Application Note

WIDEBAND MM-WAVE SIGNAL GENERATION AND ANALYSIS

Products:

- R&S®SMA200A
- R&S®SMB100A
- R&S®SMA100B
- R&S®SZU100A
- R&S®FSW
- R&S®FSW-B2001/B4001/B6001/B8001
- R&S®FSW-B21
- R&S®FSW-B21
- R&S®FSW-K70
- R&S®VSE
- R&S®FS-Z75
- R&S®FS-Z90
- R&S®RTO2000
- R&S®RTP

R. Minihold, R. Wagner | 1MA257 | Version 7e | 02.2022

Note:

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Contents

1 Overview

Generation of wideband digital modulated signals in V-band and above is a challenging task and typically requires a set of multiple instruments. This application note aims at simplifying the task and looks into the analysis part as well. Latest signal and spectrum analyzers like the R&S®FSW67 and R&S®FSW85 are first to allow use in V-band up to 67 GHz and E-band up to 85 GHz respectively without external frequency conversion. Up to 8.3 GHz of modulation bandwidth can be covered using the R&S®FSW-B8001 option. Millimeter wave use of analyzers ranging from 26 GHz up is shown.

Application note 1MA217 describes V-band signal generation and analysis up to 500 MHz modulation bandwidth. This application note expands modulation bandwidth up to 2 GHz and covers both V- and E-band examples.

This application note uses the following abbreviations for Rohde & Schwarz products:

- The R&S®SMW200A Vector Signal Generator is referred to as **SMW200A**
- The R&S®SMB100A RF and Microwave Signal Generator is referred to as **SMB100A**
- The R&S®SMA100B RF and Microwave Signal Generator referred to as **SMA100B**
- The R&S®FSW Signal and Spectrum Analyzer is referred to as **FSW**
- The R&S®RTO2000 Digital Oscilloscope is referred to as **RTO2000**
- The R&S®RTP High-performance oscilloscope is referred to as **RTP**
- The R&S®FSW-B2001 2 GHz Analysis Bandwidth is referred to as **FSW-B2001**
- The R&S®FSW-B4001 4.4 GHz Analysis Bandwidth is referred to as **FSW-B4001**
- The R&S®FSW-B6001 6.4 GHz Analysis Bandwidth is referred to as **FSW-B6001**
- The R&S®FSW-B8001 8.3 GHz Analysis Bandwidth is referred to as **FSW-B8001**
- The R&S®FSW-B21 LO/IF Connections for External Mixers is referred to as **FSW-B21**
- The R&S®FSW-K70 Vector Signal Analysis is referred to as **FSW-K70**
- The R&S®VSE Vector Signal Explorer Software is referred to as **VSE**
- The R&S®VSE-K70 Vector Signal Analysis is referred to as **VSE-K70**
- The R&S®FS-Zxx Harmonic Mixers are referred to as **FS-Zxx**
- The R&S®SZU100A IQ Upconverter are referred to as **SZU100A**
- The R&S®SMW-B13XT Wideband Main Module is referred to as **SMW-B13XT**
- The R&S®SMW-B9 Wideband Baseband Generator with ARB, 500MHz RF bandwidth is referred to as **SMW-B9**

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2 Motivation

High modulation bandwidth up to 2 GHz and beyond, are proposed e.g. for automotive radar and "5G" mobile communication applications.

The 802.11ad WLAN standard already uses V-band frequencies with a modulation bandwidth of 1.76 GHz (single carrier mode). Table 1 highlights mm-wave bands which are already used by communication and automotive radar applications.

Frequency bands in the mm-wave range (license light or unlicensed)		
V-band (57 GHz to 64 GHz)	unlicensed spectrum in many countries	Already used for Wireless LAN according to 802.11ad standard Potential use for "5G" applications
Lower E-Band (71 GHz to 76 GHz)	License-light spectrum	Potential use for "5G" applications
Middle-E-band (77 to 81 GHz)		Used by high-resolution automotive radar applications.
Upper E-band (81 GHz to 86 GHz)	License-light spectrum	Potential use for "5G" applications
W-band (92 to 95 GHz)	Indoor uses are unlicensed in many countries; outdoor use is "license-light"	Potential use for "5G" applications except 94 GHz to 94.1 GHz which is in use for radio astronomy

Table 1: Bands in the mm-wave range which are already used by communication and automotive radar applications or which are considered as interesting for "5G" as unlicensed of "license-light" bands.

Figure 1 illustrates available license-light or unlicensed frequency ranges in V-, E- and W-band in the frequency domain.

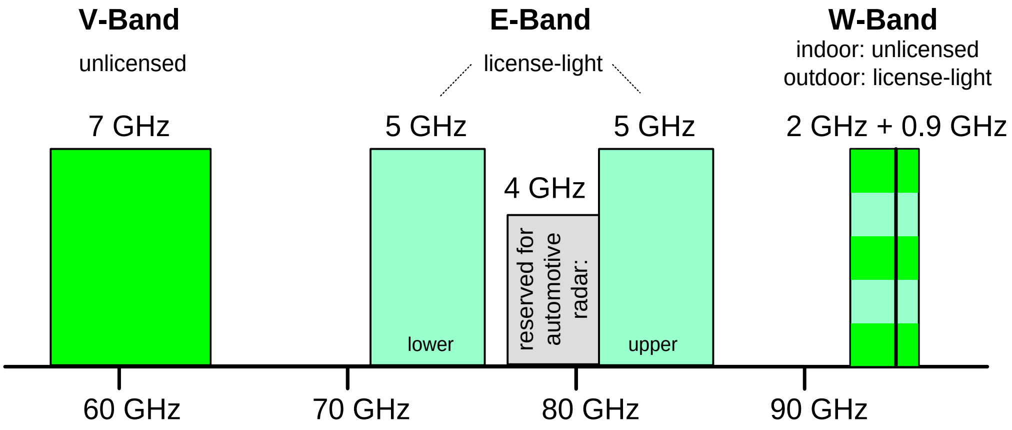

Figure 1: Unlicensed or license-light frequency ranges in V-, E-Band and W-Band

Generation of wideband digital modulated signals in V-band and above is a challenging task and typically requires a set of multiple instruments. Latest signal and spectrum analyzers like the FSW67 and FSW 85 are first to allow use in V-band up to 67 GHz or in E-band up to 85/86[1] GHz respectively without external frequency conversion. With installed FSW-B2001, -B4001, -B6001 or -B8001 the, the FSW26 through FSW85 family of analyzers cover a demodulation bandwidth of 2 GHz, 4.4 GHz, 6.4 GHz and 8.3 GHz. This application note describes setups for wideband digital modulated signal generation in V- band and E-band and shows the use of FSW67 and FSW85 for wide-band V- Band and E-band applications as well as use of

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[1] only in vector signal analysis mode, FS-K70 required

FSW26/43/50 plus FS-Zxx mixers in the range 57 GHz to beyond 80 GHz. Chapter 4.3 describes how the receiver part of V-and E-band transceiver can be tested with the RTP or RTO2000 Oscilloscope with installed VSE Software and VSE-K70 option.

3 Setups

3.1 Setup for V-band

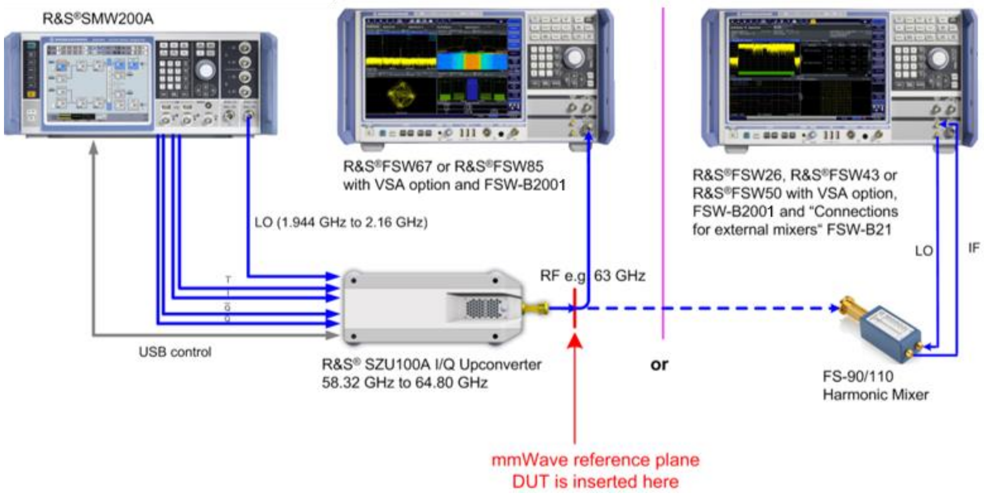


Figure 2: Setup for wide band V-band Signal Generation and Analysis

The SMW200A with up to 2 GHz modulation bandwidth generates a modulated test signal. For a differential I/Q connection its analog I, I_{inv} and Q, Q_{inv} signals fed to the I, I_{inv} and Q, Q_{inv} input of the SZU100A Upconverter. The differential mode is recommended due to better common mode noise suppression over the single ended connection.

