremely low phase noise, a very high sensitivity is required. The FSWP can be equipped with a second local oscillator (FSWP-B60 option) for cross-correlation. This can improve the sensitivity by up to 25 dB. With this analyzer's low-noise internal sources, often only a few correlations are needed to measure a high quality oscillator. That allows users to receive reliable results faster, shortening development and manufacturing times. Amplifiers, doublers, splitters and other two-port components cause additive phase noise even though they do not generate a signal. The FSWP offers an internal signal source (FSWP-B64 option) for measuring this additive phase noise contribution.

Key features of the FSWP

- Frequency range from 1 MHz up to 26.5 GHz
- High sensitivity for phase noise measurements thanks to cross-correlation and extremely low-noise internal reference sources
  - typ. –172 dBc (1 Hz) at 1 GHz carrier frequency and 10 kHz offset
  - typ. –153 dBc (1 Hz) at 10 GHz carrier frequency and 10 kHz offset
- Simultaneous measurement of amplitude noise and phase noise
- Measurement of phase noise on pulsed sources at the push of a button
- Internal source for measuring additive phase noise, including on pulsed signals
- Signal and spectrum analyzer and phase noise analyzer in a single box
  - High-end signal and spectrum analyzer, 10 Hz to 8 GHz/26.5 GHz
  - Wide dynamic range thanks to low displayed average noise level (DANL) of –156 dBm (1 Hz) (without noise cancellation) and high TOI of typ. 25 dBm
  - 80 MHz signal analysis bandwidth
  - Total measurement uncertainty: < 0.2 dB up to 3.6 GHz,< 0.3 dB up to 8 GHz
  - Touchscreen operation
  - Large 12.1" display for simultaneous viewing of multiple measurement windows
  - Various measurement applications can be run and displayed in parallel
  - Pulsed Phased Noise Measurements, Analog Modulation Analysis for AM/FM/φM, Noise Figure Measurements and Vector Signal Analysis
- High measurement speed
- Low-noise internal DC sources for VCO characterization

Fig. 6-26 shows typical Inherent SSB phase noise plots of the FSW signal and spectrum analyzer for a range of different RF frequencies.

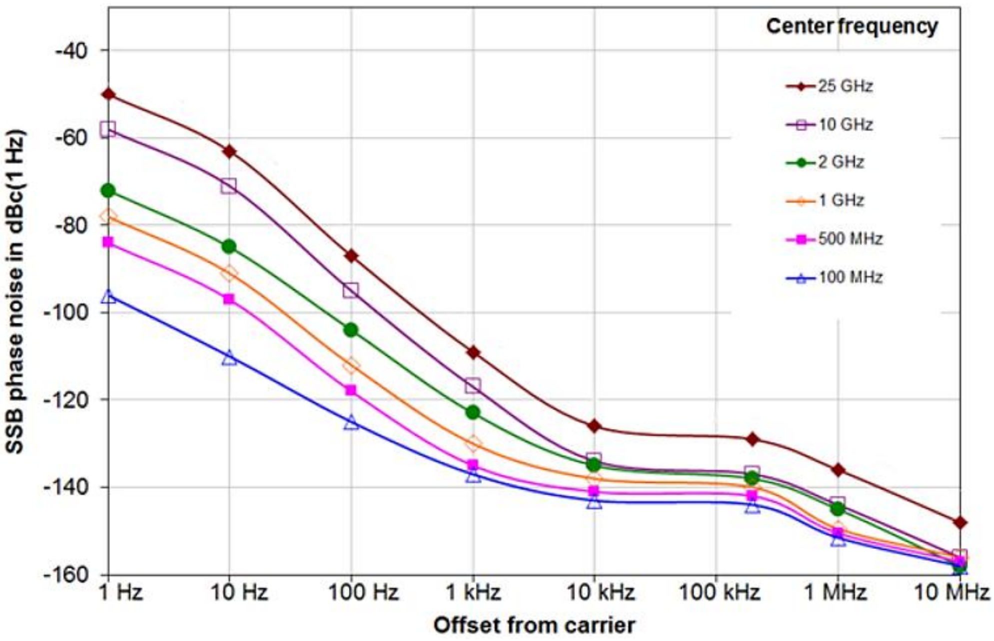


Fig. 6-26: Typical phase noise of a FSWP at different center frequencies in spectrum analyzer mode (with the FSWP-B4 option for offsets ≤ 10 Hz)

6.4.6 Spurious 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 inside 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. It is probably worth noting that out-of-band emissions are important to test throughout the manufacturing process from module level through to the final product. It is important that spurious emissions from a payload do not impact telemetry control systems, navigation, or even cross-link communication systems.

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

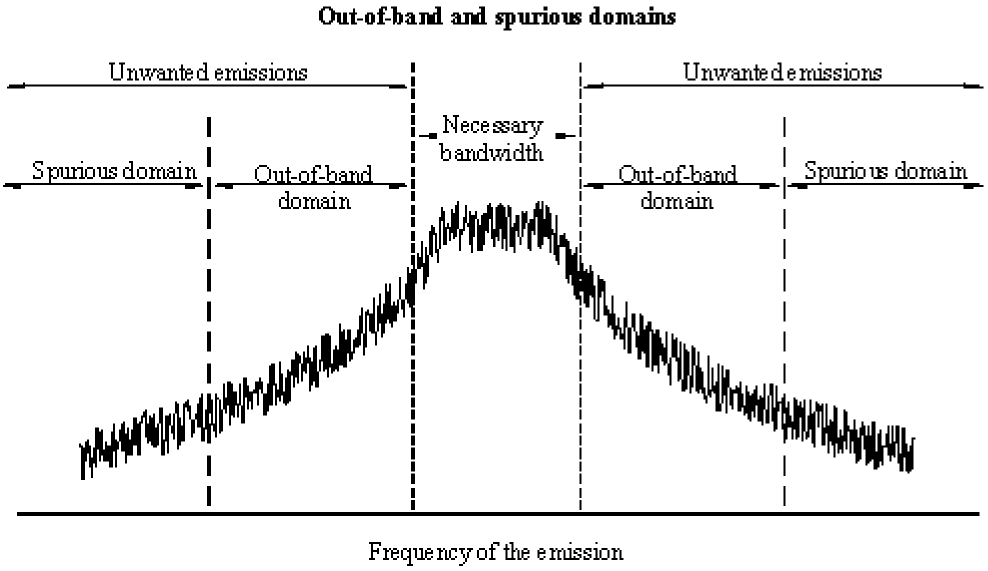


Fig. 6-27: Out of band and spurious domains of unwanted emissions

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

A typical out-of-band emission requirement might be as low as -135 dBm to 40 GHz. With enough test margin (minimum 6 dB), this could take several weeks to sweep an analog spectrum analyzer but using the FSW stepped FFT spectrum analyzers, this measurement can be performed in about an hour.

