Products: R&S®SMF100A, R&S®SMBV100A

Upconverting Modulated Signals to Microwave with an External Mixer and the R&S®SMF100A Microwave Signal Generator

Application Note

A vector-modulated microwave signal can be generated by mixing an I/Q-modulated signal with a microwave carrier. This Application Note describes the frequency upconversion using a standard passive mixer.

ROHDE & SCHWARZ

Subject to change – C. Tröster, F. Thümmler, T. Röder   11.2008 – 1GP65_0E

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1 Note

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

- The R&S®SMF100A microwave signal generator is referred to as SMF
- The R&S®SMBV100A vector signal generator is referred to as SMBV

Other product and company names mentioned here are trademarks or trade names of their respective companies.

2 Overview

Vector modulation is becoming more and more widespread in microwave and satellite communications applications. Direct generation of digital modulation at microwave frequencies is, however, expensive and difficult to implement. An alternative to generating I/Q-modulated signals in the microwave range is frequency upconversion of usual (low-frequency) vector signals. This Application Note describes the principle of upconversion using an external mixer. The basics of mixer operation are introduced and the conversion process is demonstrated in detail with a test setup and corresponding measurements. The mixer selection guide will make it easier to choose a proper mixer for individual applications.

3 Mixer Fundamentals

Generally, mixers are electrical devices that can be used for converting RF power at one frequency to RF power at another frequency. This Application Note describes the upconversion of a modulated signal from a vector signal generator to the microwave frequency range by means of an external mixer and a microwave generator as LO source.

Basic mixer principle

An ideal mixer multiplies the signals applied to its two inputs. In the simple case of sinusoidal input signals with frequencies $f_1=\omega_1/2\pi$ and $f_2=\omega_2/2\pi$, the mixer action is described by

$$A(t) = A_1 \sin(\omega_1 t + \varphi_1) \cdot A_2 \sin(\omega_2 t + \varphi_2)$$

$$= \frac{A_1 A_2}{2}\left[\cos\left[(\omega_1 - \omega_2)t + (\varphi_1 - \varphi_2)\right] - \cos\left[(\omega_1 + \omega_2)t + (\varphi_1 + \varphi_2)\right]\right]$$

The equation shows that the resulting output signal of an ideal mixer consists of only two frequency components: the sum and the difference of the input frequencies.

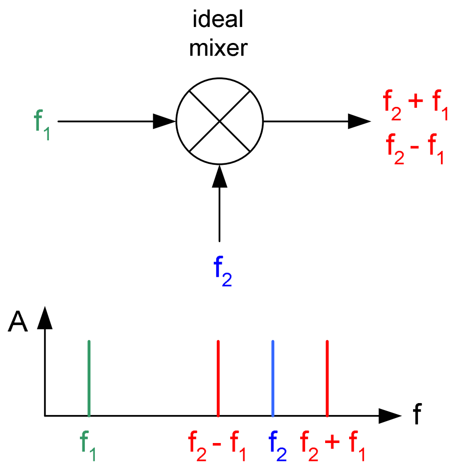


Fig. 1: Input and output signals of an ideal mixer used as frequency upconverter.

In a setup where the mixer is used as an upconverter a signal with a low carrier frequency is applied to the IF (intermediate frequency) port of the device while a CW signal with a higher frequency is applied to the LO (local oscillator) port. The upconverted output signal is present at the RF (radio frequency) port. The corresponding input and output spectra are shown in Fig. 2. The two frequency components of the RF signal are termed upper and lower sideband, representing the sum and the difference of the input signals, respectively. For further signal processing, one sideband is filtered out in subsequent filter stages.

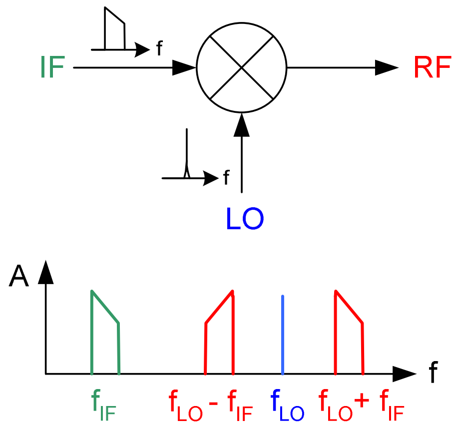


Fig. 2: Input and output signals of an ideal mixer used as frequency upconverter.

The performance of a real mixer differs from that of an ideal mixer. Thus, a basic understanding of the mixer characteristics will help you choose the right device for your application. The following points are important issues that are discussed in more detail.

- Conversion loss
- Isolation
- Harmonics and combination products
- Linearity
- Intermodulation products
- Noise figure
- Impedance and VSWR
- LO noise

Conversion loss

Conversion loss is a quantity specifying how efficiently a mixer converts the signal energy from the input frequency to the output frequency. It is defined as the ratio of the input power to the output power of one sideband measured in dB for a given LO level. An inherent loss results from the mixing principle, which is 3 dB for each sideband. A passive mixer that is composed of diodes causes additional attenuation of the input signal power. The resulting conversion loss varies with the applied LO power. At a certain LO level, the conversion loss reaches a minimum and thus the mixer should be operated at this optimal power level.

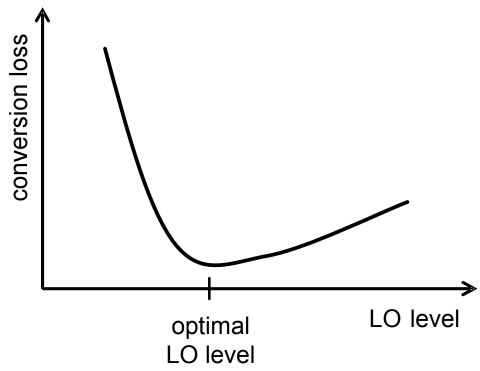


Fig. 3: Qualitative diagram of the conversion loss in dB as a function of LO input power in dBm.

The conversion loss may also vary with frequency, such that for given IF and LO input power levels, the RF output level may change over the frequency span of intended operation. This may lead to distortion of the RF signal, thus degrading signal quality. Especially signals featuring high IF bandwidths may be affected by a non-constant conversion loss response of the mixer.

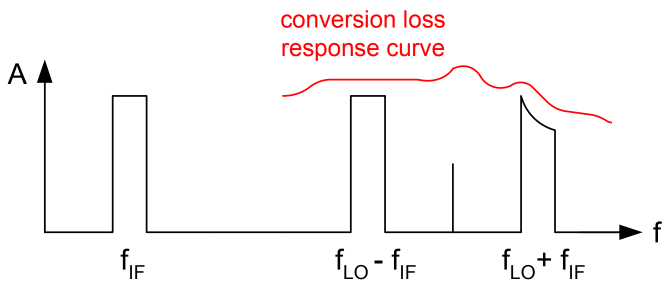


Fig. 4: Variation of the conversion loss with frequency and the possible impact on the RF signal.