The SMW200A produces a CW Signal (1.944 GHz to 2.16 GHz) which is fed as LO signal for the up-conversion to the LO input of the SZU100A. For ease of operation the SMW200A controls the SZU100A remotely via the USB connection. This allows making the settings for frequency and level via the SMW200A user interface.

► Signal Analysis:

Wide Band Signal Analysis is provided by one of:

- an FSW67 with VSA option FSW-K70 and option FSW-B2001 (up to 67 GHz)
- an FSW85 with VSA option FSW-K70 and option FSW-B2001 (up to 86 GHz)
- an FS-Z75 harmonic mixer and an FSW26 or FSW43 with VSA option FSW-K70 and options "Connections for external mixers" FS-Z21 and FS-B2001

3.2 Setup for E-bands

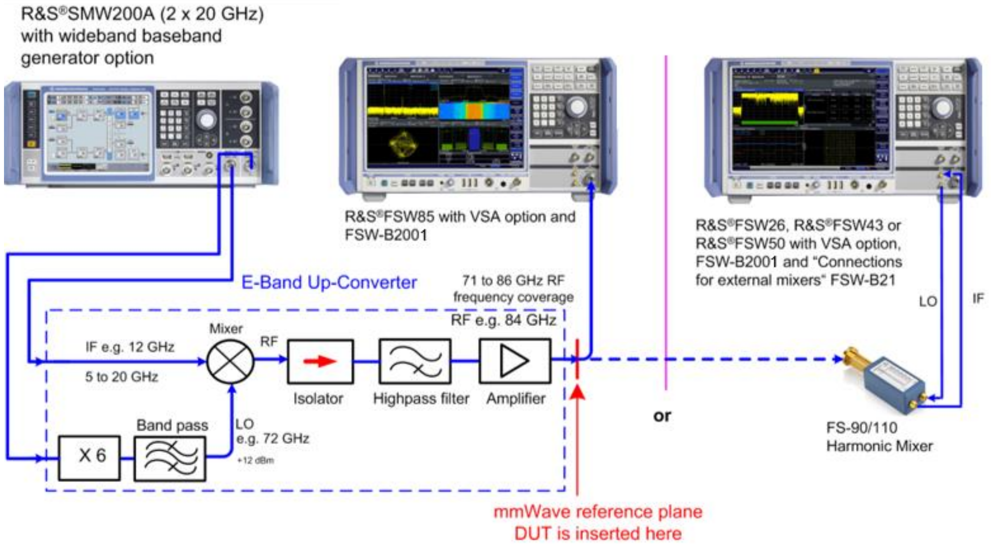


Figure 3: Setup for wide band E-band Signal Generation and Analysis

For signal generation, the E-band upconverter is realized by using discrete components: Here a multiplier by 6 is used (because of the availability) and the other components are chosen corresponding to requested frequency range.

Especially the bandpass filter are chosen carefully to eliminate higher harmonics of the multiplier from the mixer LO port, which could possibly cause spurious problems in the upconverters output signal (see 3.2.1 and 3.2.2).

► Generation of modulated IF signal 5 to 20 GHz:

The SMW200A (20 GHz model) with up to 2 GHz modulation bandwidth and internal wideband baseband Generator with arbitrary waveform generator generates the modulated IF signal. This signal is fed to the IF input of the E-band waveguide mixer.

► Generation of LO signal for up-conversion

The second channel of the SMW200A (or alternatively a suitable SMB100A or SMA100B) produces a CW Signal e.g. 12 GHz which is fed to the input of an active multiplier. The output of the multiplier e.g. 72 GHz is further band pass filtered and used as a local signal for an E-band upconverter-mixer.

► Up-conversion

The mixer linearly up-converts the IF input signal to RF (mm-wave frequency range) following the formula: $f_{RF} = f_{LO} \pm f_{IF}$.

The RF output of the upconverter mixer is terminated by an isolator and followed by a high pass filter which suppresses the lower sideband: $f_{LO} - f_{IF}$ and the LO feedthrough. The isolator reduces pass band ripple. The used upper sideband $f_{LO} + f_{IF}$ is amplified and is available at the “mm-Wave reference plane” for testing e.g. an E- band receiver, or E- band transceiver components like an amplifier.

On the analysis side, the higher frequency demands the use of an FSW85 instead of an FSW67. Alternatively, using an external mixer, an FS-Z90 instead of an FS-Z75.

Using the recommended setup for mm-Wave signal generation and analysis is fairly straightforward. However, depending on the frequency settings, some crucial points and how to overcome them are highlighted in the following.

3.2.1 Spurious Due to Harmonics of Multiplier

The E-band upconverter uses a multiplier with a factor of 6. Due to imperfections of the multiplier, the output signal contains harmonics of the input signal and has to be band-pass filtered. For a LO frequency of 66 GHz, the 6x-multiplier input signal is 11 GHz. The 7th harmonic is at 77 GHz and is in the E-band and has to be filtered.

3.2.2 Spurious Due to Mixing

Possible spurious at the mm-reference plane caused by the formerly described up-conversion follow the rule:

$f_{SP} = n * f_{IF} \pm m * f_{LO}$, where $n = \pm 0, 1, 2, 3$ ... and $m = \pm 0, 1, 2, 3$ ...

Beside multiples of the f_{LO} component, spurious appear in the shape of the digitally modulated IF signal. The bandwidth of these signals is $n * (bandwidth\ at\ f_{IF})$

Typically, the lower order spurious like $2 * f_{LO} - 3 * f_{IF}, 2 * f_{LO} - 4 * f_{IF}, 3 * f_{LO} - 4 * f_{IF}$, ... have the higher power levels compared to the higher order ones.

Low order spurious signals may become critical if they fall into the band of interest and/or get close to the wanted output signal. Modulation parameters such as EVM of the wanted signal may degrade significantly in this case.

The perhaps tempting choice of LO and IF frequencies being close to each other results in a situation where lower order (and hence stronger) spurious will fall into the vicinity of the wanted signal.

Example (E-band):

If we aim to generate an 84 GHz digitally modulated signal in the E-band frequency range 71 to 86 GHz, then using e.g. an IF frequency of 12 GHz and a LO frequency of 72 GHz we get:

- $2 * 72\ GHz - 3 * 12\ GHz = 108\ GHz$: significant level (3rd IF harm.) but far out of band.
- $2 * 72\ GHz - 4 * 12\ GHz = 96\ GHz$: still 10 GHz out of band, but reasonably low level
- (4th harm.), certainly must be monitored.
- $3 * 72\ GHz - 4 * 12\ GHz = 168\ GHz$: far out of band

Rules of thumb:

The higher IF frequencies used in composition of a band to be covered tend to be the more critical ones.

The lower order harmonics of any given IF are the more critical ones.

Mixing products with $3 * f_{LO}, 4 * f_{LO}$ and higher which fall into the band of interest are higher order IF harmonics and therefore generally have low power.

3.3 Using of Harmonic Mixer

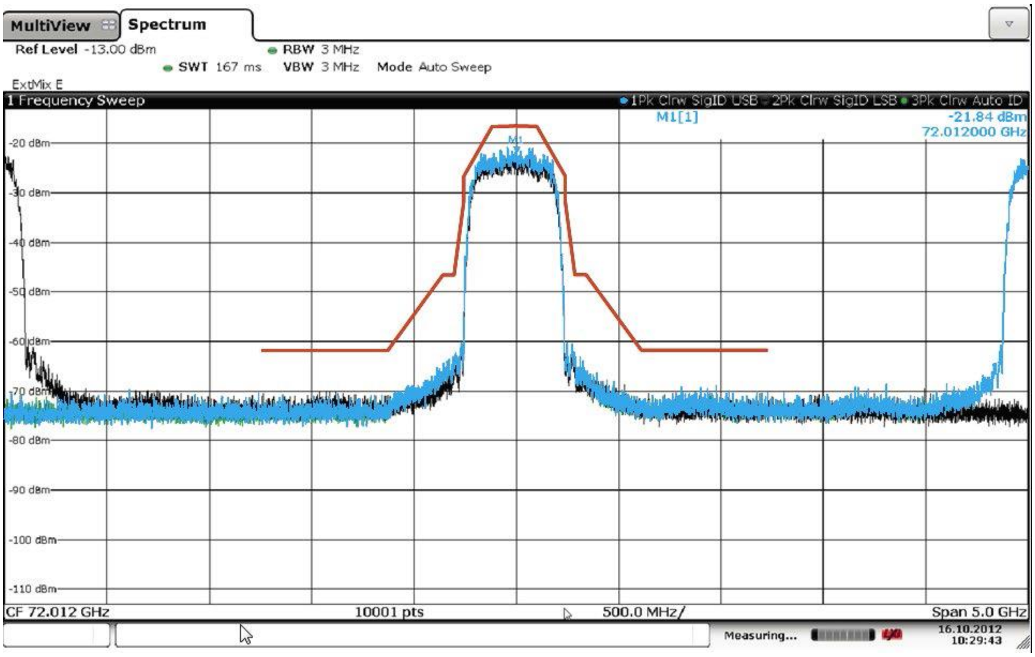
The R&S®FSW85 covers measurements up to 85 GHz. Using the FSW to carry out spectrum measurements beyond the nominal 85 GHz limit, e.g. further up in the E-Band is possible with external harmonic mixers of the FS-Z family. For frequencies below 85 GHz, use of harmonic mixers instead of the FSW85 model may also be attractive with regard to budget.