The International Telecommunication Union (ITU) defines the Out of Band (OoB) domain depending on the necessary bandwidth (B_N) and whether B_N below the lower threshold value (B_L), between B_L and the upper threshold value (B_U), or beyond B_u, see Table 6-1.

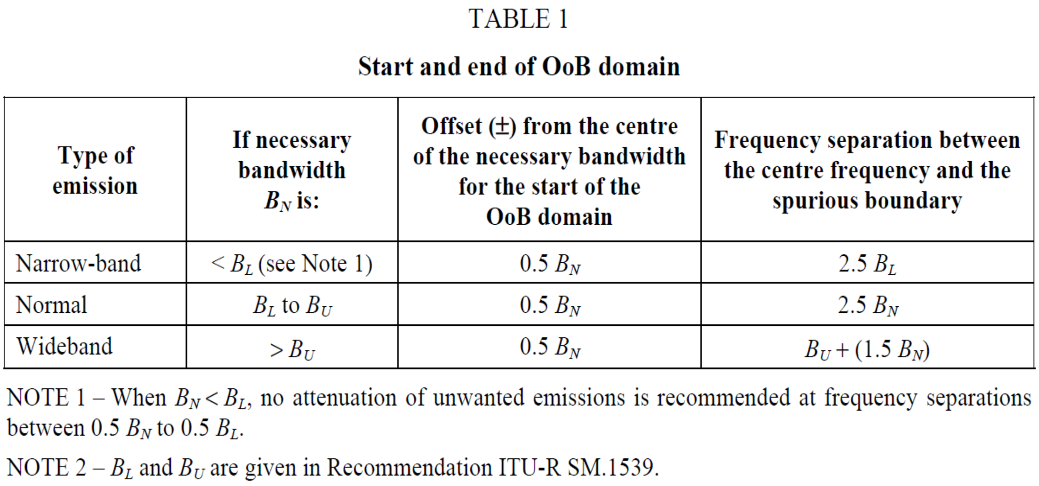


TABLE 1

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 6-1: Start and end of OoB domain according to ITU-R-REC-SM.1541-4 and ITU-R-REC-SM.1539-1

For measuring spurious outputs, the test setup in Fig. 6-21 is used (same test setup as for phase noise measurements). Normally there are two types of spurious output specifications defined for frequency up-converters:

- Signal-related spurious specified in dBc (referenced to the level of the output carrier signal).
  For the measurement, a spurious-free RF input signal at nominal power is fed into the up-converter.
- Signal-independent spurious specified in dBm (absolute level). For this 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 FSW Spectrum Emission Mask (SEM) function is highly recommended. SEM can be configured for both, absolute and relative limits.

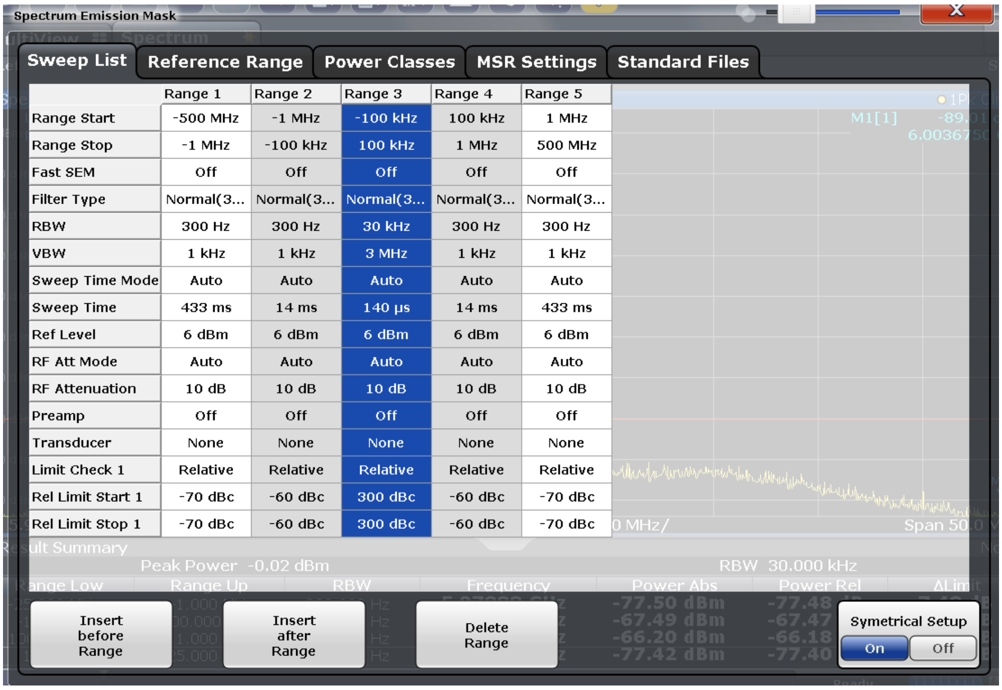
6.4.6.1 Signal-related spurious outputs

SMW configuration *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 SMW 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 Fig. 6-28 (insert 2 ranges, change start and stop frequencies of ranges, change bandwidths and set relative limits)