Isolation

Isolation is a measure of signal leakage or feed-through from one mixer port to another port. Good isolation corresponds to low leakage. Unbalance of the internal transformers or lead inductance is the main cause of port-to-port leakage. The amount of feed-through from the LO to the RF port is specified by the LO-RF isolation. In an analogous way, the LO-IF isolation defines the level at which the LO signal appears at the IF port.

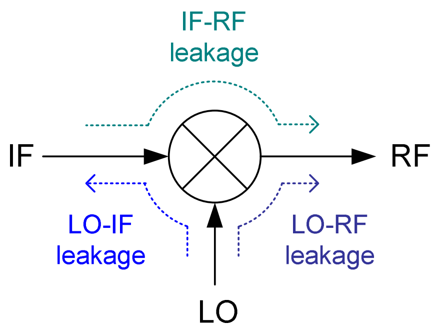


Fig. 5: Signal leakage between the mixer ports.

Isolation is measured in dB and is a frequency-dependent quantity. High isolation is preferable, since signal leakage will create spurious signal components in the output spectrum. Generally, the LO input level is significantly higher than the IF input level. Therefore, good LO-RF isolation is important when using the mixer as an upconverter.

The isolation that a mixer can provide depends on its circuitry. Unbalanced mixers do not offer isolation between their ports and hence both input frequencies appear unsuppressed at the output. A single balanced mixer provides suppression of one of its input frequencies. In order to suppress both input frequencies at the output, a double balanced mixer architecture is required, which offers isolation between all three ports.

Harmonics and combination products

As already described, an ideal mixer produces signals with frequencies at f_{LO}-f_{IF} and f_{LO}+f_{IF}. However, a real mixer produces more signals according to the following formula:

$$f_{v,w} = \left| v \cdot f_{LO} + w \cdot f_{IF} \right|$$

where v and w are integers (…,−2, −1, 0, 1, 2, …). For example, the lower and the upper sideband are obtained for v = 1, w = −1 and v = w = 1, respectively. The various output signals differ inherently in amplitude. The lower and upper sidebands are the strongest mixing products. All the other combination products have lower amplitude. Nevertheless, they may appear in the spectrum at relatively high levels. This is particularly true for the LO harmonics. Generally, harmonics are multiples of a signal, e.g. for v = 2 and w = 0 the resulting signal appears at $2f_{LO}$. Multiples of the LO frequency as well as other combination products can distort the output spectrum. However, the higher f_{LO} is, the higher also the frequency of the first, second, etc., LO harmonic and thus the lower the harmonic distortion in a fixed frequency range. Fig. 6 illustrates the possible combination frequencies in the RF spectrum.

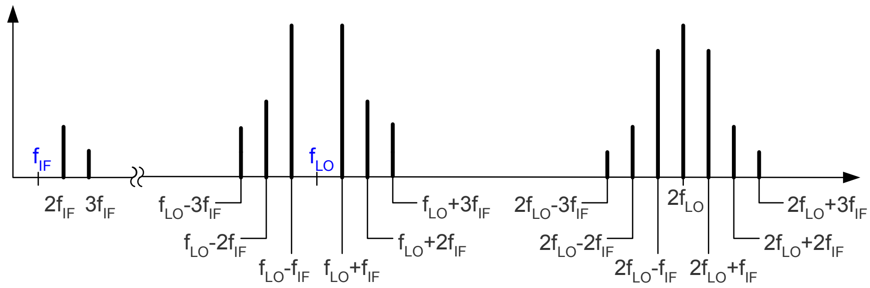


Fig. 6: Qualitative diagram of the mixer's output frequency spectrum showing the combination products for v = 0, 1, 2 and w = −3, −2, −1, 0, 1, 2, 3.

Linearity

The mixer's ability to process high input levels without major distortion of the output signal is described by two quantities: the 1dB compression point and the intercept point (see next subheading, “Intermodulation products”).

Normally, the signal level at the output of the mixer is proportional to the level at the input port (assuming a constant LO input level). However, when the input power exceeds a certain maximum level, the ratio between input and output level is no longer a constant. The output power begins to saturate and reaches a maximum level at high input powers. The input level at which the output level deviates from the linear trend by 1 dB is termed 1dB compression point. It is essentially a measure of the mixer's linearity for high input levels.

The (linear) dynamic range of a mixer is generally defined as the amplitude difference between the noise floor and the 1dB compression point. Since the noise level of different passive mixers is roughly the same, the compression point normally determines the dynamic range.

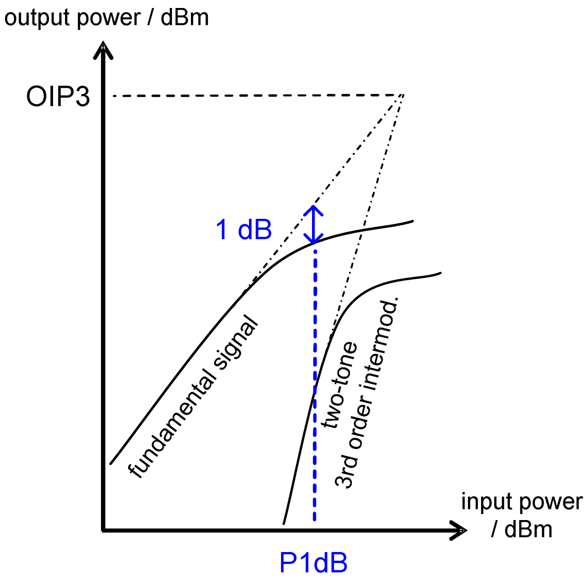


Fig. 7: Output power as a function of input power for the fundamental signal (slope equals 1 in the linear regime) and the two-tone third-order intermodulation products (slope equals 3 in the linear regime). Shown are the 1dB compression point (blue) and the output intercept point.

