Application Note

MM-WAVE BAND SIGNAL GENERATION AND ANALYSIS

Products:

- ► R&S®SMF100A
- ► R&S®SMZ75/SMZ90
- ► R&S®SGS100A
- ► R&S®FSW
- ► R&S®FS-Z75/90/110
- ► R&S®AFQ100B

Roland Minihold | 1MA217 | Version 2e | 11.2021

Note:

Please find the most up-to-date document on our homepage
http://www.rohde-schwarz.com/appnote/1MA217

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Contents

1 Overview

This application note describes how to generate and analyze wideband digitally modulated signals in the mm-wave range.

Rohde & Schwarz measuring equipment and some 3rd party off-the-shelf accessories are used for both signal generation and analysis. Measurement results are shown which demonstrate the typical performance for millimeter wave signals in terms of error vector magnitude (EVM) and adjacent channel power (ACLR).

Two test setups and their measurement results on a commercial V-band transceiver module are presented.

2 Motivation

High modulation bandwidth in mm-wave bands is proposed i.e. for automotive radar and "5G" mobile phone applications. The E-band frequency range from

- 77 GHz to 81 GHz is foreseen for future high-resolution automotive radar applications.

Beside bands below 6 GHz and around 11 GHz, 28 GHz and 38 GHz, a large chunk of potential "5G" bandwidth is available in:

- V-band (57 GHz to 64 GHz); unlicensed spectrum in many countries
- lower E-band (71 GHz to 76 GHz); “license-light”[1)] spectrum
- upper E-band (81 GHz to 86 GHz); “license-light” spectrum
- W-band (92 GHz to 95 GHz) indoor uses are unlicensed in many countries, outdoor use is “license-light” with exception of 94.0 GHz to 94.1 GHz which is in use for radio astronomy range.

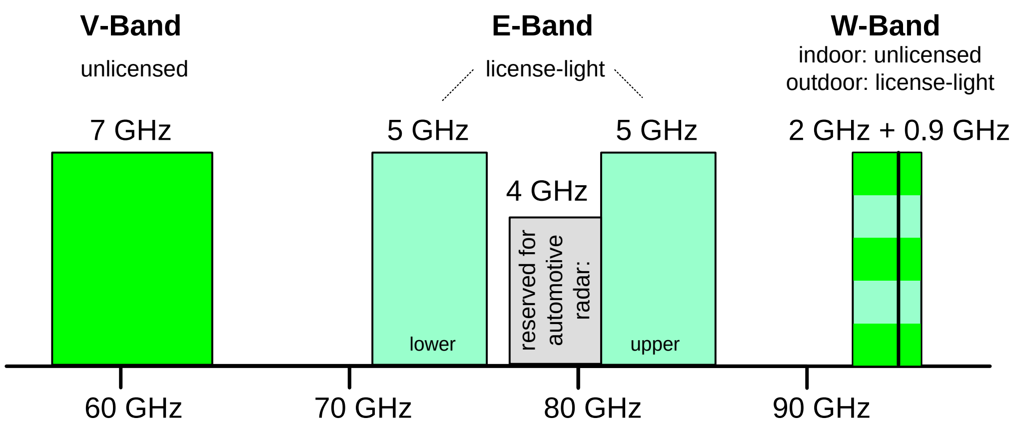

Figure 1: Unlicensed or license-light frequency ranges in V-, E-Band and W-Band

This application note concentrates on signal generation and - analysis in V-band and above. So far, no ready-to-use one-box test equipment is available as an off-the-shelf product to generate or analyze wideband digital modulated signals in V-Band and above. Latest signal and spectrum analyzers like the R&S®FSW67 **are first to allow** use in V-band up to 67 GHz and slightly beyond without external frequency conversion.

This application note describes a setup how to overcome the situation for E- and W-bands and shows use of FSW67 for V-Band applications.

Abbreviations

- The **R&S®AFQ100B** UWB signal and I/Q modulation generator is referred to as **AFQ**
- The **R&S®SGS100A** SGMA RF source is referred to as **SGS**
- The **R&S®SMZ90 / R&S®SMZ75/ R&S®SMZ110** Frequency Multipliers are referred to to as **SMZxx**
- The **R&S®FS-Z90 / R&S®FS-Z75 / R&S®FS-Z110** Harmonic Mixers are referred to as FS**-Zxx**
- The **R&S®FSW67 / R&S®FSW50 / R&S®FSW43** signal and spectrum analyzers are referred to as **FSW**