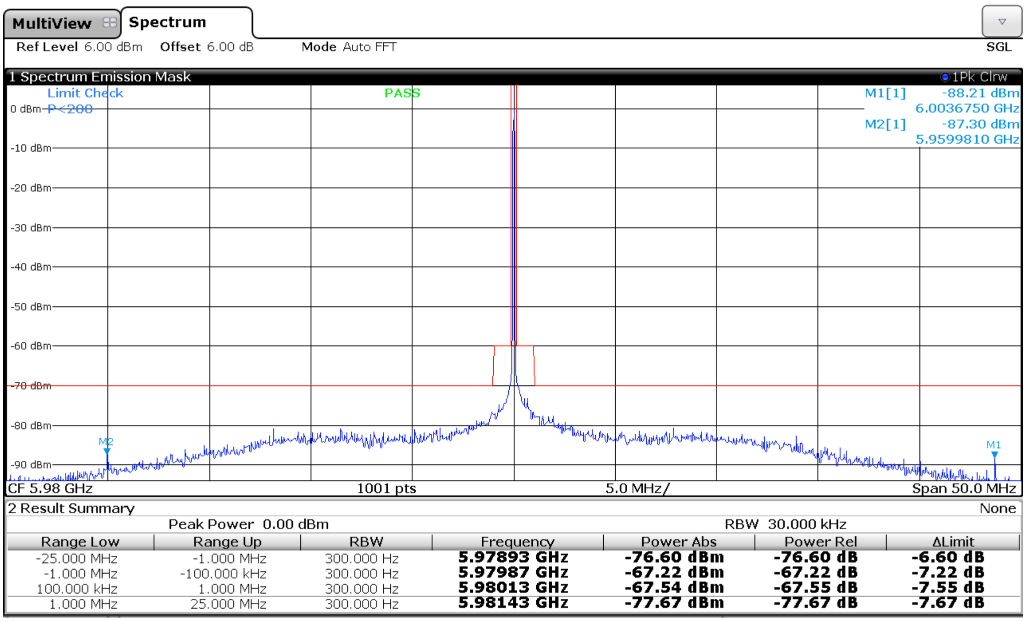


	Range 1	Range 2	Range 3	Range 4	Range 5
Range Start	-500 MHz	-1 MHz	-100 kHz	100 kHz	1 MHz
Range Stop	-1 MHz	-100 kHz	100 kHz	1 MHz	500 MHz
Fast SEM	Off	Off	Off	Off	Off
Filter Type	Normal(3...	Normal(3...	Normal(3...	Normal(3...	Normal(3...
RBW	300 Hz	300 Hz	30 kHz	300 Hz	300 Hz
VBW	1 kHz	1 kHz	3 MHz	1 kHz	1 kHz
Sweep Time Mode	Auto	Auto	Auto	Auto	Auto
Sweep Time	433 ms	14 ms	140 µs	14 ms	433 ms
Ref Level	6 dBm	6 dBm	6 dBm	6 dBm	6 dBm
RF Att Mode	Auto	Auto	Auto	Auto	Auto
RF Attenuation	10 dB	10 dB	10 dB	10 dB	10 dB
Preamp	Off	Off	Off	Off	Off
Transducer	None	None	None	None	None
Limit Check 1	Relative	Relative	Relative	Relative	Relative
Rel Limit Start 1	-70 dBc	-60 dBc	300 dBc	-60 dBc	-70 dBc
Rel Limit Stop 1	-70 dBc	-60 dBc	300 dBc	-60 dBc	-70 dBc

Fig. 6-28: 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 of -60 dBc and -70 dBc respectively (see Fig. 6-29). The highest spurious levels in each range are displayed in the result summary. Additionally spurious can be assigned by means of the markers.



Ref Level 6.00 dBm Offset 6.00 dB Mode Auto FFT

M1[1] -88.21 dBm 6.0036750 GHz
M2[1] -87.30 dBm 5.9599810 GHz

CF 5.98 GHz 1001 pts 5.0 MHz/ Span 50.0 MHz

2 Result Summary None

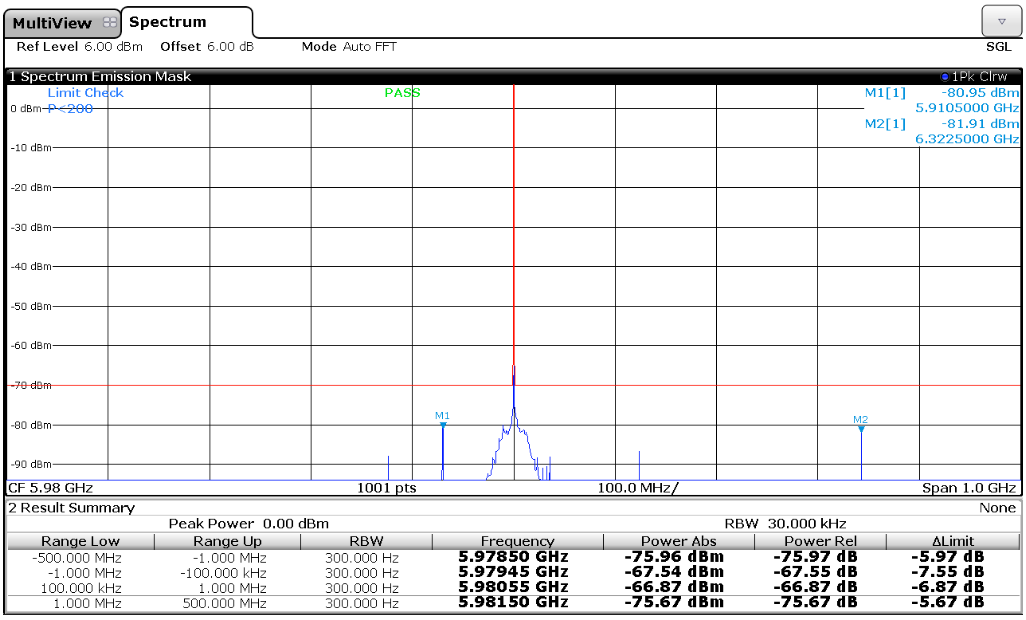
Peak Power 0.00 dBm RBW 30.000 kHz

Range Low	Range Up	RBW	Frequency	Power Abs	Power Rel	ΔLimit
-25.000 MHz	-1.000 MHz	300.000 Hz	**5.97893 GHz**	**-76.60 dBm**	**-76.60 dB**	**-6.60 dB**
-1.000 MHz	-100.000 kHz	300.000 Hz	**5.97987 GHz**	**-67.22 dBm**	**-67.22 dB**	**-7.22 dB**
100.000 kHz	1.000 MHz	300.000 Hz	**5.98013 GHz**	**-67.54 dBm**	**-67.55 dB**	**-7.55 dB**
1.000 MHz	25.000 MHz	300.000 Hz	**5.98143 GHz**	**-77.67 dBm**	**-77.67 dB**	**-7.67 dB**

Fig. 6-29: 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 the spurious farther away from the carrier, see Fig. 6-30.