Intermodulation products

Intermodulation products are signals that result from the interaction of two or more signals in a non-linear device. Note that there is a difference between combination products and intermodulation products. For the latter to appear, two or more signals must be present at the input port simultaneously. For example, two interacting input signals will produce (two-tone) intermodulation products at the following frequencies:

$$f_{n,m} = \left| n \cdot f_1 + m \cdot f_2 \right|$$

where *m* and *n* are integers (…,−2, −1, 0, 1, 2, …). Here, f_1 could be the frequency of the desired input signal and f_2 the frequency of an additional (maybe unwanted) input signal simultaneously present at the same mixer port. In case of a multicarrier input signal, e.g. a two-carrier signal, f_1 and f_2 would be the carrier frequencies. The sum $|n|+|m|$ is called the order of the intermodulation product. The most critical are the third-order components with frequencies $f_{2,-1} = 2f_1 - f_2$ and $f_{-1,2} = -f_1 + 2f_2$, since they may be spectrally close to the designated input signal. Consequently, after upconversion (i.e. mixing with the LO signal) these unwanted components may appear close to the desired output signal and thus may not be easily filtered. The problem associated with these third-order intermodulation products is that their amplitude rises rapidly with increasing input power. If the power level of the input signals is increased by e.g. 10 dB each, the corresponding third-order intermodulation products increase by 30 dB. Hence, at a certain input power, they will reach the level of the wanted output signal. This situation is specified by the third-order intercept point (IP3). It can be related either to the input power (IIP3) or to the output power (OIP3) - see Fig. 7. In reality, as the input power is increased, the mixer compresses before the level of the intermodulation products can equal the level of the output signal. Thus, the mixer's intercept point is a theoretical point that is determined by extrapolation, as shown in Fig. 7.

Noise figure

The noise figure is the signal-to-noise ratio at the input divided by the signal-to-noise ratio at the output expressed in dB.

$$NF = 10 \ \log\left(\frac{(S/N)_{input}}{(S/N)_{output}}\right)$$

In the case of passive mixers, the main cause of the reduction of the signal-to-noise ratio is the conversion loss. While the input signal is degraded at a certain rate (conversion loss), the noise level stays almost constant. The rise of the noise floor due to the noise of the mixing diodes is small in comparison.

Impedance and VSWR

The input and output impedances of a mixer usually differ more or less from the characteristic system impedance (normally 50 Ω). The deviation is often specified by the voltage standing wave ratio (VSWR), which is a measure of the amount of reflection on a conductor due to the mismatch of the conductor and the terminating (mixer) impedances. The VSWR is defined as the ratio of the rms voltages of the incoming and the reflected waves:

$$VSWR = \frac{V_i + V_r}{V_i - V_r}$$

where V_i and V_r are the voltages of the incoming and the reflected waves, respectively. Expressed in terms of impedances the VSWR is given by the following formula:

$$VSWR = \frac{1+|\rho|}{1-|\rho|} \qquad \text{with} \qquad \rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

where Z_L is the input impedance of the mixer and Z_0 is the characteristic impedance of the system. Ideally, if there is no reflection (perfect match, $Z_L = Z_0$), the reflection coefficient ρ is zero and the VSWR is 1. Full reflection (open or short circuit) results in a reflection coefficient of 1 and an infinite VSWR. Note that the VSWR is a scalar (amplitude only) quantity and does not include any phase information, and thus does not specify if the impedance is above or below 50 Ω. For example, a VSWR of 2:1 measured in a 50 Ω system can correspond to a mixer input impedance of 25 Ω or 100 Ω. In fact, as a function of frequency, the impedance of a broadband mixer swept over a frequency range of an octave or more typically varies between its minimum and maximum values (e.g. from 25 Ω to 100 Ω for the example above). The VSWR of all three mixer ports depend on the LO input power, which sets the operating point of the internal diodes of a passive mixer. Changing the LO power affects the diode operating point. This results in an impedance change of all three ports and a change of the corresponding VSWR.

LO source

As mentioned already, a proper LO source is essential for efficient mixer operation. But not only is the signal level of importance, also the signal purity is a crucial parameter. The noise of the LO source generally consists of amplitude jitter and phase noise. Provided the LO level is at its specified optimal value, amplitude noise does not play a significant role. However, the phase noise of the LO source will be converted to RF and will consequently decrease the signal quality of the output signal. Hence, a stable LO source with very low phase noise is essential in order to achieve good signal purity of the wanted RF signal.

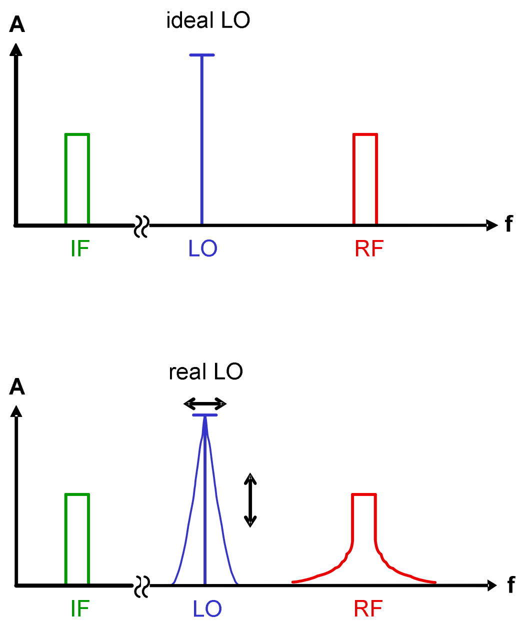


Fig. 8: Schematic frequency spectra illustrating the influence of the LO phase noise on the wanted RF signal.

4 Internal versus External Mixer

The microwave signal generator R&S®SMR offers an internal mixer for upconversion of an applied IF signal (options R&S®SMR-B23, -B24 and -B25). One advantage of this hardware option is that the test setup can be more clearly arranged due to reduced cabling and components required. The internal mixer is not only a compact solution but also a convenient solution. Concerns such as the selection of a mixer with favorable specifications and the adjustment of the optimal LO drive power have already been taken care of.

The major advantage of using an external mixer as upconverter is flexibility. You can choose a device that is specifically suitable for an individual application concerning input characteristics and performance. This offers the possibility of optimizing the signal characteristics of the RF output with respect to the particular system requirements. An individual mixer may also reduce the costs, since over-specification of the mixer characteristics and thus overspending can be avoided.

5 Mixer Selection Guide

In order to select a suitable mixer, it is essential to understand and determine the requirements of the application. This includes the involved frequency ranges of operation, the required power output, the available LO drive power, the required isolation, the system impedance, the type of connectors, etc. One should evaluate to what extent the system can tolerate harmonic distortion and if intermodulation distortion will pose a problem. The market offers a wide variety of different mixer models. Depending on the system requirements, there may be an oversupply or lack of eligible devices. In the latter case, some compromises may have to be made. This section describes important points that should to be taken into account in the selection process.

Note that the specifications are usually given for the mixer operating as a downconverter, i.e. RF/LO as input parameters and IF as output parameter. Certainly for passive mixers and for devices approved for usage as upconverter, the relevant specifications can be reversed. For example, the specified RF-to-IF isolation denotes the IF-to-RF performance of the mixer when it is employed as an upconverter.

What to consider?