3 Setups

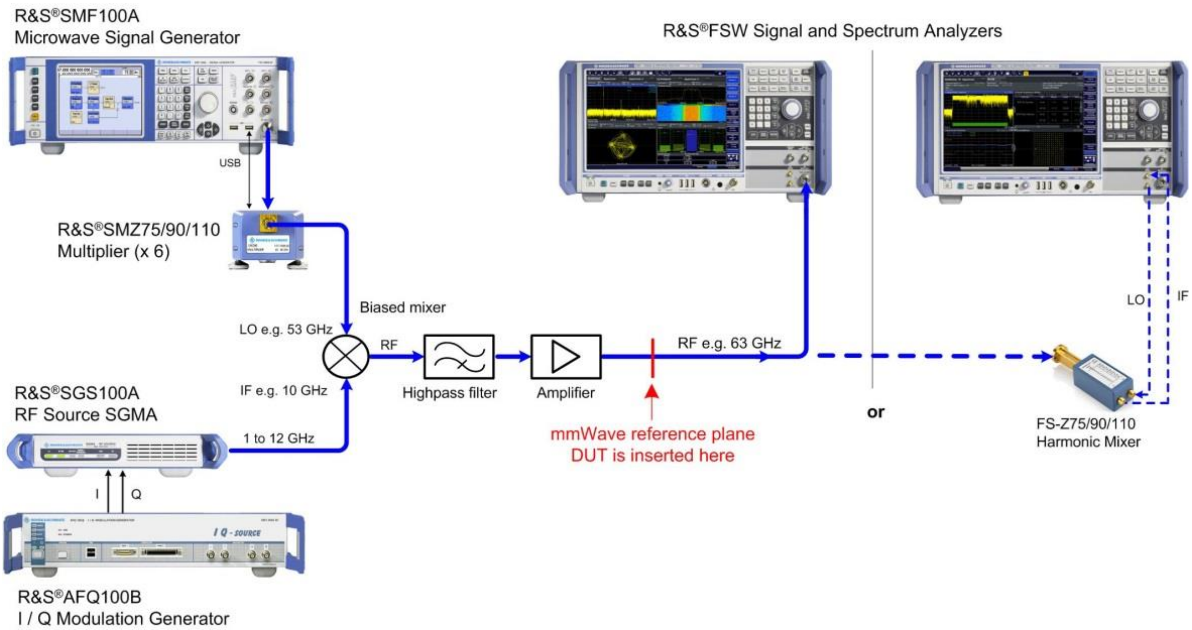

Figure 2: Two setups for generating and analyzing mm-wave band signals in V, E- and W-bands

3.1 mm-wave Band Signal Generation

In this setup the I/Q Modulation Generator AFQ100B generates generic wideband digital modulated baseband signals (e.g. simple QPSK, QAM or generic OFDM signals) up to a bandwidth of 500 MHz and modulates the RF Source SGS via analog I and Q outputs. The SGS feeds a vector-modulated RF signal in the IF range of e.g. 1 to 12 GHz to the IF port of the up-converting mixer. The output signal of Microwave Signal Generator SMF is fed to a suitable model of SMZxx which multiplies the frequency by a factor of 6 to the necessary frequency range 57 to up to 110 GHz for the LO signal of the mixer.

The up-converting mixer is a biased mixer module and thus an output power of the SMZxx of typically +4 dBm is sufficient to drive the LO port of this mixer. The mixer up-converts the IF input signal to the mm-wave range at the RF port with good linearity. The upper sideband (f_{LO} + f_{IF}) is used at the RF port. The high pass filter inserted after the up-converting mixer suppresses LO feed-through as well as the lower sideband (f_{LO} - f_{IF}). Thus, a spectrally clean signal is available at the mm-wave reference plane. In this paper, measurements are first done without a DUT in order to demonstrate the performance available in the targeted frequency range.

In a following chapter, the signal available at the reference plane is used to feed a device under test (DUT) like e.g. an amplifier or receiver. Optionally a suitable booster amplifier may be inserted following the high-pass filter which allows higher signal levels at the reference plane.

A mixer similar to the biased V-band waveguide mixer type SFB-12-E2 from Sage Millimeter Inc. was used for the measurements shown in this application note. It offers a conversion loss of about 10 dB when up-converting from IF to RF.

3.2 mm-Wave Band Signal Analysis

To characterize the quality of a V-/E- or W-Band signal, a spectrum and signal analyzer FSW fitted with options FSW-B21 and one of the FS-Z series of harmonic mixers can be used. Covering the complete unlicensed V-band 57 to 63 GHz, model FSW67 with 67GHz preamp option FSW-B24 allows one-box measurements, i.e. without the added complexity of external harmonic mixer use.

For frequencies above 67 GHz a suitable harmonic mixer FS-Z75, FS-Z90, FS-Z110 is needed to down-convert the mm-wave signal to an IF. The harmonic mixer family FS-Z is available for frequencies up to 110 GHz and down-converts the mm-wave signal to an IF which is fed to the IF port of an FSW with option FSW-B21. The LO signal for the 3-port harmonic mixer FS-Zxx is delivered from the LO out/IF in connector which is also part of the FSW-B21 option. For modulation analysis of un-coded single-carrier digitally modulated signals the internal Vector Signal Analysis option FSW-K70 of a FSW is sufficient.

For the analysis of generic OFDM signals the flexible OFDM Signal Analysis Software FS-K96PC is used together with the FSW.

Both R&S generators and analyzers can currently handle up to 500 MHz modulation bandwidth (the FSW needs option 500 MHz Analysis Bandwidth FS-B500 to do so).

Analysis of carrier-aggregated up-converted LTE or LTE-A signals can be performed using the FSW-K1xx family of options readily available for that purpose (please see FSW ordering info at the end of this document).

4 Considerations when using the setup for mm-Wave Band signal generation

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.

4.1 Spurious generation

4.1.1 Spurious due to multiplier SMZ if used as LO source

The SMZxx nominally multiplies the SMF input signal by a factor of 6 which is the main spectral component. However, the SMZ generates any harmonic of the input signal at its output with a reduced, but still significant RF level. Specified suppression of these unwanted components referred to the desired 6th harmonic component is specified to be better than -20 dBc.

At the mixer's output, a part of these components will appear due to feed-through and appear as CW spurious. Most of these are far-off the desired mixer output frequency and will not harm the purity of the wanted signal e.g. in terms of EVM. In addition, power level of these components is further reduced by the up-conversion.

However, care has to be taken to avoid the frequency f_{SMF*7} which for the purpose of this paper is the closest one with respect to the desired output frequency $f_{LO} + f_{IF}$.

Example:

In order to provide a 57 GHz to 64 GHz V-Band signal, a local oscillator frequency of 54 GHz may be used in conjunction with an IF ranging from 3 to 10 GHz. The 54 GHz LO is suppressed by a suitable high pass filter. Additional to the wanted LO signal harmonics of 54 GHz/6 = 9 GHz appear at the LO port of the mixer and via feed-through (at further reduced level) at the RF port of the mixer. The critical 7th harmonic is 63 GHz (7 * 9 GHz) and falls within the desired 57 GHz to 64 GHz band. It would strongly degrade any close-by RF signal if not addressed.