3.3.1 Spurious Due to Harmonic Mixer

When the FS-Z family harmonic mixers are employed, additional considerations apply.

FS-Z mixers multiply the spectrum analyzer’s local oscillator output signal and use a suitable harmonic to down convert the DUT's millimeter-wave signal to the analyzer’s intermediate frequency. However, the number of harmonics created in the mixer and the input signal and its own harmonics produce a multitude of signal components in the spectrum. In addition, the image frequency range is not suppressed as there is no pre-selector for this purpose.

The FSW signal and spectrum analyzer family with the FSW-B21 option (LO/IF connectors for external mixers) have a major advantage compared to conventional instruments. With an intermediate frequency of 1.3 GHz (in spectrum analyzer mode, in VSA mode an intermediate frequency of 2 GHz is used), the FSW analyzers have an image-free frequency range of 2.6 GHz. This makes it easy to measure wideband-modulated signals, even if their bandwidth reaches into the GHz range. Together with the latest generation of Rohde & Schwarz harmonic mixers, e. g. the FS-Z90 (60 GHz to 90 GHz), the achievable dynamic range is truly unique. The mixer has a typical conversion loss of 23 dB at 80 GHz, resulting in a displayed average noise level (DANL) of approximately -150 dBm/Hz for the test setup, i.e. including the mixer's and analyzer's contributions.



Ref Level -13.00 dBm
RBW 3 MHz
SWT 167 ms
VBW 3 MHz
Mode Auto Sweep
ExtMix E
1 Frequency Sweep
1Pk Clrw SigID USB 2Pk Clrw SigID LSB 3Pk Clrw Auto ID
M1[1] -21.84 dBm 72.012000 GHz
CF 72.012 GHz
10001 pts
500.0 MHz/
Span 5.0 GHz
Measuring...
16.10.2012 10:29:43

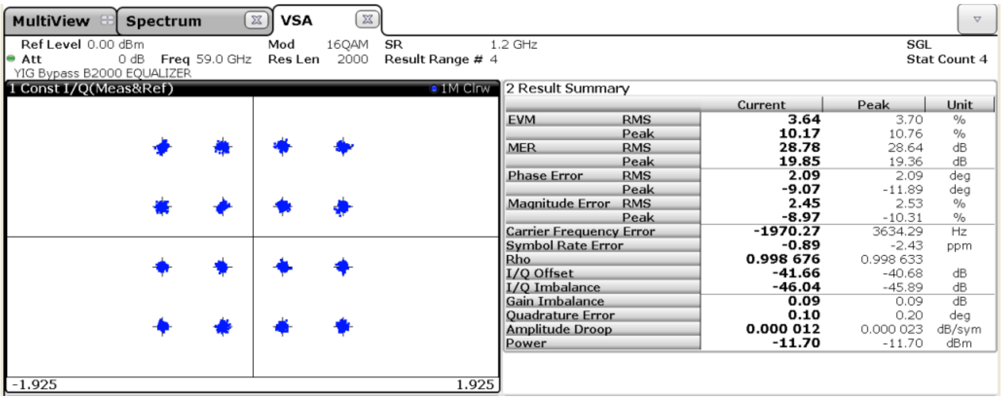
Figure 4: Measurement of a 500 MHz bandwidth E band input signal with an FSW signal and spectrum analyzer with the FS-Z90 Harmonic Mixer. The input and image-frequency signal are 2.6 GHz apart. Measuring the spectrum mask or analyzing the modulation quality of significantly wider signals is possible without any difficulty.

4 Test Results

This section serves to verify and demonstrate the typical performance of both R&S signal generation and signal analysis capabilities in the mm-wave ranges covered by this paper. Note that for all of the following modulation measurements the FSW equalizer is active in VSA mode and eliminates the frequency slope influence within the modulation bandwidth. Without using the equalizer function in VSA mode, the measured EVM values increase by a factor of 4 to 5. However, for typical wideband digital modulation systems such as OFDM (also with IEEE 802.11ad single carrier mode) the EVM is defined with equalized frequency slope, so that the EVM measurement results shown are representative for real world values.

4.1 Typical Performance of the Proposed Test Setup

Figure 5 shows the typical EVM performance of the proposed setup shown in Figure 2 using an FSW85 with option "2 GHz Analysis Bandwidth" FSW-B2001. The SMW200A generates the LO Signal for the SZU100A up converter. The 16QAM modulated baseband signal is generated by the internal arbitrary waveform generator with a symbol rate of 1.2 Gsymb/s. This I/Q baseband signal is up-converted by the SZU100A to 59 GHz. The FSW analyses the 59 GHz signal and measures an EVM of 3.6%.



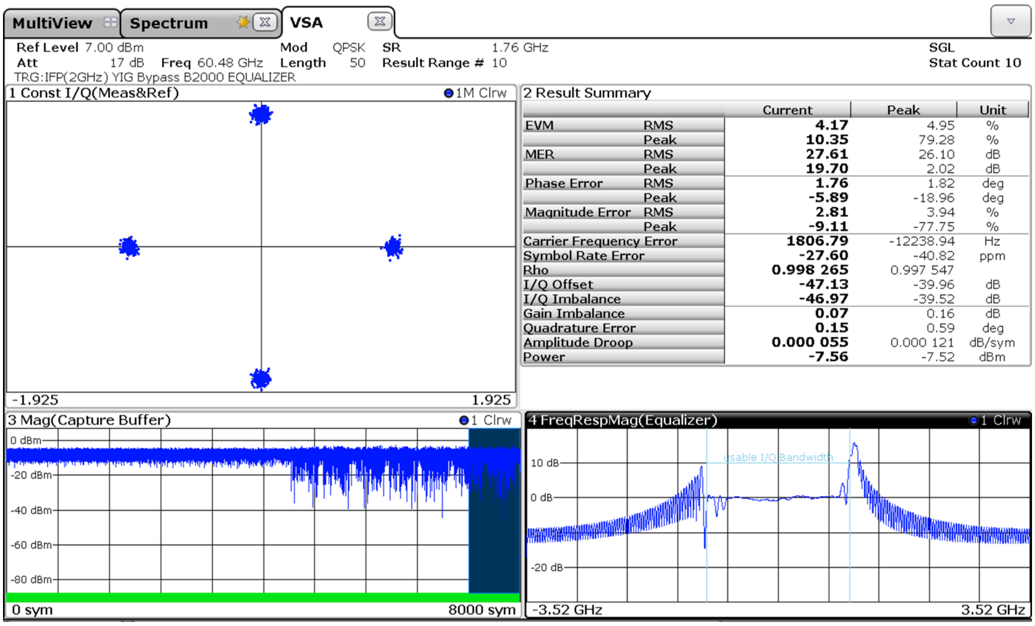
Ref Level 0.00 dBm
Att 0 dB Freq 59.0 GHz
YIG Bypass B2000 EQUALIZER
Mod 16QAM
Res Len 2000
SR 1.2 GHz
Result Range # 4
SGL
Stat Count 4

2 Result Summary

		Current	Peak	Unit
EVM	RMS	3.64	3.70	%
	Peak	10.17	10.76	%
MER	RMS	28.78	28.64	dB
	Peak	19.85	19.36	dB
Phase Error	RMS	2.09	2.09	deg
	Peak	-9.07	-11.89	deg
Magnitude Error	RMS	2.45	2.53	%
	Peak	-8.97	-10.31	%
Carrier Frequency Error		-1970.27	3634.29	Hz
Symbol Rate Error		-0.89	-2.43	ppm
Rho		0.998 676	0.998 633	
I/Q Offset		-41.66	-40.68	dB
I/Q Imbalance		-46.04	-45.89	dB
Gain Imbalance		0.09	0.09	dB
Quadrature Error		0.10	0.20	deg
Amplitude Droop		0.000 012	0.000 023	dB/sym
Power		-11.70	-11.70	dBm

Figure 5: Constellation diagram and EVM measurement on a 59 GHz up-converted wideband 16QAM signal from a SMW200A signal generator modulated by the internal arbitrary waveform generator

Figure 6 shows another example: The performance of the test setup when generating and analyzing an IEEE 802.11ad (WiGig) signal at channel 2 (60.48 GHz) with π/2-QPSK single carrier modulation at 1.76 Gsymb/s. At this higher modulation rate still an EVM of < 5% can be achieved. The FSW displays the constellation diagram, result summary, capture buffer and the frequency response of the equalizer. (The configuration of the displayed results is conveniently possible using the FSW touchscreen.)