LO input

- The power requirement at the LO input of the mixer is specified by the manufacturer and should be met in order to keep the conversion loss at a minimum. Typical levels may range from 7 dBm up to 23 dBm depending on the device properties. One has to make sure that the LO signal source is capable of providing the required drive power.
- Since the signal quality at the mixer's output depends on the purity of the LO signal, a stable source with very low phase noise and very low harmonics/non-harmonics should be used.
- The manufacturer also specifies the LO frequency range. Only within this frequency band will the mixer perform in accordance with the specifications.
- Typically, in the mixer's output spectrum the LO frequency and its harmonics will be present. The specified LO-to-RF isolation of the device should therefore be taken into account in order to keep the spurious components low (if necessary for your application). At the same time, it may be beneficial to use the lowest LO power that will allow the requirements of the application to be met in order to minimize the amount of LO leakage within the system.
- The required LO power and the 1dB compression point of the mixer are related parameters. Basically, the higher the LO power the higher the 1dB compression point and thus the wider the dynamic range. Consequently, a high 1dB compression point involves a high LO level.

IF input

- The IF port also has a certain frequency coverage that typically is significantly smaller than the LO coverage. Depending on the application, this may be a critical mixer parameter, e.g. when using a high-frequency IF signal. In this case, the availability of mixers with the appropriate IF frequency range may be limited.

- The desired IF bandwidth determines the minimum IF carrier frequency to be used with f_{IF} > ½ IF BW. However, f_{IF} should be chosen larger than the theoretical minimum to facilitate filtering of the resulting RF signal. In principle, a high IF carrier frequency is generally advantageous.
- The IF input power level is essentially limited by the 1dB compression point. Also the intercept point can be a critical parameter, e.g. when using a multicarrier IF signal. Here, in order to reduce the resulting intermodulation products in the RF output, the applied IF level has to be decreased.

RF output

- As for the LO and IF inputs, there is a certain frequency range of operation specified for the RF port.
- The output power depends on the IF input power and the conversion loss of the mixer. If the application requires high output power, a device having low conversion loss and a high 1dB compression point (allowing for high IF input power) should be chosen.
- The conversion loss may vary in the specified frequency range and so may the amplitude of the RF signal. For signals with a wide IF bandwidth, this can reduce the signal quality. Here, the conversion loss response curve should be tolerably flat over the frequency range of intended operation.
- In general, the output spectrum is strongly influenced by the mixer's transfer characteristics and the specific input parameters. Hence, the influencing factors need to be optimized according to the individual needs of possible applications.

Selecting a suitable mixer

Usually, the given parameters of the wanted vector-modulated microwave signal are the desired RF frequency (range) and the bandwidth. Another parameter may be the RF output level, in case a minimum level is required.

First one should choose the LO and IF carrier frequencies. Since $f_{RF} = f_{LO} \pm f_{IF}$, the setting of the IF frequency influences the LO frequency and vice versa. The filtering process of the mixer's output spectrum, e.g. suppressing the unwanted sideband and the LO carrier, becomes more and more difficult the smaller the IF frequency, requiring filters with a very steep transfer function. Thus, generally a high IF frequency is preferable. However, a high LO frequency is also advantageous, since the LO harmonics will then appear in greater intervals in the spectrum. Each harmonic is accompanied by mixing products at combination frequencies $f_{LO\_harmonic} \pm f_{IF}$. Hence, harmonic distortion can be substantial. However, it can be easily restrained by applying a high LO frequency. For this reason, a compromise between maximizing the LO and the IF frequency that will best suit the requirements has to be found.

The output power of the LO signal source at the desired LO frequency is an important quantity, since the mixer should be driven at an optimum LO level, which is typically around 10 dBm to 13 dBm for millimeter-wave mixers. Higher available output power may nevertheless be beneficial, because options for improved conversion characteristics (e.g. increased dynamic range, better suppression of intermodulation products) require enhanced LO input power.

Various companies offer a wide range of products. Naturally, a mixer that best meets the specifications should be chosen. Extra performance will usually add to the costs. Once one has decided on the LO and IF frequencies one can start to look for mixer models with suitable frequency ranges for RF, LO and IF. In cases where no mixer model is available that offers the required IF frequency range while simultaneously providing the right frequency ranges for LO and RF, the selection of the LO and IF frequencies will have to be revised.

In case the application requires a certain RF output level, two important mixer characteristics have to be considered in particular: conversion loss and 1dB compression point. The conversion loss of the (passive) mixer at the used IF frequency determines the IF input power to be applied. Typically, the conversion loss is in the order of 10 dB for high-frequency mixers. If, for example, the required RF level is −2 dBm minimum and the conversion loss 8.5 dB, then the required IF power would be 6.5 dBm minimum. The 1dB compression point of the mixer basically sets a limit for the IF input power. That means that the specified 1dB compression point should be higher than the anticipated maximum IF input level. If the applied IF power were 6.5 dBm minimum and 13 dBm maximum, then the mixer's 1dB compression point should be higher than 13 dBm, e.g. about 15 dBm. One should keep in mind, that generally the higher the desired 1dB compression point, the higher the required LO drive power. If the application requires a very high output power, one may have to use active mixers with conversion gain (not discussed in this paper) or amplify the RF output of a passive mixer using a subsequent RF amplifier.

In case the IF signal is a multi-tone signal, the third-order intercept point of the mixer is an essential parameter. The applied IF input level should be well below the specified third-order intercept point. For example, an intercept point of +15 dBm should be more than sufficient if the IF level is low, e.g. −25 dBm; but if the IF level is e.g. 0 dBm, then the suppression of the intermodulation products may be insufficient. Thus, a mixer should be chosen having a third-order intercept point that adequately exceeds the maximum IF input level anticipated in order to keep the distortion low.

When selecting a mixer model one should keep in mind that mixers are available in different housings and with different connectors, although for RF mixers the most common connector type is SMA.

6 Test Setup

Vector-modulated microwave signals can be generated by mixing the output of a microwave signal generator acting as LO source with the output of a vector signal generator, which provides the modulated IF input signal. In this configuration, the external mixer acts as a frequency upconverter. The resulting RF output of the mixer is an I/Q-modulated signal in the microwave frequency range.

The output signal may require subsequent filtering depending on the desired signal characteristics needed for the individual applications. The quality of the RF signal depends on the mixer transfer characteristics and the signal purity of the two input signals.

Fig. 9 shows a possible test configuration using the R&S®SMF100A microwave generator for LO drive at frequencies up to 22 GHz (or optionally up to 43.5 GHz) and the R&S®SMBV vector signal generator for supplying I/Q-modulated IF signals from 9 kHz up to 3.2 GHz (or optionally up to 6 GHz). With this LO source, maximum drive power ranging between

14 dBm and 22 dBm can be provided at microwave frequencies, which permits the choice of an external mixer requiring high LO input or the insertion of attenuating components into the LO transmission line. Instead of the SMBV, basically any signal generator or combination of signal generators capable of producing the desired modulated output signal can be used. Alternatives could be an R&S®SMJ100A or an R&S®SMU200A.