Ref Level 6.00 dBm Offset 6.00 dB Mode Auto FFT

M1[1] -80.95 dBm 5.9105000 GHz
M2[1] -81.91 dBm 6.3225000 GHz

CF 5.98 GHz 1001 pts 100.0 MHz/ Span 1.0 GHz

2 Result Summary None

Peak Power 0.00 dBm RBW 30.000 kHz

Range Low	Range Up	RBW	Frequency	Power Abs	Power Rel	ΔLimit
-500.000 MHz	-1.000 MHz	300.000 Hz	**5.97850 GHz**	**-75.96 dBm**	**-75.97 dB**	**-5.97 dB**
-1.000 MHz	-100.000 kHz	300.000 Hz	**5.97945 GHz**	**-67.54 dBm**	**-67.55 dB**	**-7.55 dB**
100.000 kHz	1.000 MHz	300.000 Hz	**5.98055 GHz**	**-66.87 dBm**	**-66.87 dB**	**-6.87 dB**
1.000 MHz	500.000 MHz	300.000 Hz	**5.98150 GHz**	**-75.67 dBm**	**-75.67 dB**	**-5.67 dB**

Fig. 6-30: Signal dependent spurious measurement using the spectrum emission mask function of the FSW according to the converter specification (span = 1 GHz).

6.4.6.2 Signal-independent spurious outputs

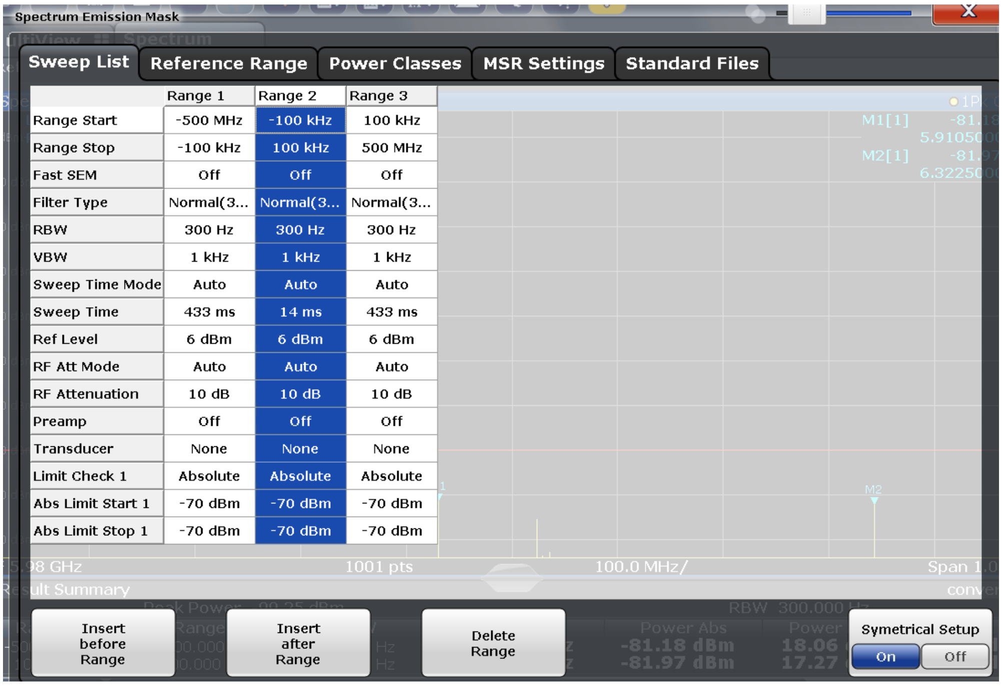
Perform the following settings on the instruments:

SMW:

- *RF OFF*

FSW:

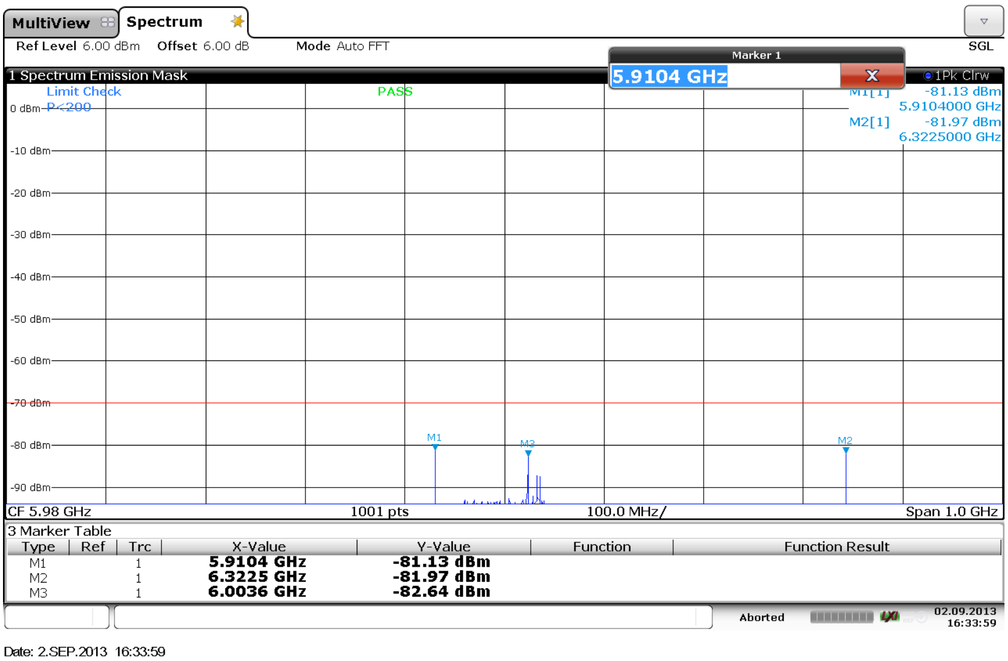
- *MEAS CONFIG: Sweep List*
- *Edit the sweep list according to* Fig. 6-31 (delete ranges, change limits to absolute values)



	Range 1	Range 2	Range 3
Range Start	-500 MHz	-100 kHz	100 kHz
Range Stop	-100 kHz	100 kHz	500 MHz
Fast SEM	Off	Off	Off
Filter Type	Normal(3...	Normal(3...	Normal(3...
RBW	300 Hz	300 Hz	300 Hz
VBW	1 kHz	1 kHz	1 kHz
Sweep Time Mode	Auto	Auto	Auto
Sweep Time	433 ms	14 ms	433 ms
Ref Level	6 dBm	6 dBm	6 dBm
RF Att Mode	Auto	Auto	Auto
RF Attenuation	10 dB	10 dB	10 dB
Preamp	Off	Off	Off
Transducer	None	None	None
Limit Check 1	Absolute	Absolute	Absolute
Abs Limit Start 1	-70 dBm	-70 dBm	-70 dBm
Abs Limit Stop 1	-70 dBm	-70 dBm	-70 dBm

Fig. 6-31: Sweep list for the spectrum emission mask for signal independent spurious according to the converter specification

Fig. 6-32 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.