Ref Level 7.00 dBm **Mod** QPSK **SR** 1.76 GHz **SGL**
Att 17 dB **Freq** 60.48 GHz **Length** 50 **Result Range #** 10 **Stat Count 10**
TRG:IFP(2GHz) YIG Bypass B2000 EQUALIZER

2 Result Summary

		Current	Peak	Unit
EVM	RMS	**4.17**	4.95	%
	Peak	**10.35**	79.28	%
MER	RMS	**27.61**	26.10	dB
	Peak	**19.70**	2.02	dB
Phase Error	RMS	**1.76**	1.82	deg
	Peak	**-5.89**	-18.96	deg
Magnitude Error	RMS	**2.81**	3.94	%
	Peak	**-9.11**	-77.75	%
Carrier Frequency Error		**1806.79**	-12238.94	Hz
Symbol Rate Error		**-27.60**	-40.82	ppm
Rho		**0.998 265**	0.997 547	
I/Q Offset		**-47.13**	-39.96	dB
I/Q Imbalance		**-46.97**	-39.52	dB
Gain Imbalance		**0.07**	0.16	dB
Quadrature Error		**0.15**	0.59	deg
Amplitude Droop		**0.000 055**	0.000 121	dB/sym
Power		**-7.56**	-7.52	dBm

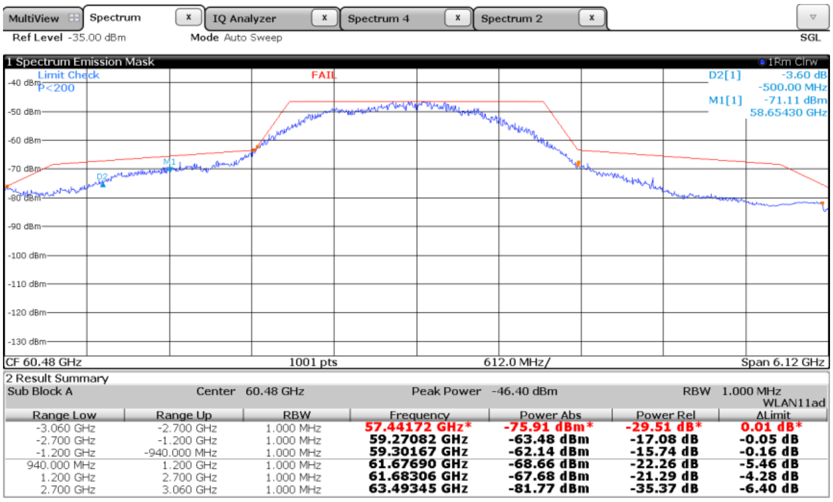
Figure 6: Modulation Measurement of an FSW on an IEEE 802.11ad (WiGig) signal generated by the setup shown in Typical applications and test results

This chapter demonstrates test results and setups with two different test devices:

- a commercial 802.11ad transmitter and
- a commercial V-band transceiver for backhaul applications

4.2 Tests on a Commercial 802.11ad Transmitter

Figure 7 shows a spectrum emission mask measurement result of an FSW 67 of an IEEE 802.11ad device transmitting at channel 2. The left slope of the spectrum induces a FAIL of the spectrum mask, prompting a re-alignment of the device.



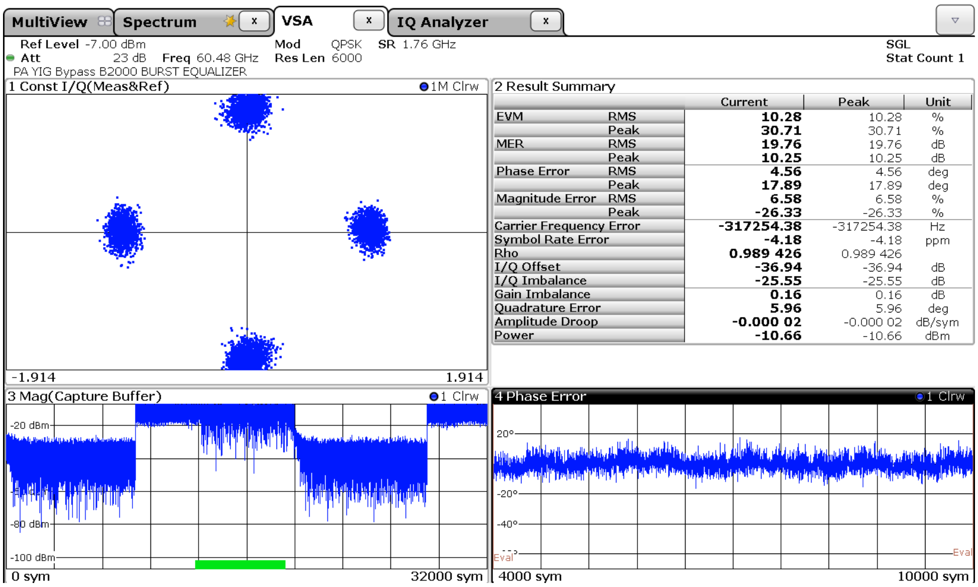
Ref Level -35.00 dBm **Mode** Auto Sweep **SGL**

2 Result Summary
Sub Block A Center 60.48 GHz Peak Power -46.40 dBm RBW 1.000 MHz
WLAN11ad

Range Low	Range Up	RBW	Frequency	Power Abs	Power Rel	ΔLimit
-3.060 GHz	-2.700 GHz	1.000 MHz	**57.44172 GHz***	**-75.91 dBm***	**-29.51 dB***	**0.01 dB***
-2.700 GHz	-1.200 GHz	1.000 MHz	**59.27082 GHz**	**-63.48 dBm**	**-17.08 dB**	**-0.05 dB**
-1.200 GHz	-940.000 MHz	1.000 MHz	**59.30167 GHz**	**-62.14 dBm**	**-15.74 dB**	**-0.16 dB**
940.000 MHz	1.200 GHz	1.000 MHz	**61.67690 GHz**	**-68.66 dBm**	**-22.26 dB**	**-5.46 dB**
1.200 GHz	2.700 GHz	1.000 MHz	**61.68306 GHz**	**-67.68 dBm**	**-21.29 dB**	**-4.28 dB**
2.700 GHz	3.060 GHz	1.000 MHz	**63.49345 GHz**	**-81.77 dBm**	**-35.37 dB**	**-6.40 dB**

Figure 7: FSW67 Spectrum emission mask measurement on an IEEE 801.11ad (WiGig) device transmitting at channel 2

Figure 8 shows a modulation measurement on an IEEE 802.11ad device transmitting at channel 2 by an FSW67. The constellation diagram, result summary, magnitude of the capture buffer and phase error are displayed.



Ref Level -7.00 dBm
Att 23 dB Freq 60.48 GHz
Mod QPSK SR 1.76 GHz
Res Len 6000
SGL
Stat Count 1
PA YIG Bypass B2000 BURST EQUALIZER

2 Result Summary

		Current	Peak	Unit
EVM	RMS	**10.28**	10.28	%
	Peak	**30.71**	30.71	%
MER	RMS	**19.76**	19.76	dB
	Peak	**10.25**	10.25	dB
Phase Error	RMS	**4.56**	4.56	deg
	Peak	**17.89**	17.89	deg
Magnitude Error	RMS	**6.58**	6.58	%
	Peak	**-26.33**	-26.33	%
Carrier Frequency Error		**-317254.38**	-317254.38	Hz
Symbol Rate Error		**-4.18**	-4.18	ppm
Rho		**0.989 426**	0.989 426	
I/Q Offset		**-36.94**	-36.94	dB
I/Q Imbalance		**-25.55**	-25.55	dB
Gain Imbalance		**0.16**	0.16	dB
Quadrature Error		**5.96**	5.96	deg
Amplitude Droop		**-0.000 02**	-0.000 02	dB/sym
Power		**-10.66**	-10.66	dBm

Figure 8: Modulation Measurement on an 801.11ad device transmitting at channel 2 by an FSW67 (showing Constellation diagram, Result Summary, Magnitude of Capture Buffer and Phase Error).

4.3 Tests on V- and E-band Transceivers for Backhaul Applications (Supplier: "Infineon Technologies AG")

In the following, test setups are described for tests on the receiver and transmitter parts of V- and E-band transceivers. Measurement results from commercial V- and E-band transceivers for backhaul applications are presented.

4.3.1 Transmitter Part

Figure 9 shows two possible test setups for testing the transmitter part of a V-band or E-band transceiver with wide band modulation. The wideband base band I-Q signal is generated by the SMW200A and fed to the I-Q inputs of the transceiver.

The RF output of the transmitter is connected directly to the RF input of an FSW67 or FSW85 with VSA option and FSW-B2001.

Alternatively, it can be connected via a suitable attenuator to an FS-Zxx series harmonic mixer. An FSW43 with VSA option, FSW-B2001 and external mixer option (FSW-B21) is used for analyzing the RF signal in this case.

If a harmonic mixer is used for measuring the output signal of a transmitter, care has to be taken not to overload it. The FS-Zxx harmonic mixers have a 1-dB compression point of typical -6 dBm. In order not to degrade the performance of the measured signal in terms of adjacent channel power or EVM, the peak level of the signal should be well below the 1-dB compression point (rule of thumb: 15 to 20 dB lower) at the mixer input. Recommended is a wave-guide level setting attenuator in front of the harmonic mixer and its according adjustment for getting optimum dynamic range.