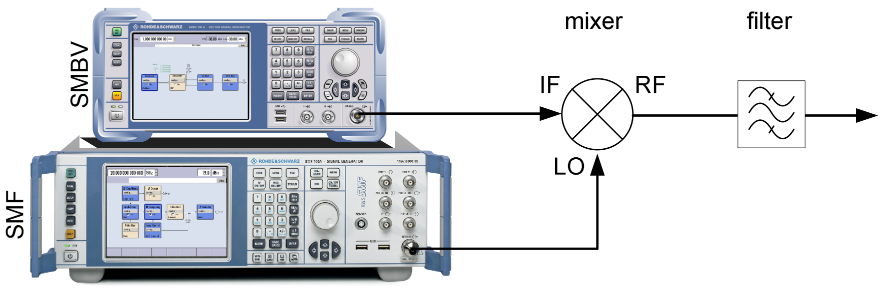


Fig. 9: Schematic of the test setup using two Rohde & Schwarz signal generators, a passive mixer and an optional filter.

For the test scenario presented here, we choose an I/Q-modulated signal at 3 GHz. The digital modulation scheme is 16QAM with 10 Msymbol/s. The LO frequency is set to 13.5 GHz (CW signal). These settings result in an RF signal at 16.5 GHz and 10.5 GHz. The specifications of the external mixer are listed below (typical values):

Input parameters	LO power	10 dBm
	LO frequency range	2 - 26 GHz
	LO VSWR	2:1
	IF frequency range	0.04 - 6 GHz
	IF VSWR	2.5:1
Output parameters	RF frequency range	2 - 26 GHz
	RF VSWR	2.5:1
Transfer characteristics	Conversion loss	6 dB
	Noise figure (single sideband)	10.5 dB
	LO-to-RF isolation	23 dB
	LO-to-IF isolation	30 dB
	1dB compression point	5 dBm
	Input intercept point	15 dBm
Other	Connector type	SMA

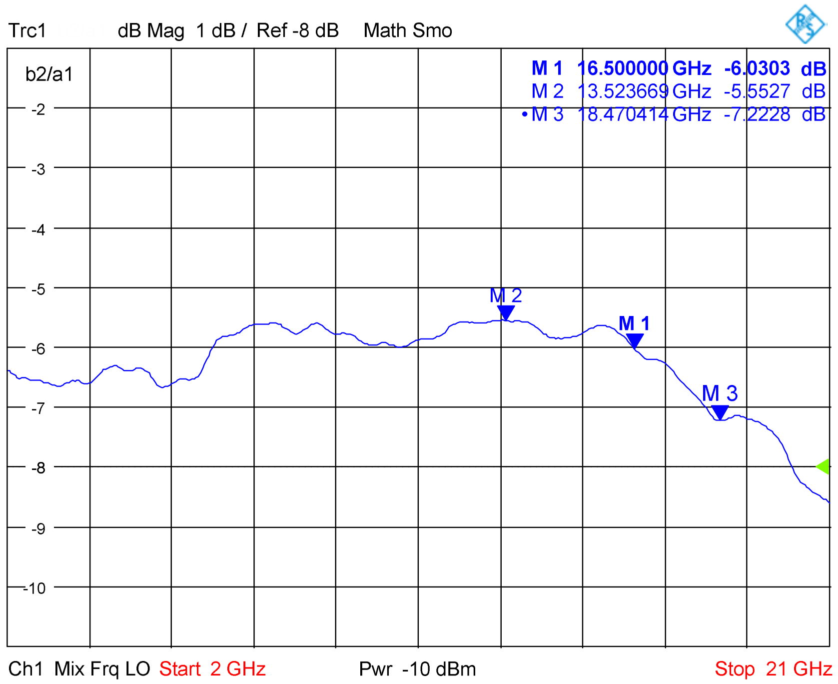


Fig. 10: Conversion loss versus radio frequency (2 GHz to 21 GHz).

In summary, these are the test scenario input parameters:

R&S®SMF100A	LO power	10 dBm
	LO frequency	13.5 GHz
R&S®SMBV	IF channel power	−10 dBm
	IF center frequency	3 GHz
	IF BW	10 MHz

The IF input signal is shown in Fig. 12. This vector-modulated signal is only one arbitrary sample of many possible alternatives. Basically any signal – CW, multicarrier, analog or digitally modulated, arbitrary waveform – can be used. Fig. 11 shows the LO input signal exhibiting excellent spectral purity.

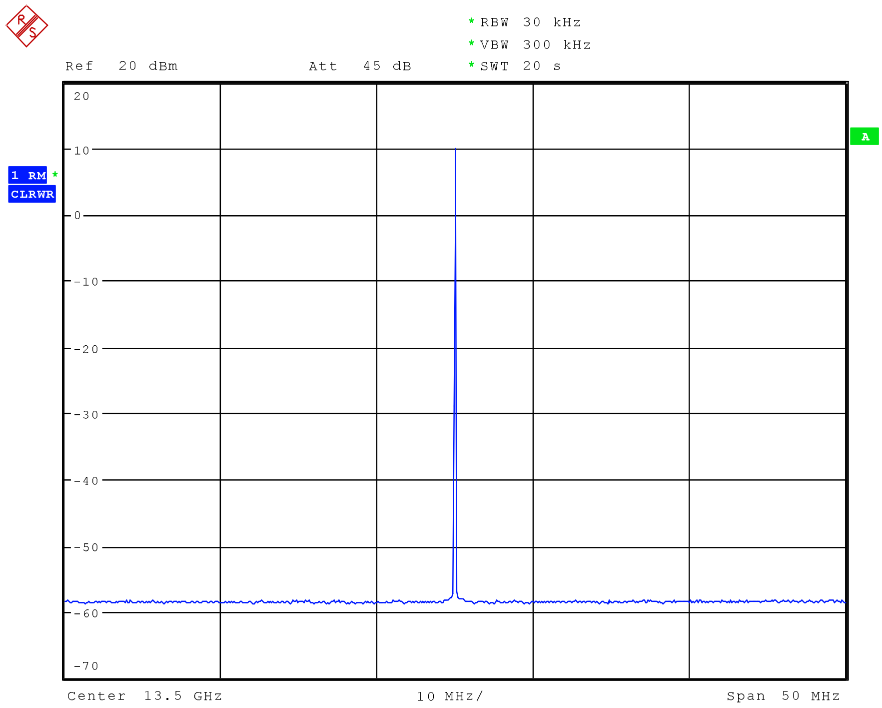


Fig. 11: Frequency spectrum of the 13.5 GHz LO input signal (continuous wave).