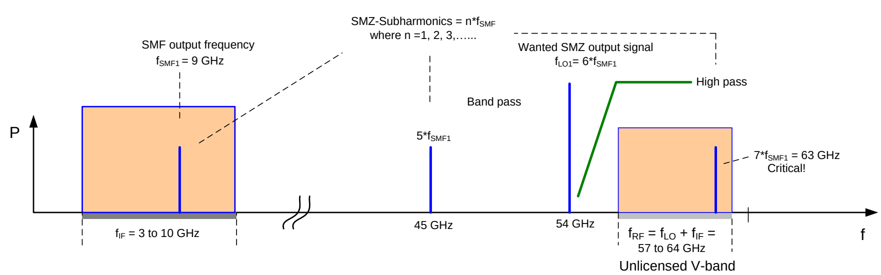

Figure 3: Visualization of spurious caused by the SMZxx sub-harmonics at 54 GHz LO Frequency

It is easy to remedy the problem: in almost all cases less than the whole range from 57 GHz to 64 GHz will be needed. The LO frequency can be shifted so that 7th harmonic falls outside a bandwidth of say +/-1 GHz of the center frequency of the wanted signal and thus will not degrade e.g. the modulation quality of wideband modulated signals.

Another, may be more convenient solution is to insert a band pass filter after the SMZ (refer to Figure 3). A suitable filter will attenuate the 63 GHz component without unduly affecting the 54 GHz LO signal. A bandwidth of approximately 3 GHz is recommended for that band pass filter to allow some frequency variation of the LO signal and to sufficiently suppress the unwanted multiples of the SMF output frequency, see Figure 4 and Figure 5.

Note: The band pass should have sufficient suppression for far-off frequencies. Otherwise the 63 GHz component may possibly be regenerated within the mixer by higher harmonics of 9 GHz. See **Error! Reference source not found.** for example filter specifications.

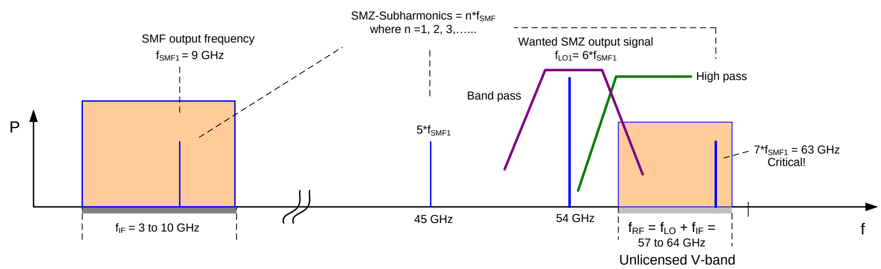

Figure 4: Introduction of a band pass filter after the SMZ output to suppress the SMZ sub-harmonics

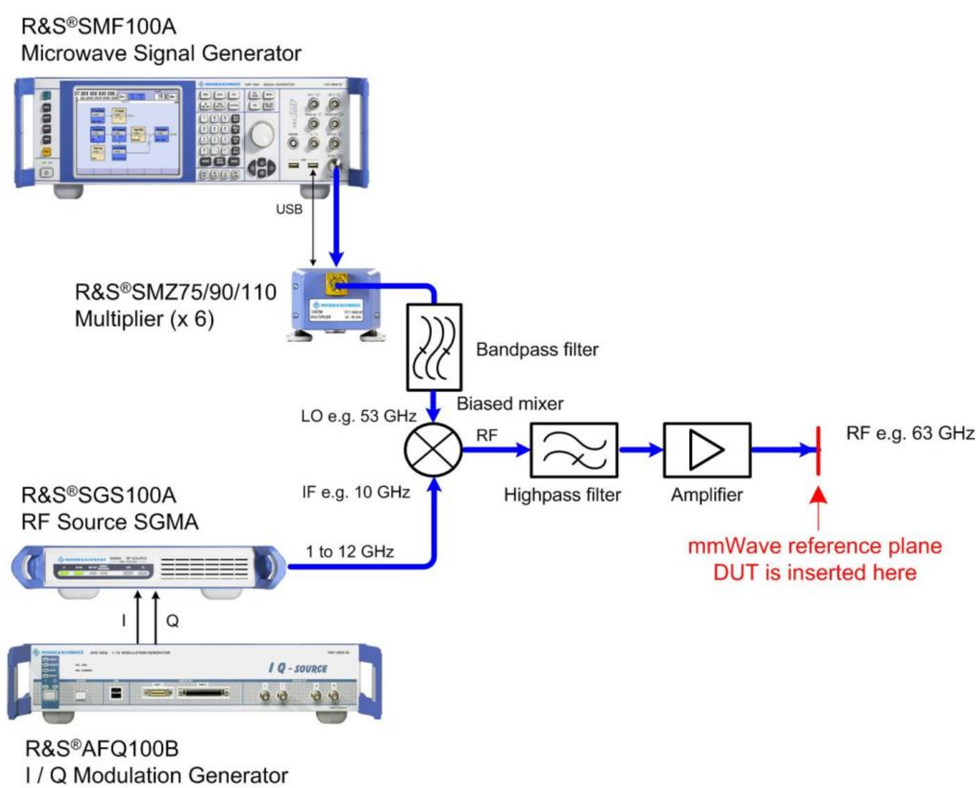

Figure 5: Modified setup for mm-wave band signal generation with band pass filter to suppress sub-harmonics

4.1.2 Spurious due to mixing

Possible spurious at the RF port caused by up-conversion follow the rule

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

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:

If we aim to generate a 63 GHz digitally modulated signal in license-exempt ISM V-band frequency range 57 to 64 GHz, then using e.g. an IF frequency of 10 GHz and a LO frequency of 53 GHz we get:

2*53 GHz - 3*10 GHz = 76 GHz: significant level (3rd IF harm.) but far out of band,

2*53 GHz - 4*10 GHz = 66 GHz: still 2 GHz out of band, but reasonably low level (4th harm.), certainly must be monitored.

3*53 GHz - 4* 10 GHz = 119 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 require a higher order IF harmonic and therefore generally are low power.