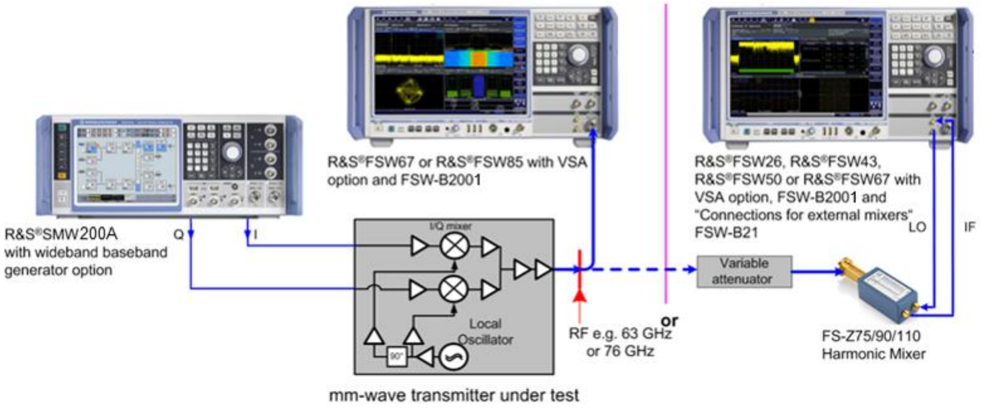
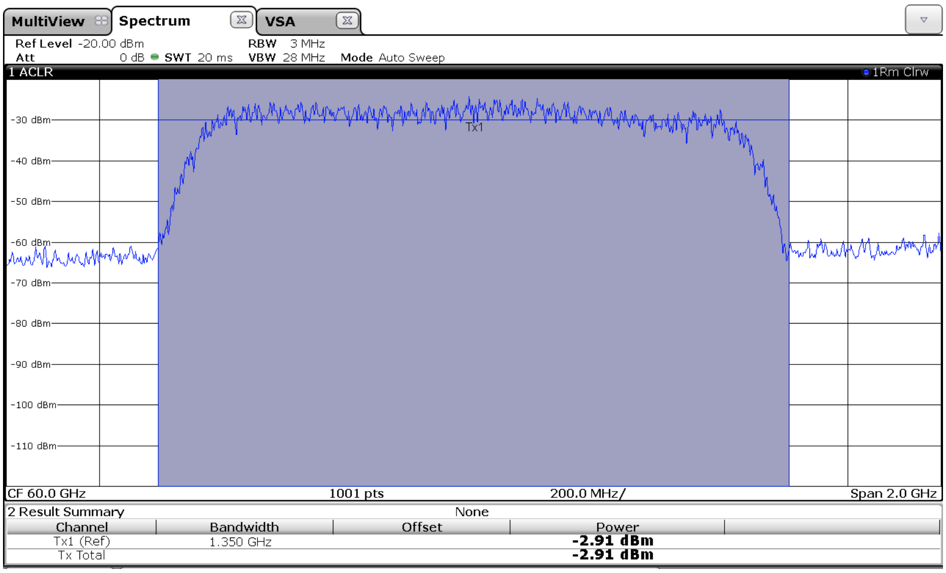


Figure 9: Possible test setups for testing the transmitter part of a V-band or E-band transceiver with wide band modulation

Figure 10 shows a spectrum and channel power measurement of an FSW85 on a commercial V-band transmitter 57 to 64 GHz for backhaul applications. The transmitter is modulated by a 16 QAM baseband signal with a symbol rate of 1.2 Gsymb/s which leads to a 1.35 GHz wide modulation spectrum.



Ref Level -20.00 dBm **RBW** 3 MHz
Att 0 dB **SWT** 20 ms **VBW** 28 MHz **Mode** Auto Sweep

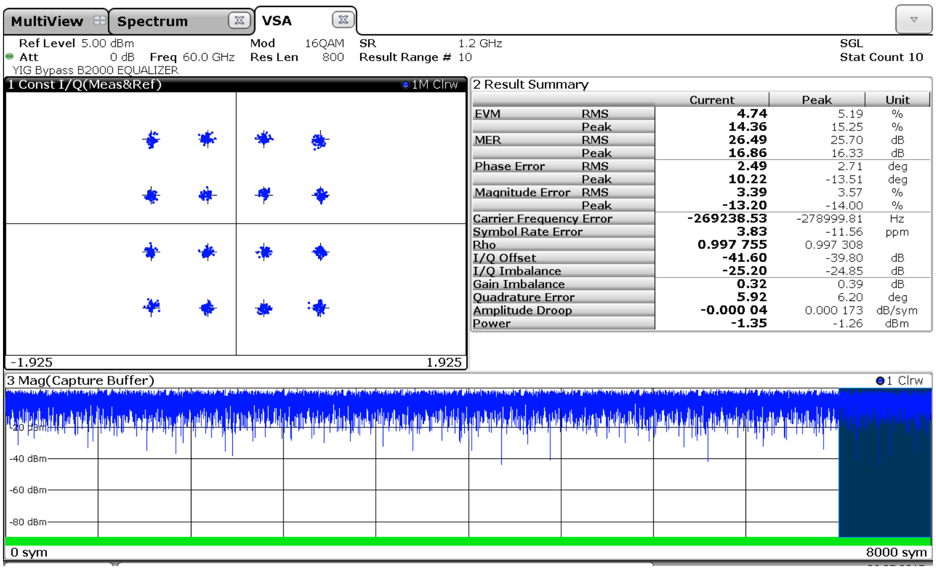
CF 60.0 GHz 1001 pts 200.0 MHz/ Span 2.0 GHz

2 Result Summary None

Channel	Bandwidth	Offset	Power
Tx1 (Ref)	1.350 GHz		**-2.91 dBm**
Tx Total			**-2.91 dBm**

Figure 10: Spectrum and Channel Power Measurement of an FSW67 on a commercial V-band transceiver for backhaul applications.

Figure 11 shows a modulation measurement on a V-band transceiver modulated by a 16QAM signal with a symbol rate of 1.2 Gsymb/s. The constellation diagram, the error summary, the magnitude of the capture buffer and the error vector magnitude over time are displayed. Again, the equalizer of the FSW Vector Signal Analysis measurement option was active with this measurement.



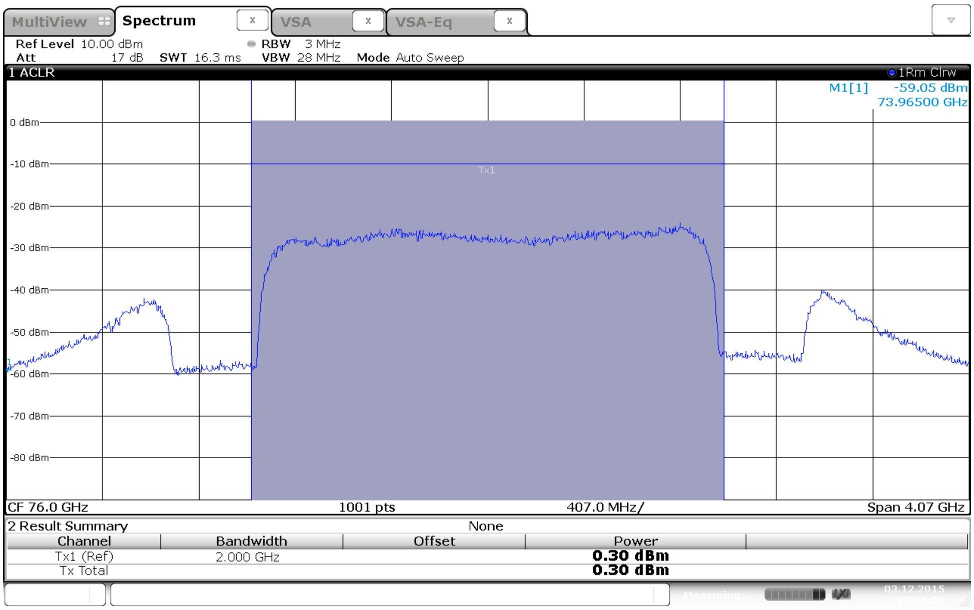
Ref Level 5.00 dBm **Mod** 16QAM **SR** 1.2 GHz **SGL**
Att 0 dB **Freq** 60.0 GHz **Res Len** 800 **Result Range #** 10 **Stat Count 10**
YIG Bypass B2000 EQUALIZER

2 Result Summary

		Current	Peak	Unit
EVM	RMS	**4.74**	5.19	%
	Peak	**14.36**	15.25	%
MER	RMS	**26.49**	25.70	dB
	Peak	**16.86**	16.33	dB
Phase Error	RMS	**2.49**	2.71	deg
	Peak	**10.22**	-13.51	deg
Magnitude Error	RMS	**3.39**	3.57	%
	Peak	**-13.20**	-14.00	%
Carrier Frequency Error		**-269238.53**	-278999.81	Hz
Symbol Rate Error		**3.83**	-11.56	ppm
Rho		**0.997 755**	0.997 308	
I/Q Offset		**-41.60**	-39.80	dB
I/Q Imbalance		**-25.20**	-24.85	dB
Gain Imbalance		**0.32**	0.39	dB
Quadrature Error		**5.92**	6.20	deg
Amplitude Droop		**-0.000 04**	0.000 173	dB/sym
Power		**-1.35**	-1.26	dBm

Figure 11: Modulated signal measurement performed, using a FSW85, on a commercial V-band transceiver for backhaul applications with 16QAM modulation (symbol rate 1.2 Gsymb/s).