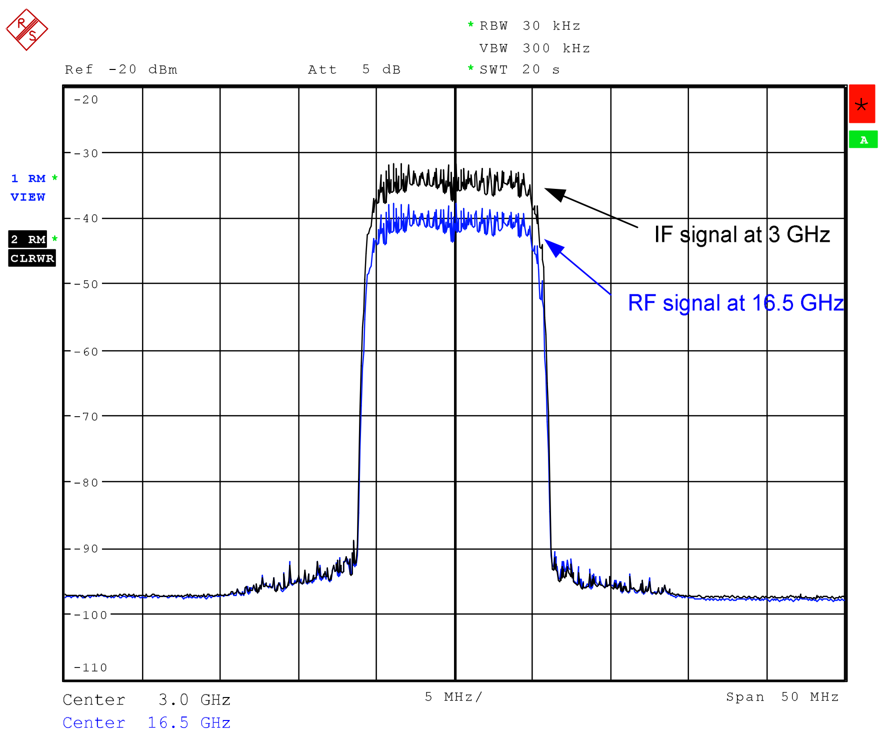


Fig. 12: Frequency spectrum of the vector-modulated IF input signal at 3 GHz and the vector-modulated microwave signal at 16.5 GHz. The channel power of the IF signal is −10 dBm.

Note

- Depending on the individual setup a system may feature a certain impedance mismatch. A simple way to reduce this mismatch is to insert matching pads into the transmission lines. These attenuator pads lower the VSWR of cascaded (connected) components by providing isolation between the impedances, effectively masking the impedance mismatches [1]. Generally, the higher the attenuation, the better the isolation. However, a system can only tolerate a certain amount of signal attenuation, e.g. the available LO power may pose a limit (it must be sufficient to drive the mixer at its optimum level and also to compensate for the inserted attenuation).
- One should keep in mind that the transmission lines are lossy to a greater or lesser extent depending on the type of cables used. Especially the microwave paths, i.e. the LO and RF paths, require adequate cabling to minimize attenuation of the signal level (semi-rigid cables or special cables for microwave applications should be used). Generally, it is recommended to keep the lengths of the transmission lines as short as possible. Additional losses may be caused intentionally by the insertion of attenuator pads for impedance matching purposes. To compensate for cable losses and inserted attenuation the output level of the generator should be set accordingly.
- Note that the VSWR of a filter is only close to 1 in the passband. In the stopband, a simple filter reflects most of the incoming signal, i.e. the VSWR is very high. However, in order to assure that the mixer performs in accordance with its specifications, the RF port needs to be terminated with a broadband impedance of 50 Ω. It is therefore advisable to use of a diplexer circuitry that provides a constant impedance versus frequency.
- Modulated signals exhibit peak powers that exceed the average power. Note that the corresponding peak envelope power (PEP) of the IF signal should still be lower than the 1dB compression point in order to avoid distortion of the modulated signal by the upconversion process. Signal peaks reaching or exceeding the 1dB compression point of the mixer will be compressed.

The RF output spectrum can be seen in Fig. 13. The upper and lower sidebands at 16.5 GHz and 10.5 GHz, respectively, are centered around the LO leakage peak at 13.5 GHz. The IF leakage peak at 3 GHz is also present in the spectrum. The smaller peaks at 6 GHz, 7.5 GHz, 19.5 GHz and 24 GHz correspond to mixer products at the combination frequencies $2f_{IF}$ (harmonic), f_{LO}-$2f_{IF}$, f_{LO}+$2f_{IF}$ and $2f_{LO}$-f_{IF}, respectively. Not covered by the frequency span of the spectrum are the first LO harmonic ($2f_{LO}$) at 27 GHz and the combination product $2f_{LO}$+f_{IF} appearing at 30 GHz. This spectrum is typical for mixers displaying the multitude of signals generated by the mixing process.

The wanted mixer signal is the upper sideband at 16.5 GHz – the vector-modulated high frequency signal (Fig. 13). Depending on the specific application, suppression of the unwanted signals in the RF output spectrum may be required. In this case, an appropriate filter or a combination of filters can be used. For this test scenario, we use a bandpass filter that rejects frequencies below 16 GHz and above 22 GHz. The relatively high frequency offset between the upper sideband and the LO carrier (here 3 GHz) facilitates filtering, which is generally difficult in the microwave frequency range. Fig. 13 also shows the filtered RF spectrum. The LO peak is greatly suppressed and the other unwanted signals (e.g. lower sideband, harmonics) are rejected. The amplitude of the selected upper sideband has been degraded by 1 dB due to the inherent insertion loss of the filter.