4.1.3 Spurious due to SMZxx sub-harmonics and mixing

Because of the sub-harmonics content within the SMZxx output signal:

$k*f_{LO}/6$ where k = 1,2,3…. possible mixing spurious at the mixer's RF port

follow the rule:

$f_{SP} = n*f_{IF} \pm k*f_{LO}/6$ where n= ± 0, 1, 2, 3… and k = ± 0, 1, 2, 3…

Critical are again mixing products which fall into the used mm-wave band and especially those close to the wanted mixer output signal. Depending on the setting of LO and IF frequencies the following products are critical:

► $7* f_{LO} /6 - f_{IF}$

► $8* f_{LO} /6 - 2* f_{IF}$

These mixing products can get close to the wanted output signal and therefor significantly degrade the performance of the wanted signal.

Note:

The band pass filter of Figure 4 will suppress the SMZ sub-harmonics and therefore also it's mixing products. Also, a shift in the LO frequency to e.g. 52 GHz may be considered to avoid these close spurious.

Some crucial examples for the V-Band:

1. For a wanted output frequency of 58.4 GHz a LO frequency of 54 GHz and an IF of 4.4 GHz is used.

If we check for the mixing products:

$7* f_{LO} /6 - f_{IF}$ = 58.6 GHz critical, this product is near the wanted output frequency and moves even closer with increasing output frequency

$8* f_{LO} /6 - 2* f_{IF}$ = 63.2 GHz, far off the wanted output frequency

2. For a wanted output frequency of 59.9 GHz a LO frequency of 54 GHz and an IF of 5.9 GHz is used.

If we check for the mixing products:

$7* f_{LO} /6 - f_{IF}$ = 57.1 GHz, far of the wanted output frequency

$8* f_{LO} /6 - 2* f_{IF}$ = 60.2 GHz !

This product is near the wanted output frequency and moves even closer with increasing output frequency.

4.2 Spurious due to harmonic mixer

The R&S®FSW67 can be used for measurements up to 70GHz. Using FSW to carry out spectrum measurements beyond the nominal 67 GHz limit, e.g. further up in the E-Band is possible with external harmonic mixers of the FS-Z family. For frequencies below 67 GHz, use of harmonic mixers instead of the FSW67 model may also be attractive with regard to budget.

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 R&S®FSW [1] signal and spectrum analyzers with theR&S®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, 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 R&S®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.

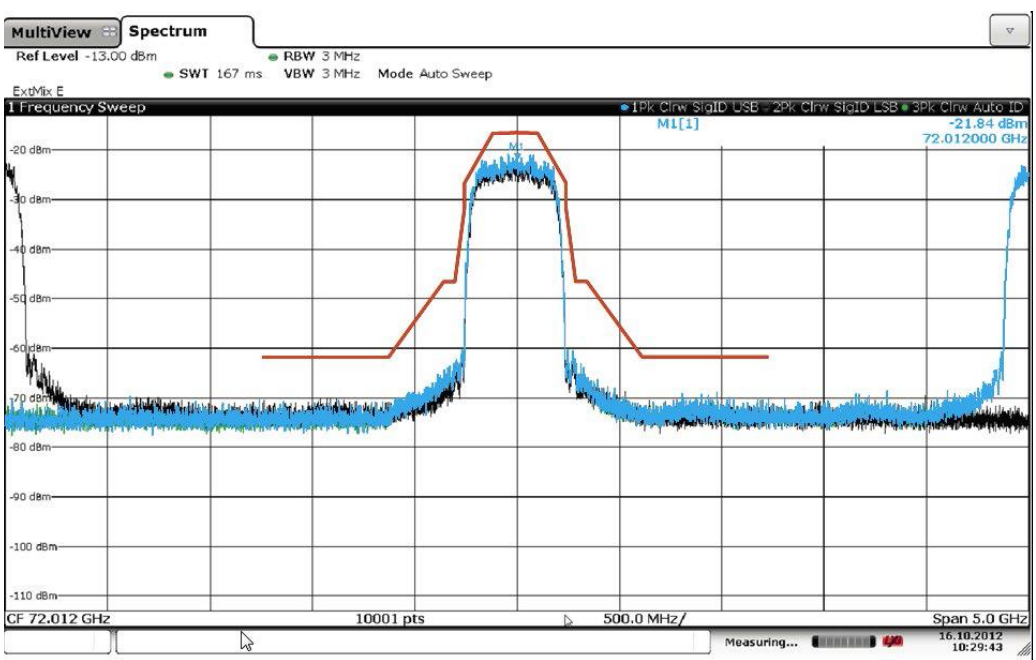

Figure 6: Measurement of a 500 MHz bandwidth E band input signal with an R&S®FSW signal and spectrum analyzer with the FS-Z90 Harmonic Mixer. The input and image-frequency signal are 2.6 GHz apart. Measuring the spectrum mask or analyzing the modulation quality of significantly wider signals in possible without any difficulty.

5 Typical Measurement 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's equalizer is active so that the frequency slope influence is eliminated within the modulation bandwidth. If the equalizer is not active the results are much worse. For example, the EVM values increase by a factor of 4 to 5. However, for typical wideband digital modulation systems such as OFDM the EVM is defined with equalized frequency slope, so that the EVM measurement results shown are comparable to real world values.

► Measurement with FSW67 at 62 GHz center frequency:

SGS power level -10 dBm (-13 dBm at mixer input)

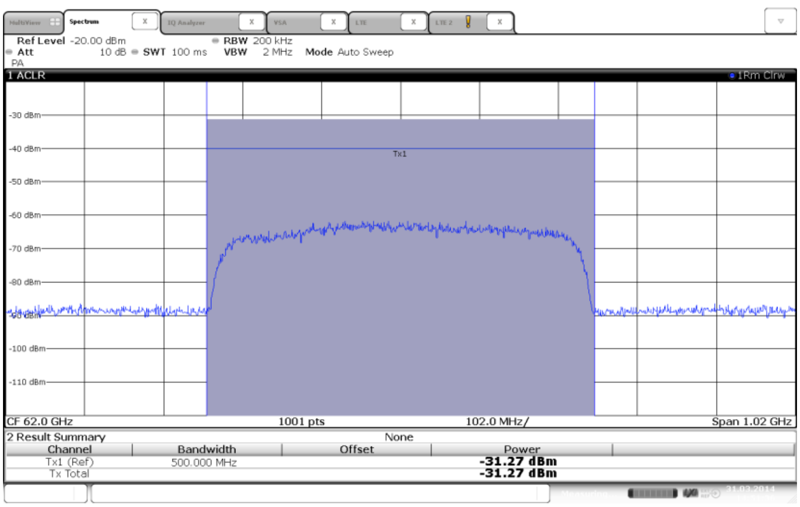

Figure 7: Channel power measurement of an FSW67 at a 16QAM signal with 450 Msymbols/s up-converted to 62 GHz