Ref Level 6.00 dBm Offset 6.00 dB Mode Auto FFT

1 Spectrum Emission Mask

M1[1] -81.13 dBm 5.9104000 GHz
M2[1] -81.97 dBm 6.3225000 GHz

CF 5.98 GHz 1001 pts 100.0 MHz/ Span 1.0 GHz

3 Marker Table

Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
M1		1	5.9104 GHz	-81.13 dBm		
M2		1	6.3225 GHz	-81.97 dBm		
M3		1	6.0036 GHz	-82.64 dBm		

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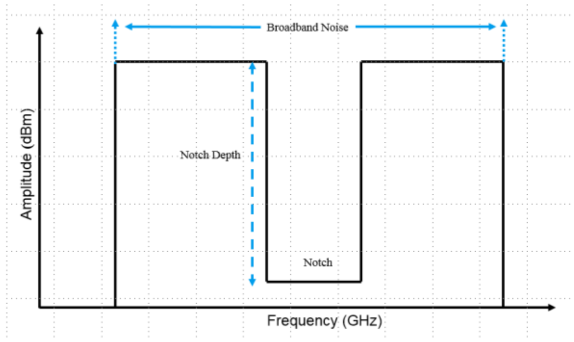
Date: 2.SEP.2013 16:33:59

Fig. 6-32: Signal independent spurious measurement of the converter under test using the spectrum emission mask function of the FSW.

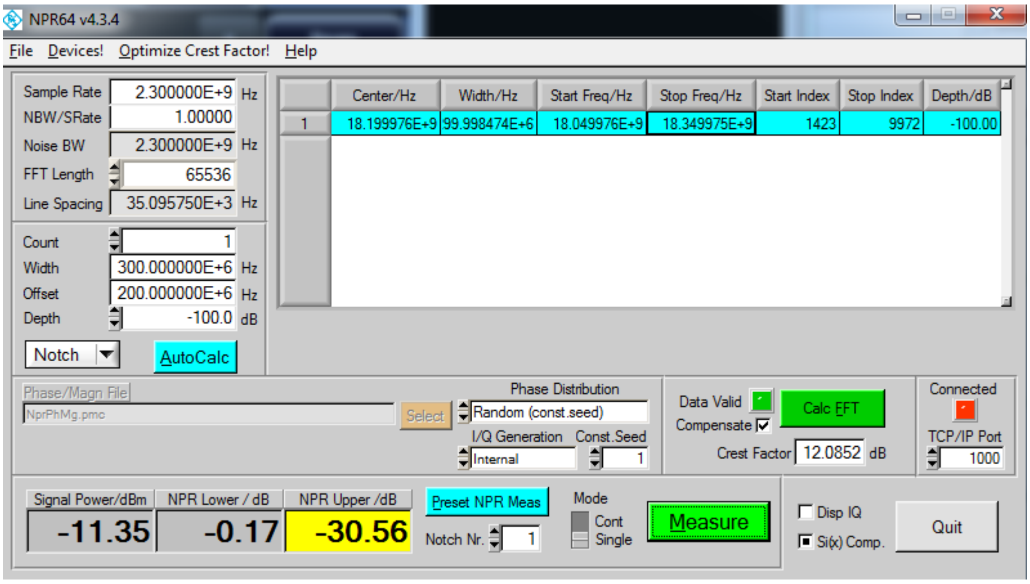
6.4.7 Noise Power Ratio (NPR)

The noise power ratio is a test performed to calculate the amount of noise and intermodulation distortion that is present in a channel. The traditional approach is to use a noise source and tunable notch filter. The NPR waveform is much more flexible and the approach less time consuming. Results show improved repeatability and the NPR test can be done by using the vector signal generator already used for the other tests in this paper. A test signal comprising noise of the bandwidth of interest is generated for this measurement. A certain portion of the noise signal is then deleted creating a notch. This can be done using a notch or band-stop filter or creating a notch digitally in baseband. This test signal is then injected through the DUT and is measured at the output of the DUT.



The Noise Power Ratio (NPR) measurement technique can characterize the linearity of a wide band amplifier over a custom frequency range, as well as the whole transmit or receive chain. The Notch Depth should be about 10dB better than expected DUT performance at this operating point. Since NPR drastically reduces measurement time compared to classic gain wobbling, it is particularly interesting for production specific applications.

The measurement setup for performing NPR measurements is shown in Fig. 6-3. The detailed description on the software settings of the R&S®NPR, as shown in Fig. 6-33, is available in 1MA29 (Noise Power Ratio Signal Generation and Measurement) [10].



Sample Rate 2.300000E+9 Hz
NBW/SRate 1.00000
Noise BW 2.300000E+9 Hz
FFT Length 65536
Line Spacing 35.095750E+3 Hz
Count 1
Width 300.000000E+6 Hz
Offset 200.000000E+6 Hz
Depth -100.0 dB

	Center/Hz	Width/Hz	Start Freq/Hz	Stop Freq/Hz	Start Index	Stop Index	Depth/dB
1	18.199976E+9	99.998474E+6	18.049976E+9	18.349975E+9	1423	9972	-100.00

Phase Distribution: Random (const.seed)
I/Q Generation: Internal
Const.Seed: 1
Data Valid
Compensate ☑
Crest Factor 12.0852 dB
TCP/IP Port 1000

Signal Power/dBm	NPR Lower / dB	NPR Upper /dB
-11.35	-0.17	-30.56

Notch Nr. 1
☐ Disp IQ
☒ S(x) Comp.

Fig. 6-33: Parameter configuration on the R&S®NPR for NPR measurement

Ref Level -30.00 dBm RBW 3 MHz
Att 0 dB SWT 10 s VBW 28 MHz Mode Auto Sweep

M1[1] -39.91 dBm
17.8400060 GHz

CF 17.839 GHz 65536 pts 180.0 MHz/ Span 1.8 GHz

2 Result Summary

Channel	Bandwidth	Offset	Power
Tx1 (Ref)	224.999 MHz		-21.47 dBm
Tx Total			-21.47 dBm

Channel	Bandwidth	Offset	Lower	Upper
Adj	224.999 MHz	359.998 MHz	-0.20 dBc	-30.33 dBc

Fig. 6-34: Spectral view of the notched signal generation and measurement using R&S®NPR

Fig. 6-33 and Fig. 6-34 shows, the achieved notch depth of better than 30 dB. The detailed description of the NPR measurement is available in 1MA29 [10].