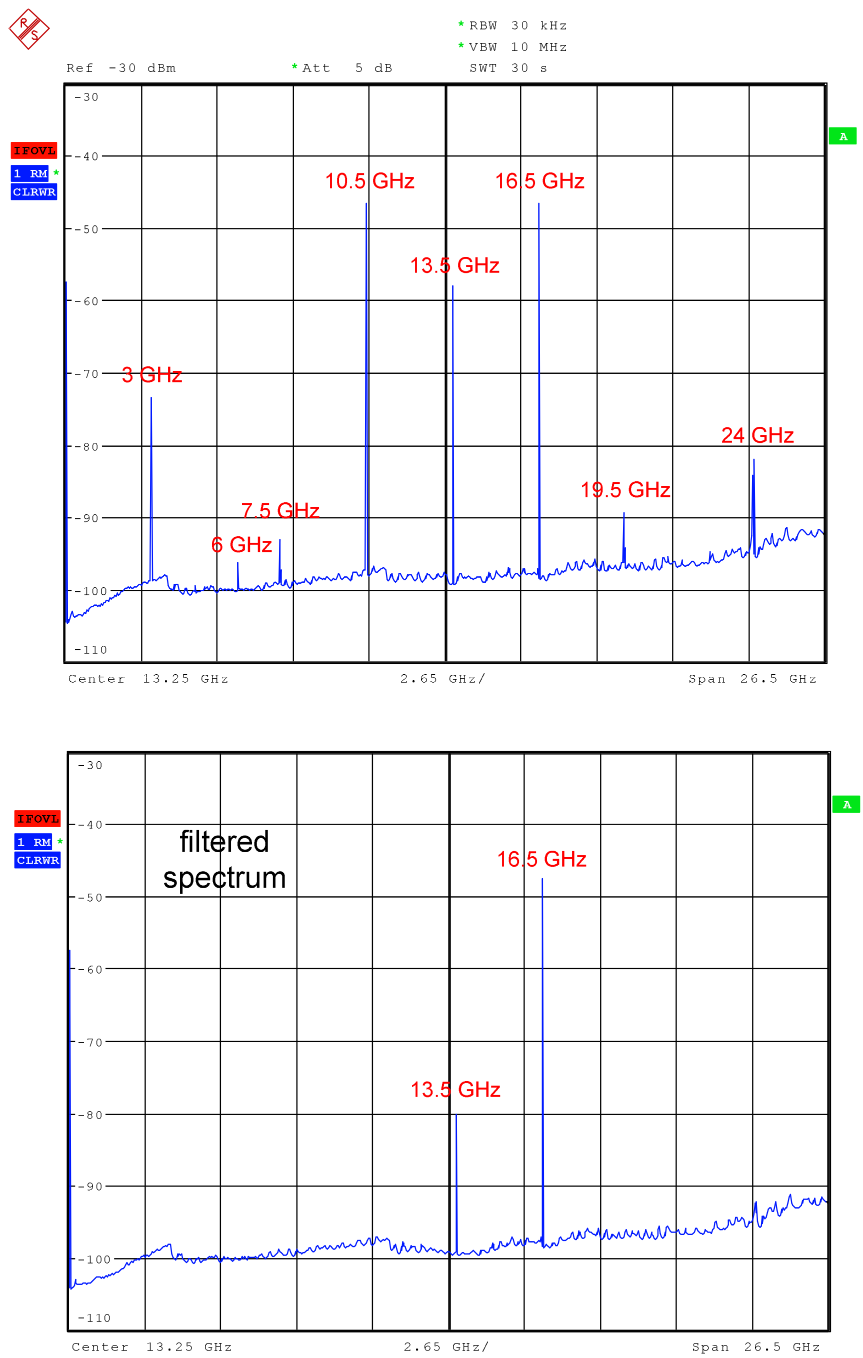


Fig. 13: Unfiltered and filtered RF frequency spectrum.

The output characteristics of the test setup are summarized in the following table. Peaks in the RF spectrum occur at the listed frequencies.

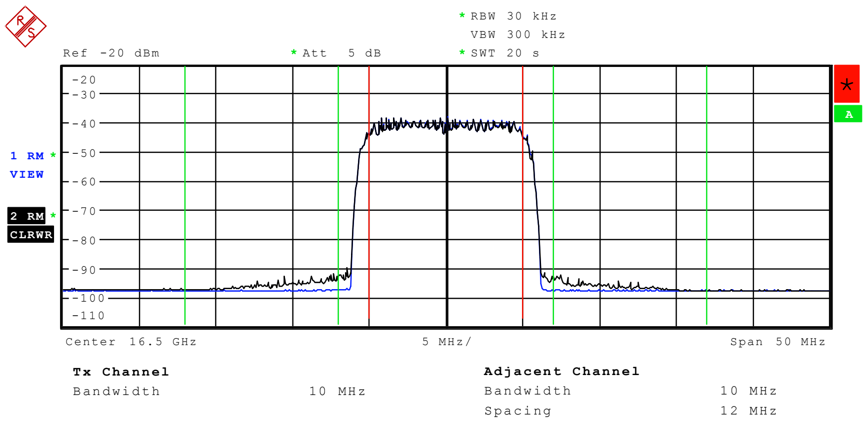
Frequency	Channel power without filter	Channel power with filter	Mixing product
3 GHz	−30 dBc	---	f_{IF}
6 GHz	−48 dBc	---	$2\ f_{IF}$
7.5 GHz	−44 dBc	---	$f_{LO} - 2\ f_{IF}$
10.5	−0.5 dBc	---	$f_{LO} - f_{IF}$
13.5 GHz	−2 dBc	−35 dBc	f_{LO}
16.5 GHz	**−16.0 dBm**	**−17.0 dBm**	$\boldsymbol{f_{LO} + f_{IF}}$
19.5 GHz	−43 dBc	---	$f_{LO} + 2f_{IF}$
24 GHz	−36 dBc	---	$2\ f_{LO} - f_{IF}$
27 GHz	−26 dBc	---	$2\ f_{LO}$
30 GHz	−36 dBc	---	$2\ f_{LO} + f_{IF}$

The wanted signal is the I/Q-modulated microwave signal at 16.5 GHz.

7 Applications

Single carrier

The test scenario described in Fig. 9 uses a single-carrier signal as IF input signal. The quality of this signal is slightly reduced by the upconversion process as shown by an adjacent channel leakage ratio (ACLR) measurement. The ACLR is defined as the ratio of the integrated signal power in the adjacent channel to the integrated signal power in the main channel. In general, the ACLR detected for the RF signal is larger than the ACLR for the IF input signal. In the test measurement shown in Fig. 14, the ACLR increases from −57.2 dBm to −55.3 dBm due to the upconversion. This is equivalent with more signal leakage into the adjacent channels.



Mixer input signal at 3 GHz		Up-converted signal at 16.5 GHz	
Power	-15.76 dBm	Power	-15.59 dBm
Lower	-57.25 dB	Lower	-55.03 dB
Upper	-57.24 dB	Upper	-55.50 dB

Fig. 14: Comparison of the ACLR measurements performed with a 3 GHz IF signal (blue) and an upconverted 16.5 GHz signal (black).

Multicarrier

When a (modulated) multicarrier signal is applied to the IF input, the mixer will generate intermodulation products. For a fixed carrier spacing the third-order intermodulation products of one carrier will overlap the adjacent carriers, thus causing distortion. To keep the intermodulation distortion of the output spectrum low the input level should be held well below the specified two-tone third-order intercept point of the mixer. Depending on the strength of the intermodulation peaks, the interference with the main carriers can be substantial. Consequently, suppression of the intermodulation products is essential to avoiding distortion of the wanted signal, which would result in a high bit error rate. Fig. 15 illustrates the effect of increasing input power − the intermodulation products in the RF signal grow by about 17 dB when the input power is raised by 6 dB.