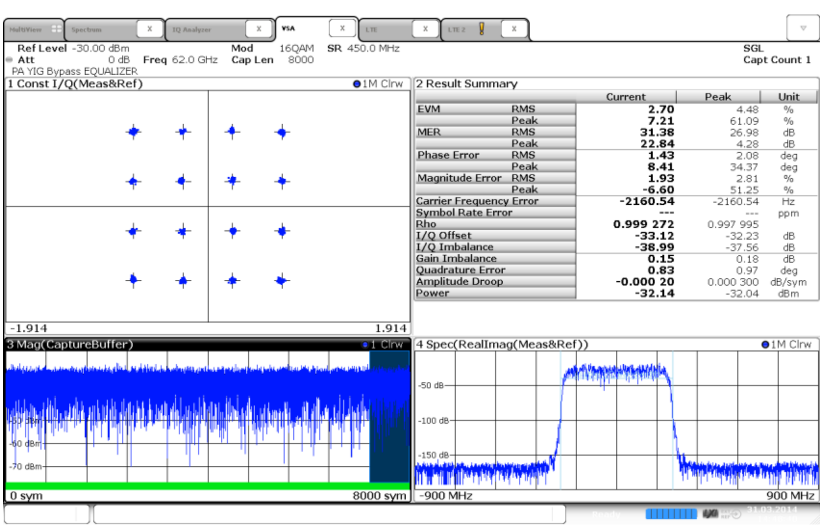

Figure 8: Modulation measurement of an FSW67 on a 16QAM signal with 450 Msymbols/s up-converted to 62 GHz (spectrum shown is equalized compared to Figure 7)

► FSW67 fed with LTE signal of 20 MHz bandwidth up-converted to 62 GHz

ACLR performance with amplifier 20 dB: channel power -20 dBm

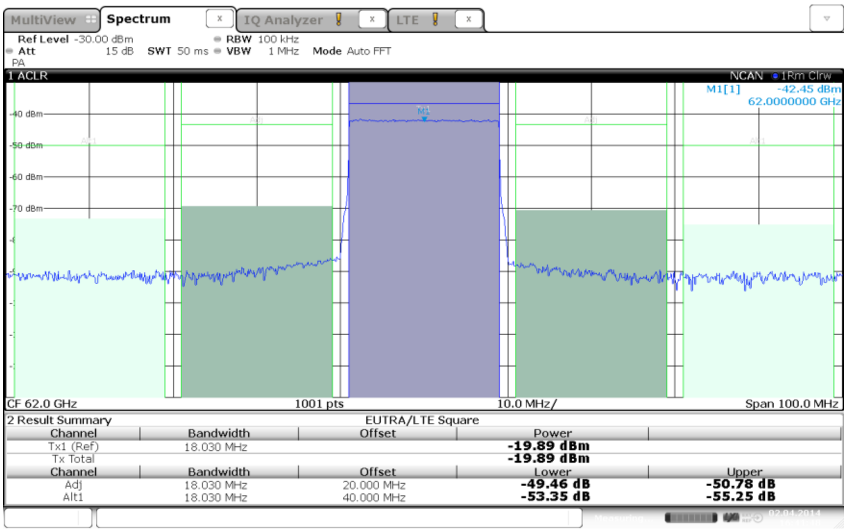

Figure 9: ACLR measurement of an FSW67 on a LTE signal with 20 MHz bandwidth up-converted to 62 GHz

EVM - performance at -20 dBm with amplifier:

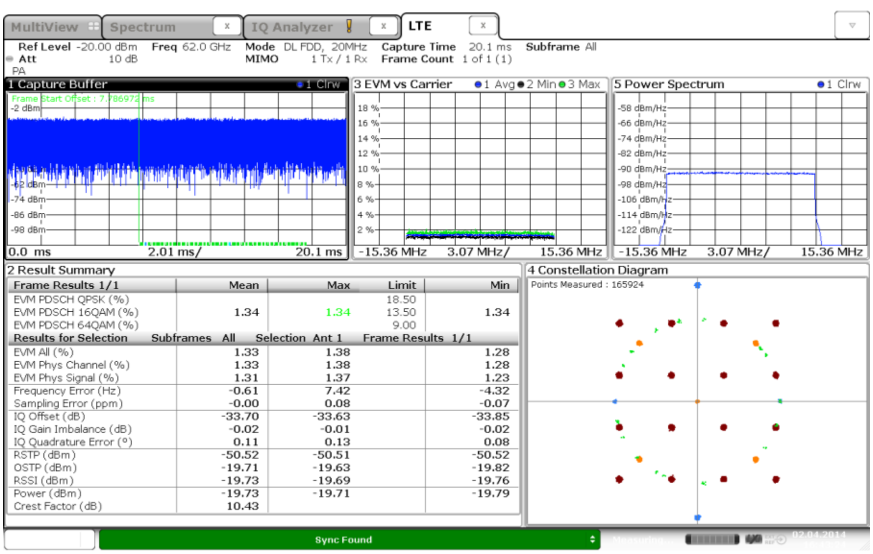

Figure 10: Modulation measurement of an FSW67 on a LTE signal with 20 MHz bandwidth up-converted to 62 GHz

6 Characterizing a V-band Transceiver

In the following, test setups are described for tests on the receiver and transmitter part of a V-band transceiver. Measurement results for a commercial V - band transceiver are shown.

6.1 Receiver Part:

The test signal for the V-Band receiver is generated as described in chapter 3.1 and repeated here as **Error! Reference source not found.**. The amplifier after the high pass filter may be removed from the setup, because receivers are normally tested at low power levels. The input level of the receiver can be varied by changing the SGMA output level; the change is linearly transferred to the up-converting biased mixer's RF output port.