Figure 12 shows a spectrum and channel power measurement of an FSW85 on a commercial E-band transmitter 71 to 76 GHz for backhaul applications. The transmitter is modulated by a QPSK baseband signal with a symbol rate of 1.8 Gsymb/s which leads to a 2 GHz wide modulation spectrum with center frequency 76 GHz.



Ref Level 10.00 dBm **RBW** 3 MHz
Att 17 dB **SWT** 16.3 ms **VBW** 28 MHz **Mode** Auto Sweep

2 Result Summary None

Channel	Bandwidth	Offset	Power	
Tx1 (Ref)	2.000 GHz		**0.30 dBm**	
Tx Total			**0.30 dBm**	

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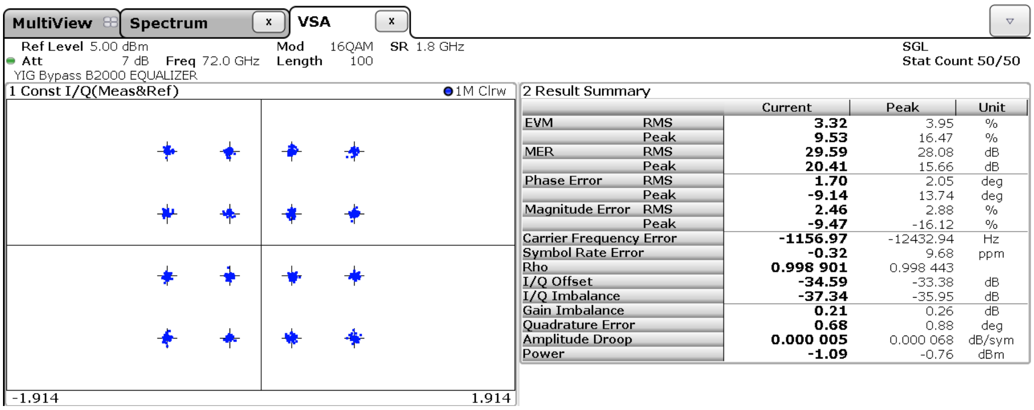
Figure 12: Spectrum and Channel Power Measurement of an FSW85 on a commercial wide band modulated E-band transceiver for backhaul applications transmitting at 76 GHz.

Figure 13 shows an FSW85 modulation measurement on an E-band transmitter with 16-QAM at the 1.8 Gsymb/s rate. The constellation diagram, the error summary, the magnitude of the capture buffer and frequency response of wide band signal (measured by the FSW equalizer) are displayed.



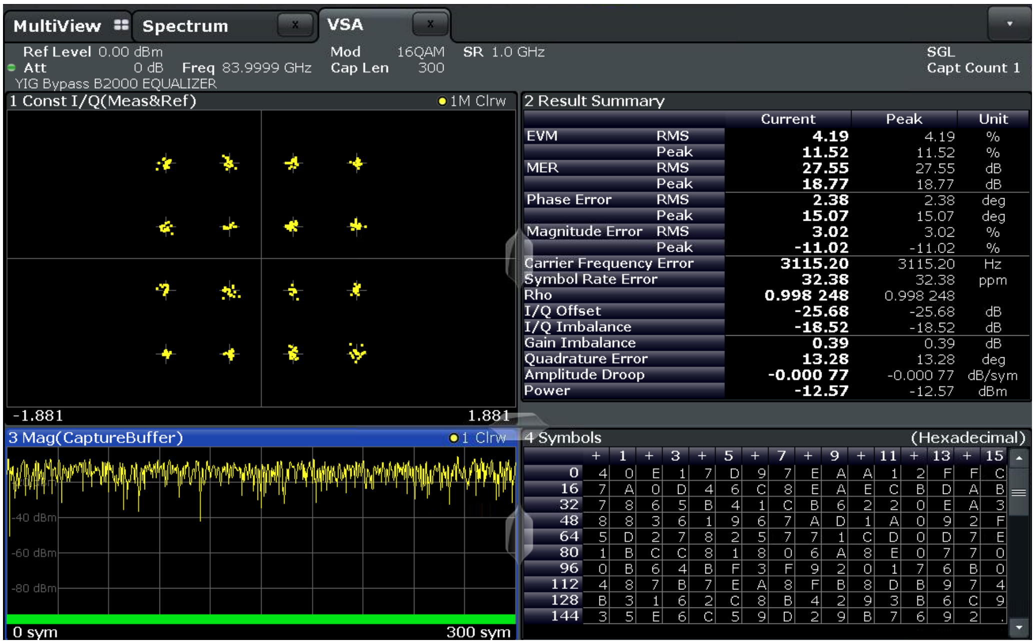
Ref Level 5.00 dBm
Att 7 dB Freq 72.0 GHz
Mod 16QAM SR 1.8 GHz
Length 100
SGL
Stat Count 50/50
YIG Bypass B2000 EQUALIZER

2 Result Summary

		Current	Peak	Unit
EVM	RMS	3.32	3.95	%
	Peak	9.53	16.47	%
MER	RMS	29.59	28.08	dB
	Peak	20.41	15.66	dB
Phase Error	RMS	1.70	2.05	deg
	Peak	-9.14	13.74	deg
Magnitude Error	RMS	2.46	2.88	%
	Peak	-9.47	-16.12	%
Carrier Frequency Error		-1156.97	-12432.94	Hz
Symbol Rate Error		-0.32	9.68	ppm
Rho		0.998 901	0.998 443	
I/Q Offset		-34.59	-33.38	dB
I/Q Imbalance		-37.34	-35.95	dB
Gain Imbalance		0.21	0.26	dB
Quadrature Error		0.68	0.88	deg
Amplitude Droop		0.000 005	0.000 068	dB/sym
Power		-1.09	-0.76	dBm

Figure 13: Modulated signal measurement performed, using a FSW85 of a commercial E-band transceiver with 16-QAM modulation at 72GHz with symbol rate 1.8 Gsymb/s.

A measurement using the same set-up, performed on a different transceiver device at 84 GHz is shown in Figure 14.



Ref Level 0.00 dBm
Att 0 dB Freq 83.9999 GHz
Mod 16QAM SR 1.0 GHz
Cap Len 300
SGL
Capt Count 1
YIG Bypass B2000 EQUALIZER

2 Result Summary

		Current	Peak	Unit
EVM	RMS	4.19	4.19	%
	Peak	11.52	11.52	%
MER	RMS	27.55	27.55	dB
	Peak	18.77	18.77	dB
Phase Error	RMS	2.38	2.38	deg
	Peak	15.07	15.07	deg
Magnitude Error	RMS	3.02	3.02	%
	Peak	-11.02	-11.02	%
Carrier Frequency Error		3115.20	3115.20	Hz
Symbol Rate Error		32.38	32.38	ppm
Rho		0.998 248	0.998 248	
I/Q Offset		-25.68	-25.68	dB
I/Q Imbalance		-18.52	-18.52	dB
Gain Imbalance		0.39	0.39	dB
Quadrature Error		13.28	13.28	deg
Amplitude Droop		-0.000 77	-0.000 77	dB/sym
Power		-12.57	-12.57	dBm

4 Symbols (Hexadecimal)

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

Figure 14: Modulated signal measurement performed, using a FSW85, of a commercial E-band transceiver with 16-QAM modulation at 84GHz with symbol rate 1.0 Gsymb/s. Screenshot captured via Remote Desktop Connection.

4.3.2 Receiver Part

The test signal for the V-Band receiver is generated as described in Figure 15.The input level of the receiver is varied by changing the SMW200A's output level.

The Vector Signal Explorer Software VSE and VSE-K70 Vector Signal Analysis option allows online data capturing and analyzing direct on the RTP or RTO2000 (Figure 15) or via an additional PC.

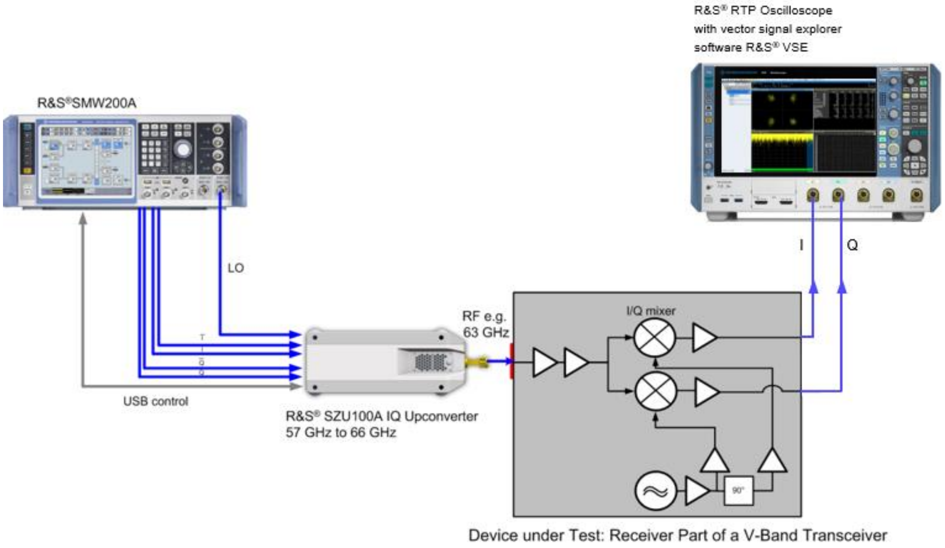


Figure 15: Schematic diagram for a setup to test the receiver part of a V-band transceiver and vector signal analysis with RTP and installed VSE software.**Fehler! Verweisquelle konnte nicht gefunden werden.** shows a photo taken of a setup for testing the receiver part of a mm-Wave transceiver. The V-Band test signal is fed from the converter output waveguide to the receiver input of the receiver under test. I and Q outputs are connected to channel 1 and 2 of the RTP or RTO2000.