6.4.8 EVM measurements in Satellite Payload Testing

The measurement techniques and the measurement parameters that are tested for the verification of expected performance of satellite payloads at the manufacturing stage, has evolved by many folds in the decades since the 1957 Sputnik launch. Recently, satellite manufactures have introduced functional testing as part of test benches for some of their recent payload test campaigns. In addition to the still very typical measurements stated in this application note, a modulation accuracy measurement can verify the quality of a satellite RF link with high precision during satellite integration as well as on-orbit operation. Error Vector Magnitude (EVM) is a popular measurement technique, which is widely used for testing cellular communication system. EVM techniques have already been used in satellite testing to characterize system level performance of a satellite payload using spectrum analyzers. EVM characterization has helped to cut down on test time by weeks in some examples. Especially for regenerative payloads, the EVM is a key test in determining the quality of the regenerated signal inside the transponder.

Fig. 6-35:2 GHz wideband vector signal analysis using R&S®FSW-B2000

When a signal is sent by an ideal transmitter or received by a receiver, it should ideally have the entire constellation precisely at all the ideal locations. But during transmission various imperfections (such as carrier leakage, low image rejection ratio, phase noise etc) cause the actual constellation points to deviate from these wanted locations. Fig. 6-36 shows the constellation diagrams 16 QAM signal that has heavily deviated from their wanted position resulting in poor EVM value.

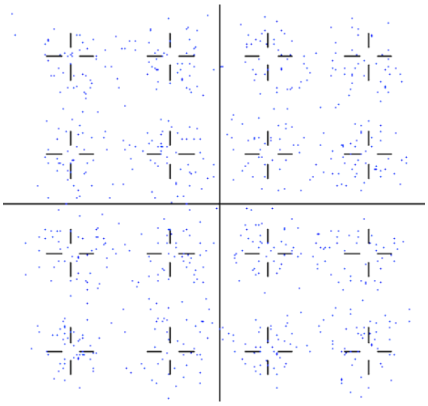
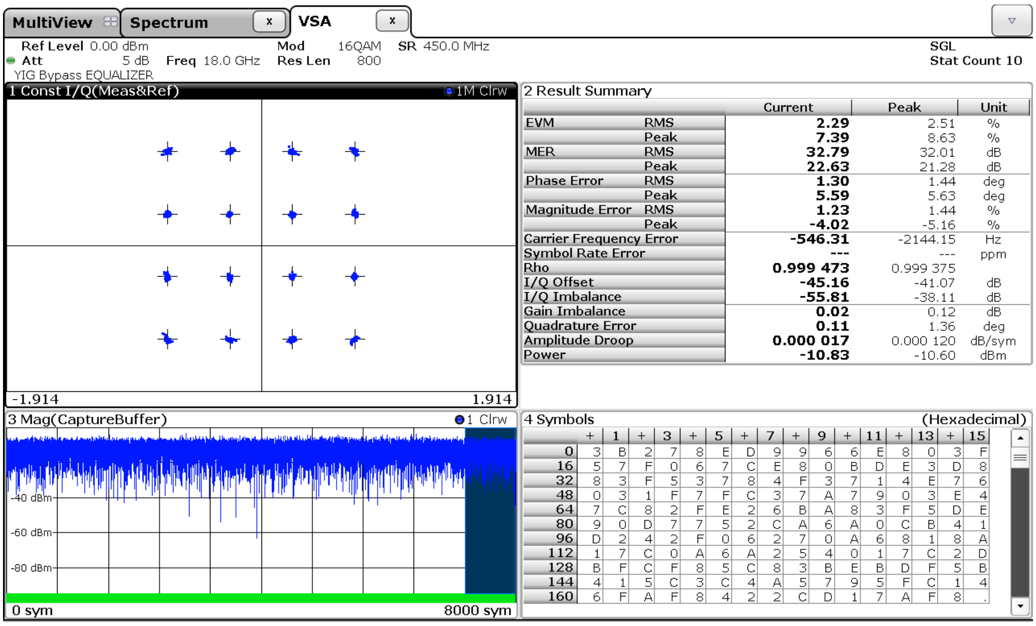


Fig. 6-36: Constellation points of a 16QAM signal deviated from these wanted locations



Ref Level 0.00 dBm
Att 5 dB
Freq 18.0 GHz
Mod 16QAM
Res Len 800
SR 450.0 MHz
SGL
Stat Count 10
YIG Bypass EQUALIZER

2 Result Summary

		Current	Peak	Unit
EVM	RMS	2.29	2.51	%
	Peak	7.39	8.63	%
MER	RMS	32.79	32.01	dB
	Peak	22.63	21.28	dB
Phase Error	RMS	1.30	1.44	deg
	Peak	5.59	5.63	deg
Magnitude Error	RMS	1.23	1.44	%
	Peak	-4.02	-5.16	%
Carrier Frequency Error		-546.31	-2144.15	Hz
Symbol Rate Error		---	---	ppm
Rho		0.999 473	0.999 375	
I/Q Offset		-45.16	-41.07	dB
I/Q Imbalance		-55.81	-38.11	dB
Gain Imbalance		0.02	0.12	dB
Quadrature Error		0.11	1.36	deg
Amplitude Droop		0.000 017	0.000 120	dB/sym
Power		-10.83	-10.60	dBm

4 Symbols (Hexadecimal)

	+	1	+	3	+	5	+	7	+	9	+	11	+	13	+	15
0	3	B	2	7	8	E	D	9	9	6	6	E	8	0	3	F
16	5	7	F	0	6	7	C	E	8	0	B	D	E	3	D	8
32	8	3	F	5	3	7	8	4	F	3	7	1	4	E	7	6
48	0	3	1	F	7	F	C	3	7	A	7	9	0	3	E	4
64	7	C	8	2	F	E	2	6	B	A	8	3	F	5	D	E
80	9	0	D	7	7	5	2	C	A	6	A	0	C	B	4	1
96	D	2	4	2	F	0	6	2	7	0	A	6	8	1	8	A
112	1	7	C	0	A	6	A	2	5	4	0	1	7	C	2	D
128	B	F	C	F	8	5	C	8	3	B	E	B	D	F	5	B
144	4	1	5	C	3	C	4	A	5	7	9	5	F	C	1	4
160	6	F	A	F	8	4	2	2	C	D	1	7	A	F	8	.