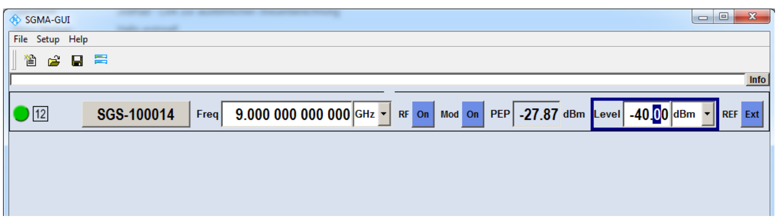

Figure 11: User Interface of SGMA RF Source

The symmetric I, Q base-band output signals of the receiver under test are fed to the baseband input signals of the FSW.

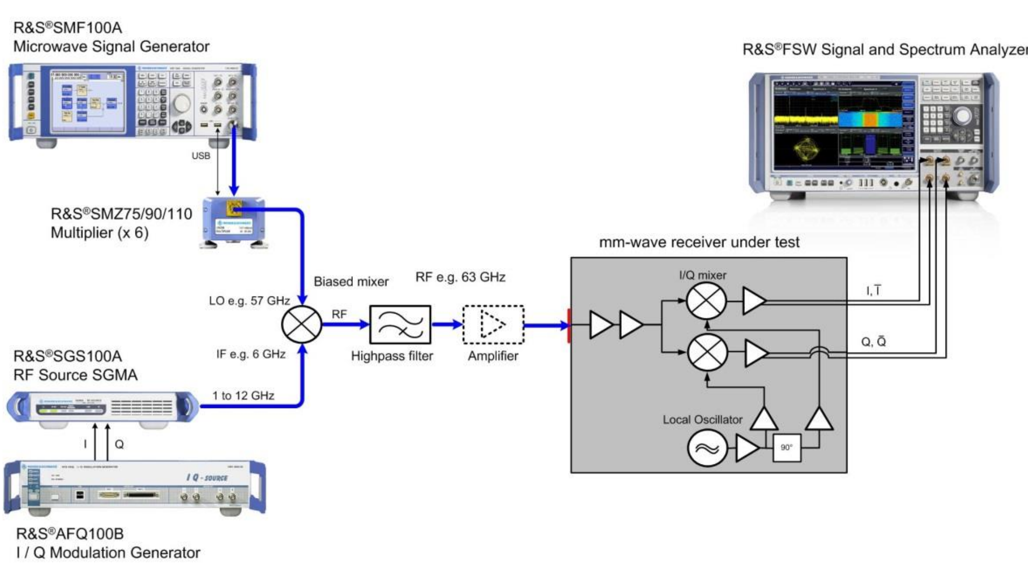

Figure 12: Schematic diagram of a setup for testing the receiver part of a mm-wave band transceiver

Figure 13 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 bottom of the transceiver to its RX wave-guide connector.

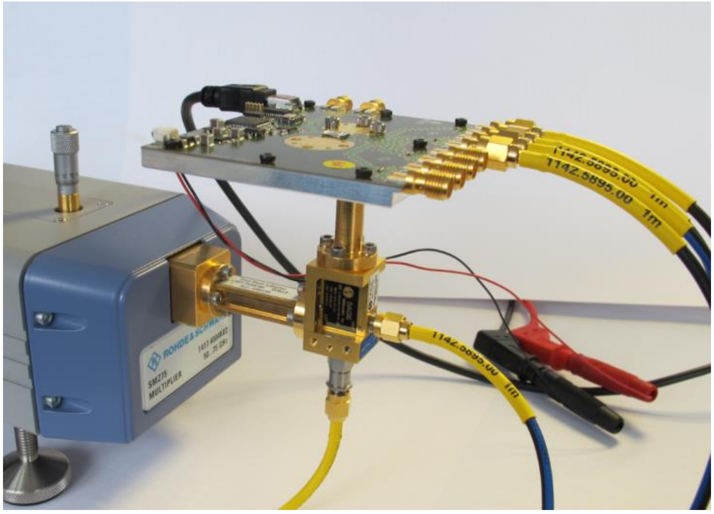

Figure 13: Photo of a practical test-setup for testing the RX part of a V-band transceiver

Figure 14 shows the EVM performance of the receiver under test at an input power level of -60 dBm using a 16QAM signal with 145 Msym/s measured via the baseband inputs of the FSW. The FSW's baseband input bandwidth of 80 MHz allows signal bandwidths up to 160 MHz at the RF side, thus catering to carrier-aggregated LTE-A front-haul/back-haul signals. The measured EVM is about 10 % 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.

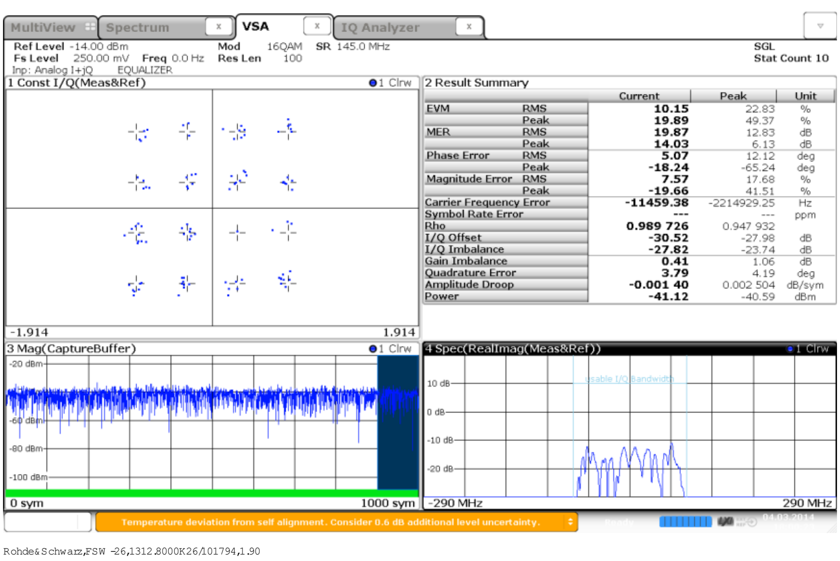

Figure 14: EVM measurement at the I,Q outputs at a mm-wave band receiver at -60 dBm input power level

6.2 Transmitter Part

Figure 15 shows the setup for testing the transmitter part of a mm-Wave transceiver using an FSW67.