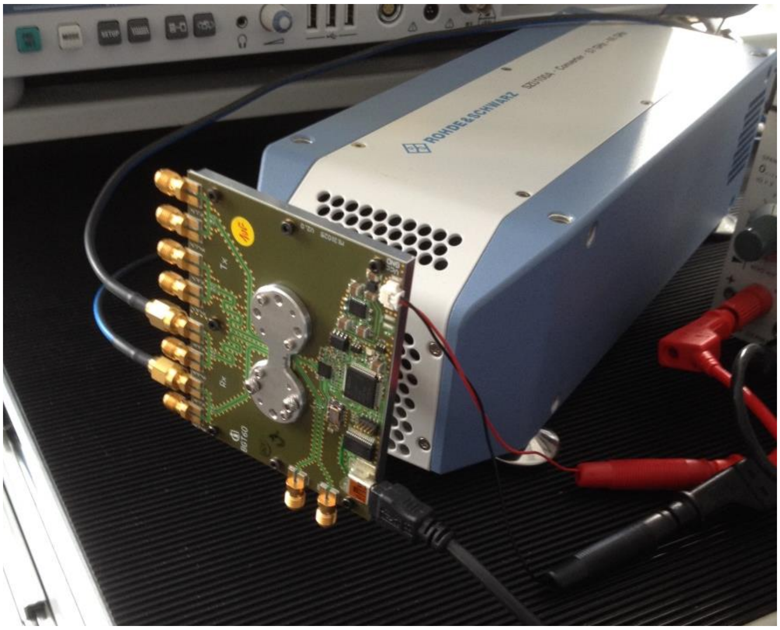
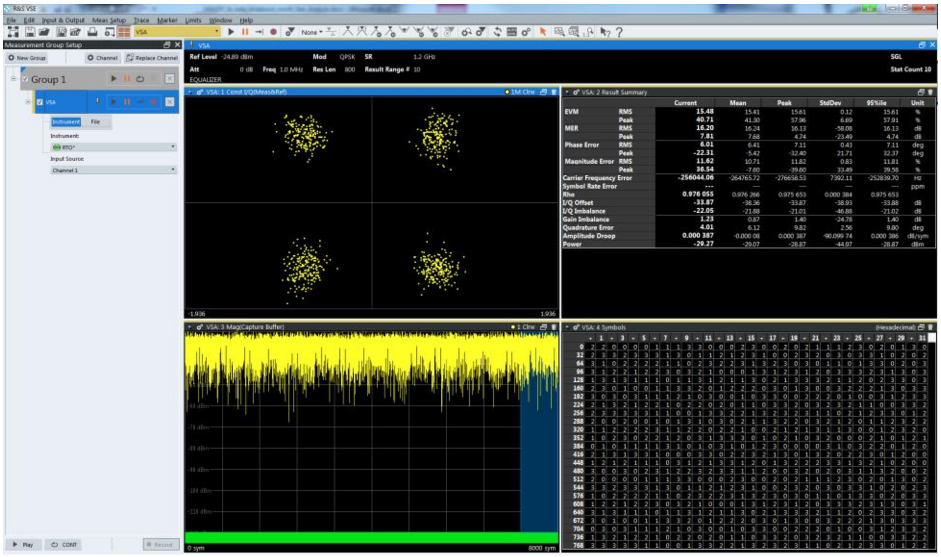


Figure 16: Photo of a practical test-setup with the SZU100A Upconverter for testing the RX part of a V-band transceiver(Supplier: "Infineon Technologies AG")

Figure 17 shows the EVM performance of the receiver under test using a QPSK signal with 1.2 Gsymb/s captured via Channel 1 & 2 of an RTP. The measured EVM is about 15 % rms. As can be seen in the I/Q constellation diagram, the different states can still be detected with low error probability at this extent of EVM.



Instrument: RTO*

Input Source: Channel 1

Ref Level -24.89 dBm | Mod QPSK | SR 1.2 GHz | SGL

Att 0 dB | Freq 1.0 MHz | Res Len 800 | Result Range # 10 | Stat Count 10

EQUALIZER

VSA: 2 Result Summary

		Current	Mean	Peak	StdDev	95%ile	Unit
EVM	RMS	15.48	15.41	15.61	0.12	15.61	%
	Peak	40.71	41.30	57.96	6.69	57.91	%
MER	RMS	16.20	16.24	16.13	-58.08	16.13	dB
	Peak	7.81	7.68	4.74	-23.49	4.74	dB
Phase Error	RMS	6.01	6.41	7.11	0.43	7.11	deg
	Peak	-22.31	-5.42	-32.40	21.71	32.37	deg
Magnitude Error	RMS	11.62	10.71	11.82	0.83	11.81	%
	Peak	36.54	-7.60	-39.60	33.49	39.58	%
Carrier Frequency Error		-256044.06	-264765.72	-276658.53	7392.11	-252839.70	Hz
Symbol Rate Error		---	---	---	---	---	ppm
Rho		0.976 055	0.976 266	0.975 653	0.000 384	0.975 653	
I/Q Offset		-33.87	-38.36	-33.87	-38.93	-33.88	dB
I/Q Imbalance		-22.05	-21.88	-21.01	-46.88	-21.02	dB
Gain Imbalance		1.23	0.87	1.40	-24.78	1.40	dB
Quadrature Error		4.01	6.12	9.82	2.56	9.80	deg
Amplitude Droop		0.000 387	-0.000 08	0.000 387	-90.099 74	0.000 386	dB/sym
Power		-29.27	-29.07	-28.87	-44.97	-28.87	dBm

Figure 17: EVM measurement with VSE at the IQ outputs of a V-band receiver. Modulation parameters: QPSK with 1.2 Gsymb/s

For E-band testing the process is similar, except that a converter suitable for E-band must be used. The amplifier after the high pass filter may be omitted from the setup, because receivers normally are tested at low input power levels.

The E-Band test signal is fed from the converter output waveguide to the receiver input of the receiver under test. I and Q outputs are connected to channel 1 and 2 of the RTP or RTO2000. The unit labelled "Converter" hosts the components inside the dotted lines in Figure 18.

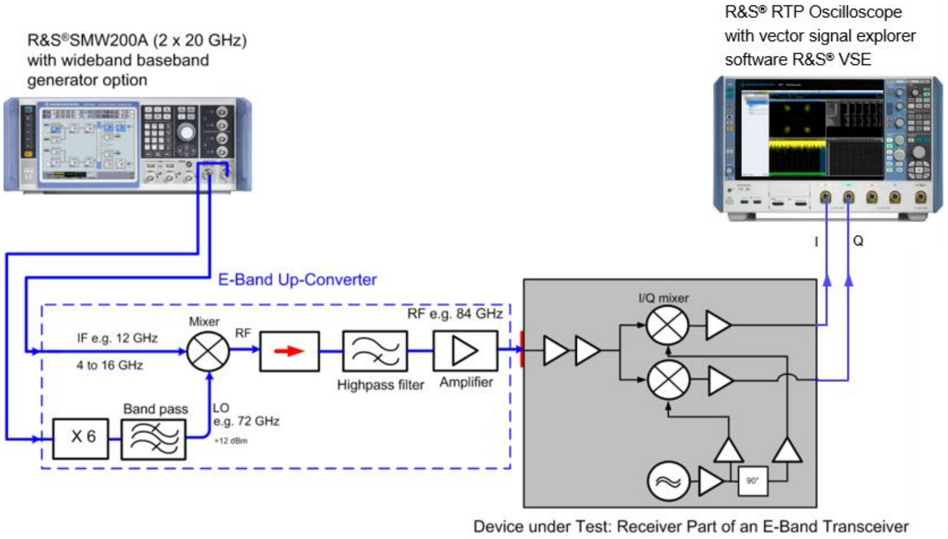
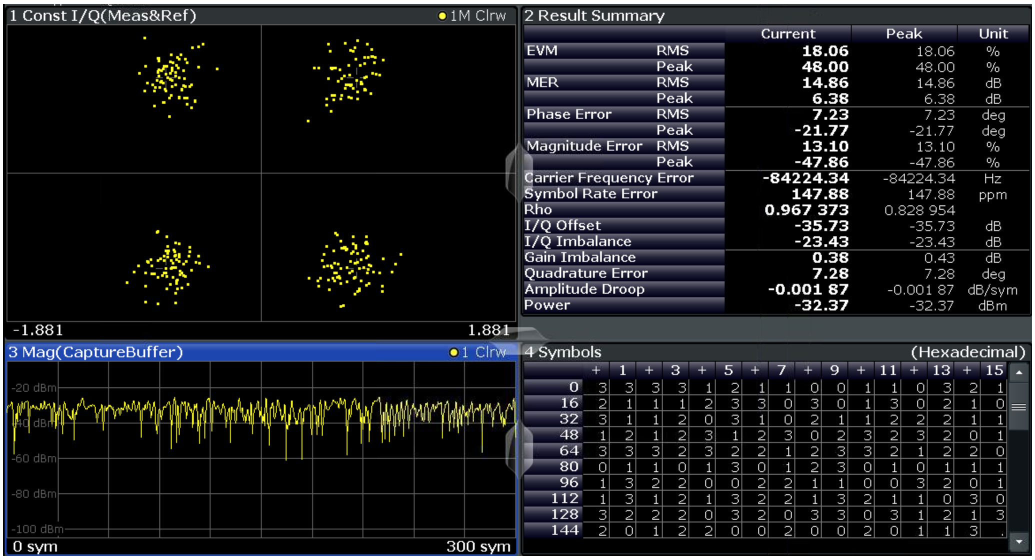