Fig. 6-37: 16 QAM signal demodulation and measurement with the VSA mode at 18 GHz

The FSW signal and spectrum analyzer with FSW-K70 (Vector Signal Analysis) option is capable of making EVM measurements for bandwidths up to 2 GHz.

The FSW-K70 option enables users to flexibly analyze digitally modulated single carriers down to the bit level. The clearly structured operating concept simplifies measurements, despite the wide range of analysis tools.

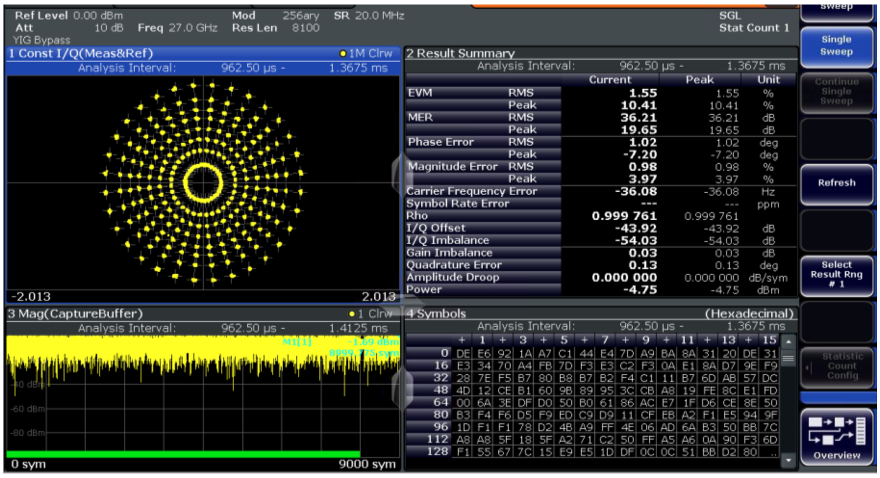
At the time of writing, FSW67 and FSW85 are the only signal and spectrum analyzers in the market offering analysis with full pre-selection at frequencies up to 67 resp. 85 GHz without the requirement to connect an external downconverter. Alternatively, option FSW-B21 allows external mixers to be connected, in which case i.e. an FSW26 can reach into mm-Wave ranges.

The ability to measure and verify performance of wideband signals of great importance. The FSW units are available with an optional capability of up to 2 GHz analysis bandwidth. The FSW-B2000 makes it possible to analyze wideband signals for center frequencies greater than 8 GHz.

With the B2000 turned ON, the R&S®FSW down converts the RF-signal to an IF of 2 GHz. The RTO1044 Oscilloscope digitizes this IF-signal. The digital data is transferred back to the FSW via LAN. The B2000 then resamples and equalizes them and down converts them to the digital baseband. The measurement applications on the FSW receive the equalized IQ data and analyze them like any data stream they obtain from the other analysis bandwidth or digital baseband options.

Configure the B2000 as data source and enter the IP-address of the oscilloscope in the INPUT menu of the FSW. The B2000 then routes the analog IF signal to the IF output, controls the oscilloscope, transfers the digital data to the FSW and does the equalization and re-sampling. Once the B2000 is activated, the supported options are usable the same way as the conventional bandwidth options. The entire setup now performs similarly as if it was a one-box equipment.

The equalization requires an alignment of the full analog signal path – from the RF-input of the FSW to the ADC of the oscilloscope in terms of phase and amplitude vs. frequency. User alignment must be performed once before connecting the RTO to the FSW 2 GHz IF output. For this alignment the RTO is connected to a comb signal at the rear panel of the FSW (part of the B2000 option hardware). An alignment wizard guides the user comfortably through the necessary alignment steps. The resulting amplitude and phase response data are needed for the equalization of the 2GHz IF connection between FSW and RTO, including the RTO digitizer. The B2000 uses both the factory alignment data and the user alignment data to provide equalized IQ data for the FSW measurement applications.



Ref Level 0.00 dBm
Att 10 dB
Freq 27.0 GHz
Mod 256ary
Res Len 8100
SR 20.0 MHz
YIG Bypass
SGL
Stat Count 1

1 Const I/Q(Meas&Ref) Analysis Interval: 962.50 µs - 1.3675 ms

3 Mag(CaptureBuffer) Analysis Interval: 962.50 µs - 1.4125 ms

2 Result Summary

Analysis Interval: 962.50 µs - 1.3675 ms

		Current	Peak	Unit
EVM	RMS	1.55	1.55	%
	Peak	10.41	10.41	%
MER	RMS	36.21	36.21	dB
	Peak	19.65	19.65	dB
Phase Error	RMS	1.02	1.02	deg
	Peak	-7.20	-7.20	deg
Magnitude Error	RMS	0.98	0.98	%
	Peak	3.97	3.97	%
Carrier Frequency Error		-36.08	-36.08	Hz
Symbol Rate Error		---	---	ppm
Rho		0.999 761	0.999 761	
I/Q Offset		-43.92	-43.92	dB
I/Q Imbalance		-54.03	-54.03	dB
Gain Imbalance		0.03	0.03	dB
Quadrature Error		0.13	0.13	deg
Amplitude Droop		0.000 000	0.000 000	dB/sym
Power		-4.75	-4.75	dBm

4 Symbols (Hexadecimal)

Analysis Interval: 962.50 µs - 1.3675 ms

	+	1	+	3	+	5	+	7	+	9	+	11	+	13	+	15
0	DE	E6	92	1A	A7	C1	44	E4	7D	A9	BA	8A	31	20	DE	31
16	E3	34	70	A4	FB	7D	F3	E3	C2	F3	0A	E1	8A	D7	9E	F9
32	28	7E	F5	B7	80	B8	B7	B2	F4	C1	11	B7	6D	AB	57	DC
48	4D	12	CE	B1	60	9B	89	95	3C	CB	A8	19	FE	8C	E1	FD
64	00	6A	3E	DF	D0	50	B0	61	86	AC	E7	1F	D6	CE	8E	50
80	B3	F4	F6	D5	F9	ED	C9	D9	11	CF	EB	A2	F1	E5	94	9F
96	1D	F1	F1	78	D2	4B	A9	FF	4E	06	AD	6A	B3	50	BB	7C
112	A8	A8	5F	18	5F	A2	71	C2	50	FF	A5	A6	0A	90	F3	6D
128	F1	55	67	7C	15	E9	E5	1D	DF	0C	0C	51	BB	D2	80	..