AFQ delivers the symmetric I,Q baseband signal for the V-Band transmitter, while the RF output signal is fed to the RF input of an FSW67 analyzer via FSW-B24 preamp.

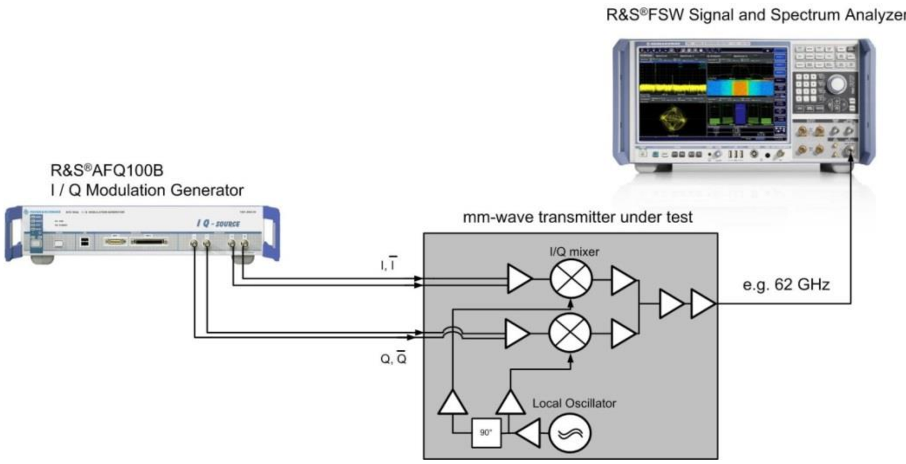

Figure 15: Schematic diagram of a setup for testing the transmitter part of a mm-wave band transceiver

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. For 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) 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, see Figure 16.

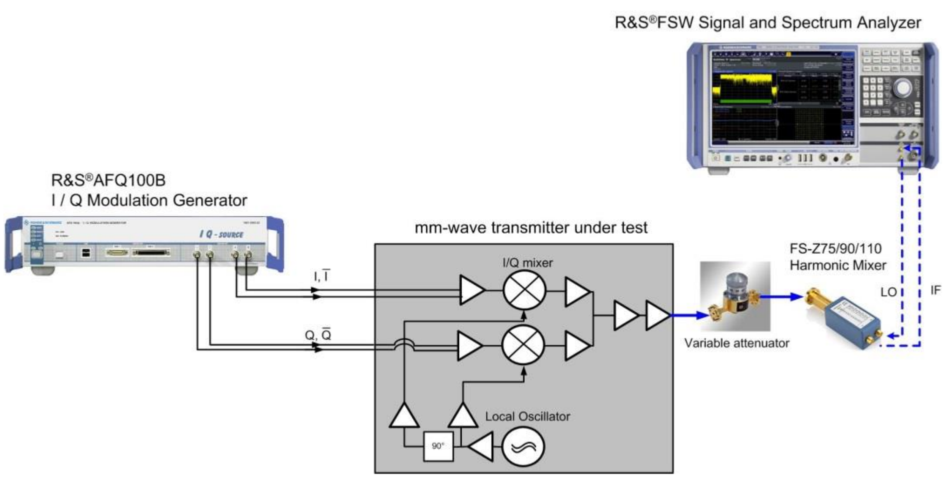

Figure 16: Schematic diagram of a setup for testing the transmitter part of a mm-Wave transceiver using an FS-Zxx harmonic mixer with a variable attenuator.

In the following screenshots taken from an FSW67 measuring the output signal of a V-band transmitter are shown.

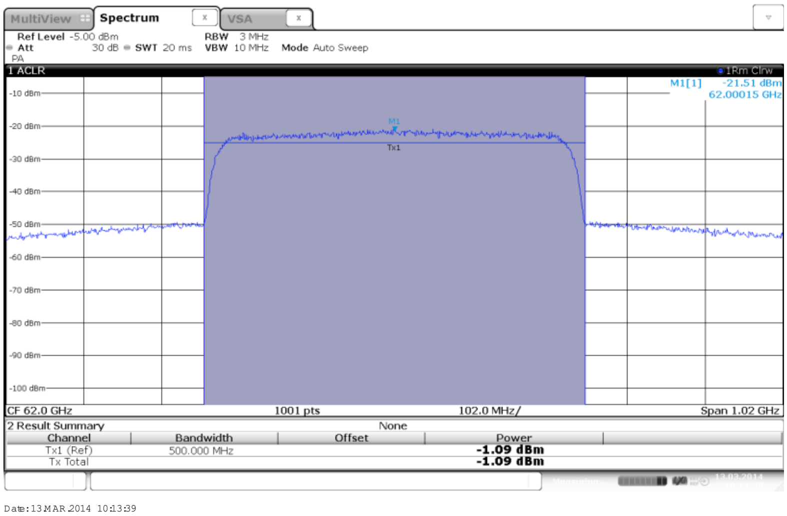

Figure 17: Channel power measurement at output signal of a V-band transmitter stimulated with a 16 QAM signal with 450 Msymbols/s