Figure 18: Schematic diagram for a setup to test the receiver part of an E-band transceiver

Figure 19 shows the EVM performance of the E-band receiver under test. The modulated signal is QPSK with symbol rate 1.0 Gsymb/s and converted to 84 GHz.



2 Result Summary

		Current	Peak	Unit
EVM	RMS	18.06	18.06	%
	Peak	48.00	48.00	%
MER	RMS	14.86	14.86	dB
	Peak	6.38	6.38	dB
Phase Error	RMS	7.23	7.23	deg
	Peak	-21.77	-21.77	deg
Magnitude Error	RMS	13.10	13.10	%
	Peak	-47.86	-47.86	%
Carrier Frequency Error		-84224.34	-84224.34	Hz
Symbol Rate Error		147.88	147.88	ppm
Rho		0.967 373	0.828 954	
I/Q Offset		-35.73	-35.73	dB
I/Q Imbalance		-23.43	-23.43	dB
Gain Imbalance		0.38	0.43	dB
Quadrature Error		7.28	7.28	deg
Amplitude Droop		-0.001 87	-0.001 87	dB/sym
Power		-32.37	-32.37	dBm

4 Symbols (Hexadecimal)

	+	1	+	3	+	5	+	7	+	9	+	11	+	13	+	15
0	3	3	3	3	1	2	1	1	0	0	1	1	0	3	2	1
16	2	1	1	1	2	3	3	0	3	0	1	3	0	2	1	0
32	3	1	1	2	0	3	1	0	2	1	1	2	2	2	1	1
48	1	2	1	2	3	1	2	3	0	2	3	2	3	2	0	1
64	3	3	3	2	3	2	2	1	2	3	3	2	1	2	2	0
80	0	1	1	0	1	3	0	1	2	3	0	1	0	1	1	1
96	1	3	2	2	0	0	2	2	1	1	0	0	3	2	0	1
112	1	3	1	2	1	3	2	2	1	3	2	1	1	0	3	0
128	3	2	2	2	0	3	2	0	3	3	0	3	1	2	1	3
144	2	0	1	2	2	0	0	2	0	0	2	0	1	1	3	.

Figure 19: EVM measurement at the IQ outputs of an E-band receiver, demodulating a signal from 84GHz.

5 Literature

[1] Rohde & Schwarz, *Application Note 1MA217 "mm-Wave Band Sigbal Generation and Analysis".*

[2] Rohde & Schwarz, *Application Note 1EF92 "Wideband Signal Analysis".*

[3] Rohde & Schwarz, "R&S®FSW signal and spectrum analyzer: measuring E band microwave connections," in *News from R&S 208*.

6 Ordering Information

Signal Generators

Designation	Type	Order No.
Vector Signal Generator	R&S®SMW200A	1412.0000.02
Frequency Options, RF path A, 100 kHz to 20 GHz	R&S®SMW-B120	1413.0404.02
Frequency Options, RF path B, 100 kHz to 20 GHz	R&S®SMW-B220	1413.1100.02
Wideband Baseband Main Module, two I/Q path to RF	R&S®SMW-B13XT	1413.8005.02
Wideband Baseband Generator with ARB (256 Msamples), 500 MHz RF bandwidth	R&S®SMW-B9	1413.7350.02
ARB Memory Extension to 2 Gsample	R&S®SMW-K515	1413.9360.02
Baseband Extension, 2000 MHz RF bandwidth	R&S®SMW-K526	1413.9318.02
Wideband Differential Analog I/Q Outputs	R&S®SMW-K17	1414.2346.02
RF and Microwave Signal Generator	R&S®SMB100A	1406.6000.02
RF Path/Frequency Option: 100 kHz to 20 GHz, with mechanical step attenuator	R&S®SMB-B120	1407.2209.02
Microwave Signal Generator	R&S®SMA100B	1419.8888.02
Frequency Range 8 kHz to 20 GHz	R&S®SMAB-B120	1420.8788.02

V-Band Upconverter

Designation	Type	Order No.
IQ Upconverter, base unit	R&S®SZU100A	1425.3003.02
Frequency option 57 GHz to 66 GHz, WR15	R&S®SZU-B1066	1425.3110.02
USB+IQ cable for R&S®SZU100A (2m), combined differential IQ/trigger/USB cable (accessory)	R&S®SZU-Z1	1425.4851.02

Signal and Spectrum Analyzers

Designation	Type	Order No.
Signal and spectrum analyzer 2 Hz to 26.5 GHz	R&S®FSW26 (1)	1331.5003.26
Signal and spectrum analyzer 2 Hz to 43.5 GHz	R&S®FSW43 (1)	1331.5003.43
Signal and spectrum analyzer 2 Hz to 50 GHz	R&S®FSW50 (1)	1331.5003.50
Signal and spectrum analyzer 2 Hz to 67 GHz	R&S®FSW67 (1)	1331.5003.67
Signal and spectrum analyzer 2 Hz to 85 GHz	R&S®FSW85 (1)	1331.5003.85
RF Preamplifier, 100 kHz to 67 GHz	R&S®FSW-B24	1313.0832.67
2000 MHz Analysis Bandwidth	R&S®FSW-B2001	1331.6916.14
4400 MHz Analysis Bandwidth	R&S®FSW-B4001 (2)	1338.5215.14
6400 MHz Analysis Bandwidth	R&S®FSW-B6001 (2)	1338.5221.14
8312 MHz Analysis Bandwidth	R&S®FSW-B8001 (2)	1338.5238.14

Designation	Type	Order No.
Vector Signal Analysis	R&S®FSW-K70	1313.1416.02
LO/IF Connections for external mixers	R&S®FSW-B21	1313.1100.26
Harmonic Mixer, 50 GHz to 75 GHz	R&S®FS-Z75	1048.0271.02
Harmonic Mixer, 60 GHz to 90 GHz	R&S®FS-Z90	1048.0371.02
Vector Signal Explorer Software	R&S®VSE	1320.7500.06
Licence Dongle	R&S®FSPC	1310.0002.03
Vector Signal Analysis	R&S®VSE-K70	1320.7522.02

Oscilloscopes

Designation	Type	Order No.
Digital Oscilloscope, 4 GHz, 20 Gsample/s, 50/200 Msample, 4 channels	R&S®RTO2044 [3)]	1329.7002.44
OCXO 10 MHz	R&S®RTO-B4	1304.8305.02
I/Q Software Interface	R&S®RTO-K11	1329.7360.02
High-performance oscilloscope, 4 GHz, 50 Msample memory, 4 channels	R&S®RTP044 [3)]	1320.5007.04
I/Q Software Interface	R&S®RTP-K11	1800.6683.02

[1)] Other Signal and Spectrum Analyzers configurations are suitable as well. More options are available. The table shows the instrument's minimum configuration for this application, but for the analyzer, models FSW26/43/50 in conjunction with FS-Z series harmonic mixers allow significant savings at the expense of slightly reduced convenience and performance. Please ask your local representative for a suitable configuration according to all your needs.

[2)] only for applications that require analysis bandwidth > 2 GHz

[3)] Other Oscilloscope configurations with higher bandwidth are suitable as well. More options are available. Please ask your local representative for a suitable configuration according to all your needs.

7 Appendix

A Recommended Parts for E-Band Upconverter

- Mixer
  - Sage Millimeter Balanced Upconverter, V-Band SFU-12-N1
- Band Pass Filter
  - BSC Filters Waveguide Band Pass Filter 64 – 72 GHz WB 8853 (Specification WB8853/01)
- Multiplier
  - AFM6 60 -90 +10 Radiometer Physics GmbH
- Isolator
  - Radiometer Physics WFI-90
- High Pass Filter
  - BSC Filters Waveguide Band Pass Filter 71 – 91 GHz WB 8852 (Specification WB8852/01)
- E-Band Amplifier
  - Radiometer Physics E MPA 67-87 16 14 WR12 medium power amplifier

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