Fig. 6-38: 256APSK modulated DVB-S2X signal measurement on the FSW at 27 GHz

Fig. 6-38 shows the DVB-S2X signal with 256APSK modulation being analyzed at 27 GHz using the K70 option on the FSW.

A complementary application note on the generation of DVB-S2X signals in K-band and analysis using Rohde & Schwarz instruments can be found in 1MA273 [15].

7 References

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8 Ordering Information

Designation	Type	Order No.
Vector Network Analyzer*		
R&S®ZVA40	Vector Network Analyzer, 10MHz to 40GHz, Four ports, four generators / sources	1145.1110.48
R&S®ZVA40-B16	Direct generator/receiver access for 4 port ZVA40	1164.0209.42
R&S®ZVA40-B9	Set of cables for the ZVA-K9	1305.6541.03
R&S®ZVA-K4	Frequency Conversion	1164.1863.02
R&S®ZVA-K9	Embedded LO Mixer Delay Measurements	1311.3128.02
R&S®ZVA-K10	Long Distance Group Delay Measurement	1164.1805.02
R&S®ZVA40-B31	Receiver Step Attenuator, Port 1	1302.5444.02
R&S®ZVA40-B32	Receiver Step Attenuator, Port 2	1302.5450.02
R&S®ZVA40-B33	Receiver Step Attenuator, Port 3	1302.5467.02
R&S®ZVA40-B34	Receiver Step Attenuator, Port 4	1302.5473.02
R&S®ZVA40-B21	Generator Step Attenuator, Port 1	1302.5409.02
R&S®ZVA40-B22	Generator Step Attenuator, Port 2	1302.5415.02
R&S®ZVA40-B23	Generator Step Attenuator, Port 3	1302.5421.02
R&S®ZVA40-B24	Generator Step Attenuator, Port 4	1302.5438.02
Signal and Spectrum Analyzer*		
R&S®FSW43	Signal und spectrum analyzer 2 Hz to 43.5 GHz	1312.8000.43
R&S®FSW50	Signal und spectrum analyzer 2 Hz to 50 GHz	1312.8000.50
R&S®FSW67	Signal und spectrum analyzer 2 Hz to 67 GHz	1312.8000.67
R&S®FSW85	Signal und spectrum analyzer 2 Hz to 85 GHz	1312.8000.85
R&S®FSW -B24	RF preamplifier, 100 kHz to 43 GHz	1313.0832.43
R&S®FSW -B8	Resolution bandwidth > 10 MHz	1313.2464.02
R&S®FSW -B160	160 MHz Analysis Bandwidth	1313.1668.02

R&S®FSW -K160R	Real-Time Spectrum Analyzer	1313.5340.02
R R&S®FSW -K70	Vector Signal Analysis	1313.1416.02
R&S®FSW -K40	Phase Noise Measurements	1313.1397.02
R&S®FSW -K30	Noise Figure Measurements	1313.1380.02
R&S®FSW -B500	500 MHz Analysis Bandwidth	1313.4296.02
R&S®FSW -K17	Multicarrier Group Delay Measurements	1313.4150.02
R&S®FSW -B4	OCXO Precision Reference Frequency	1313.0703.02
R&S®FSW-B17	Digital Baseband Interface	1313.0784.02
R&S®FSW-B71	Analog Baseband Inputs	1313.1651.13
R&S®FSW-B25	Electronic Attenuator, 1 dB steps	1313.0990.02
R&S®FSWP26	Phase Noise Analyzer, 1 MHz to 26.5 GHz	1322.8003.26
R&S®FSWP-B60	Cross Correlation, 26 GHz	1322.9800.26
R&S®FSWP-B64	Additive Phase Noise Measurements	1322.9900.26
R&S®FSWP-B4	High Stability OCXO	1325.3890.02
R&S®FSWP-B1	Spectrum Analyzer, 10 Hz to 26 GHz	1322.9997.26
R&S®FSWP-B8	Resolution Bandwidth > 10 MHz	1313.2464.26
R&S®FSWP-B13	Highpass Filter for Harmonic Measurements	1325.4350.02
R&S®FSWP-B24	RF Preamplifier, 100 kHz to 26.5 GHz	1325.3725.26
R&S®FSWP-B80	80 MHz Analysis Bandwidth	1325.4338.02
R&S®FSWP-K4	Pulsed Phase Noise Measurements	1325.5043.02
R&S®FSWP-K7	Analog Modulation Analysis for AM/FM/φM	1325.4238.02
R&S®FSWP-K30	Noise Figure Measurements	1325.4244.02
R&S®FSWP-K70	Vector Signal Analysis	1325.4280.0
Vector Signal Generator*		
R&S®SMW200A	Vector Signal Generator	1412.0000.02
R&S®SMW-B140	100 kHz to 40 GHz, RF Path A	1413.0604.02
R&S®SMW-B13	Signal Routing and Baseband Main Module, one I/Q path to RF	1413.2807.02
R&S®SMW-B10	Baseband Generator with ARB (64 Msample) and Digital	1413.1200.02

	Modulation (realtime), 120 MHz RF bandwidth	
R&S®SMW-B22	Enhanced Phase Noise Performance and FM/φM Modulator	1413.2207.02
R&S®SMW-K24	Multifunction Generator	1413.3332.02
R&S®SMW-K739	Differential Analog I/Q Inputs	1413.7167.02
R&S®SMW-K512	ARB Memory Extension to 1 Gsample	1413.6919.02
R&S®SMW-K61	Multicarrier CW Signal Generation	1413.4280.02
R&S®SMW-K522	Baseband Extension to 160 MHz RF bandwidth	1413.6960.02
Power Sensor*		
R&S®NRP33S	100 pW to 200 mW, 10 MHz to 33 GHz three-path diode power sensors	1419.0064.02
R&S®NRP33SN	100 pW to 200 mW, 10 MHz to 33 GHz (LAN)	1419.0070.02
R&S®NRP33SN-V	10 MHz to 33 GHz, 100 pW to 200 mW, LAN, TVAC-Compliant	1419.0129.02
R&S®NRP-Z55	Thermal Power Sensor model .04, DC to 44 GHz	1138.2008.04
R&S®NRP-Z56	Thermal Power Sensor, DC to 50 GHz	1171.8201.02
R&S®NRP-Z57	Thermal Power Sensor, DC to 67 GHz	1171.8401.02
R&S®NRP-Z21	-67 dBm to +23 dBm, 10 MHz to 18 GHz, three-path diode power sensors	1137.6000.02

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