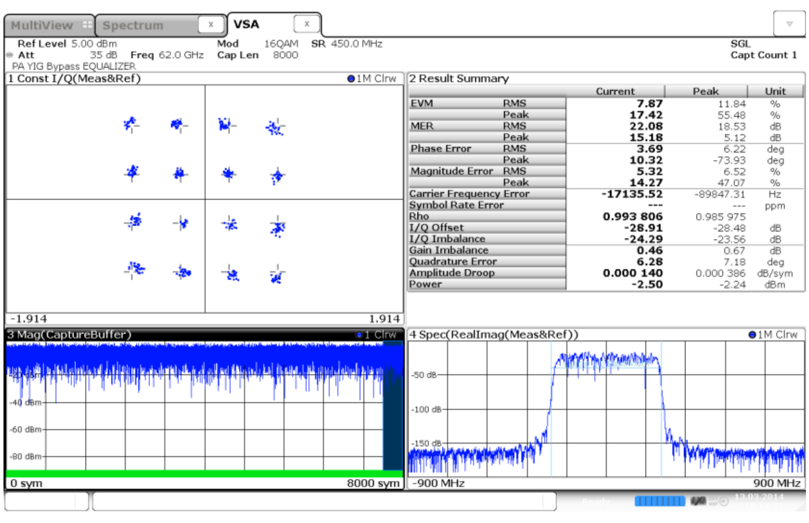

Figure 18: Modulation quality measurement on a V-band transmitter stimulated with with a 16 QAM signal with 450 Msymbols/s

7 Literature

[1] Rohde & Schwarz, *R&S®FSW Signal and Spectrum Analyzer Data Sheet.*

[2] Rohde & Schwarz, *R&S®SGS100A SGMA RF Source - Data Sheet.*

[3] Rohde & Schwarz, *R&S®SMF100A Microwave Signal Generator Data Sheet.*

[4] Rohde & Schwarz, *R&S®SMZ Frequency Multiplier Data Sheet.*

[5] Rohde & Schwarz, *R&S®AFQ100A/B UWB Signal and I/Q Modulation Generator Data Sheet.*

[6] Rohde & Schwarz, *R&S®FS-Z60/-75/-90-110 Harmonic Mixers Product Brochure.*

[7] Rohde & Schwarz, *R&S®FS-K70 Vector Signal Analysis Data Sheet.*

[8] Rohde & Schwarz, *R&S®FS-K96PC OFDM Vector Analysis Software Data Sheet.*

[9] D. W. Wendler, *R&S®FSW signal and spectrum analyzer: measuring E band microwave connections,* Rohde & Schwarz, News from R&S 208.

8 Ordering Information

Signal Generators

Designation	Type	Order No.
Microwave Signal Generator	R&S®SMF	1167.0000.02
Frequency Range 1 GHz to 22 GHz	R&S®SMF-B122*	1167.7004.03
Frequency Multiplier, 50 GHz to 75 GHz	R&S®SMZ75*	1417.4004.02
SMGA RF Source	R&S®SGS100A	1416.0505.02
1 MHz to 6 GHz, I/Q (with vector modulation)	R&S®SGS-B106V	1416.2350.02
Frequency Extension to 12.75 GHz, I/Q	R&S®SGS-B112V	1416.1576.02
Electronic Step Attenuator	R&S®SGS-B26	1416.1353.02
Frequency Multiplier, 50 GHz to 75 GHz	R&S®SMZ75*	1417.4004.02
Mechanically Controlled Attenuator for the R&S®SMZ75	R&S®SMZ-B75M	1417.6007.02
UWB Signal and I/Q Modulation Generator	R&S®AFQ100B	1410.9000.02
Waveform Memory 256 Msample	R&S®AFQ-B10*	1401.5106.02

Signal Generators

Designation	Type	Order No.
Signal and spectrum analyzer 2 Hz to 67 GHz	R&S®FSW67*	1312.8000.67
RF Preamplifier, 100 kHz to 67 GHz	R&S®FSW-B24	1313.0832.67
500 MHz Analysis Bandwidth	R&S®FSW-B500	1313.4296.02
Analog Baseband Inputs 40 MHz Analysis Bandwidth	R&S®FSW-B71	313.1651.67
80 MHz Analysis Bandwidth for Analog Baseband Inputs	R&S®FSW-B71E	1313.6547.02
Vector Signal Analysis	R&S®FSW-K70	1313.1416.02
LO/IF Connections for external mixers	R&S®FSW-U21	1313.6318.26

* Other Signal Generator and Signal and Spectrum Analyzers configurations and Multiplier Models are suitable as well. More options are available. The instrument minimum configuration for this application is shown in the table, but for the analyzer, models FSW43/50 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.

9 Appendix

In the following example filter specifications for using the unlicensed V-band 57 GHz to 64 GHz with the recommended setup of Figure 5 are given. Used parts for the measurements documented in this application note are stated as well. Parts for the licensed-light E- and W-bands would be specified accordingly.

9.1 Recommended Specifications for V-Band High Pass Filter

Pass band: >= 57 GHz

Pass band attenuation: < 1 dB

Stop band: < 53 GHz

Stop band rejection: > 40 dB

e.g. **Sage Millimeter Inc.: SWF-57353340-12-H1**

(Note: 2 x Taper Transitions WR15 -WR12 are needed with SWF-57353340-12-H1 to adapt to the V-Band mixer. **e.g. Sage Millimeter Inc: SWT-1512-LB**).

9.2 Recommended Specifications for V-Band Band Pass Filter

Pass band: 57 GHz to 64 GHz

Pass band loss: >1. 5 dB

Stop band: > 44 GHz, > 62 GHz (to 75 GHz)

Stop band rejection: > 50 dB

e.g. from **BSC Filters Ltd.**

9.3 Recommended Specifications for V-Band Biased Mixer

RF Frequency: 50 GHz to 70 GHz

IF Frequency: DC to 25 GHz

LO: 50 GHz to 75 GHz/ 0 to +3 dBm

Conversion Loss: 12 dB

e.g. **Sage Millimeter Inc.: SFB-15-E2**

9.4 Recommended Specifications for V-Band Amplifier

Frequency Range: 57 to 64 GHz

Gain: 20 dB min, 25 dB max

P -1dB: 16 dBm

Gain Flatnes: +- 2dB

VSWR: 2:1 typ.

e.g. **Sage Millimeter Inc.: SBP-5736432016-1515-S1**

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Application Note | mm-Wave Band Signal Generation and Analysis
Data without tolerance limits is not binding | Subject to change