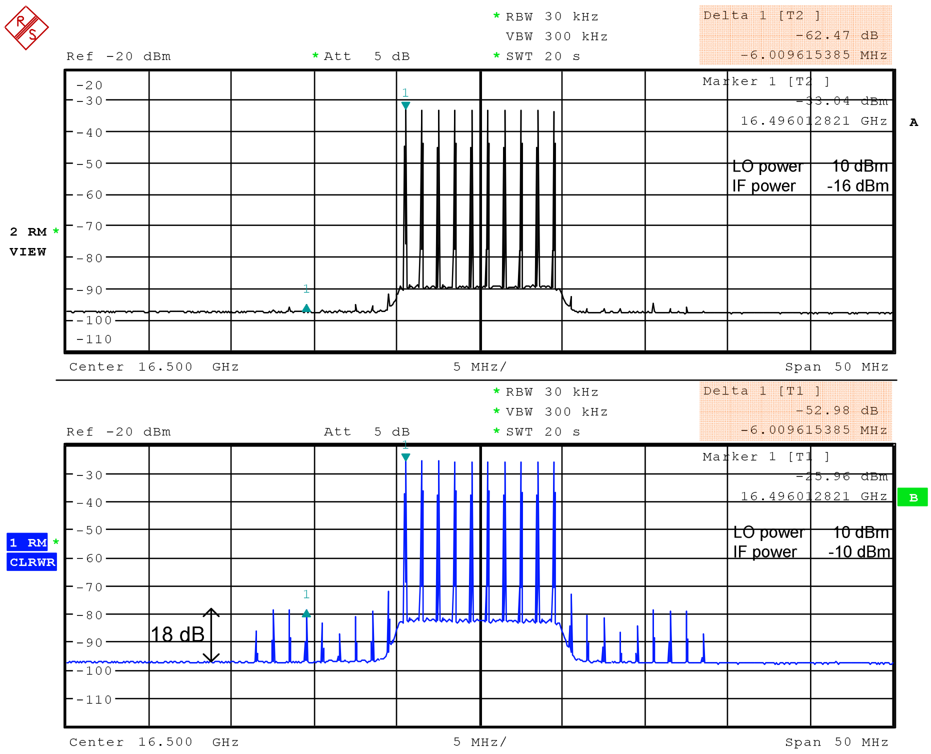
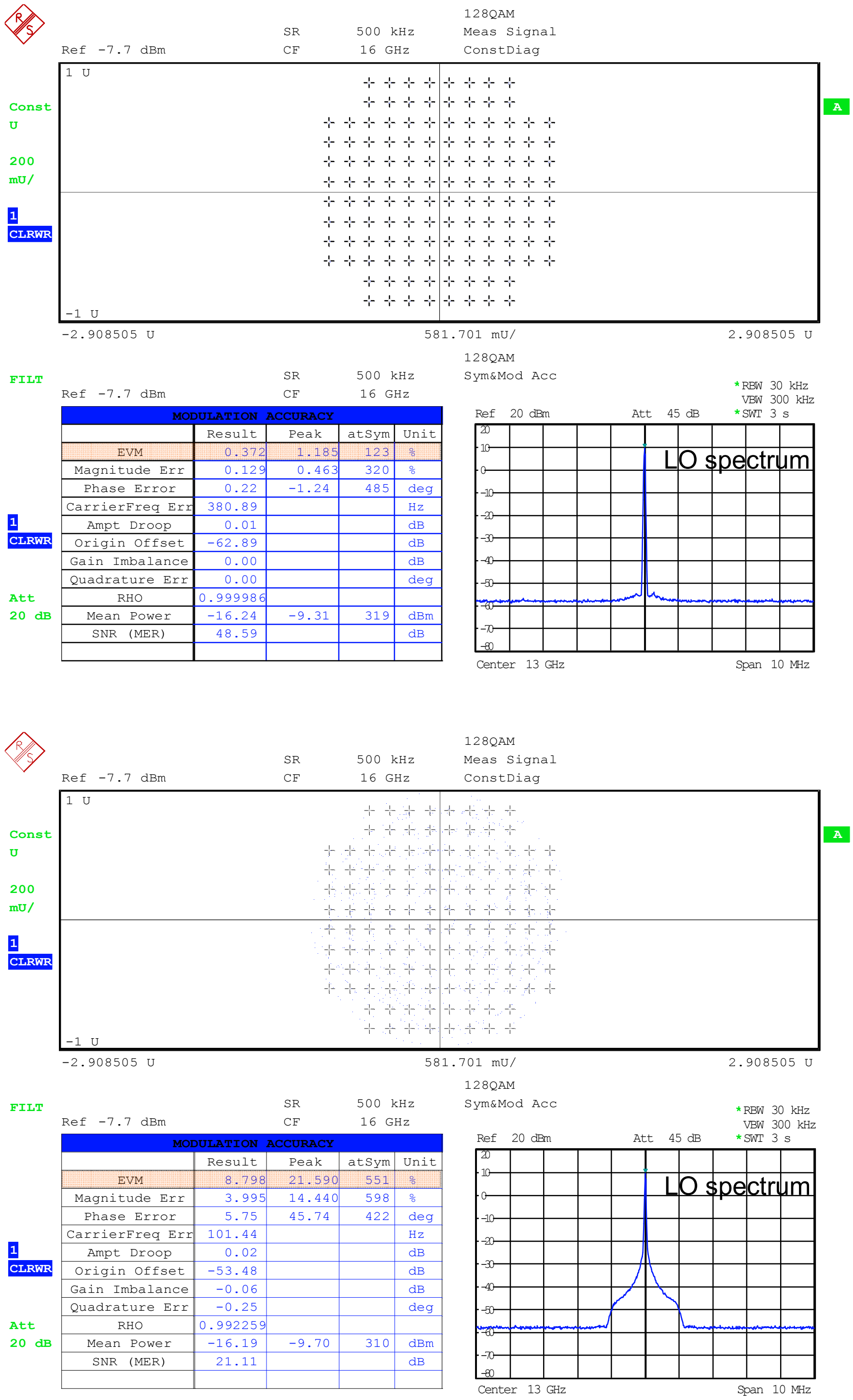


Fig. 15: Upconverted multicarrier signals for two different IF input powers.

High-order modulation

As already mentioned, the spectral purity of the LO source greatly influences the quality of the I/Q-modulated RF signal. One way to quantify the quality of the modulation is to perform an error vector magnitude (EVM) measurement. The error vector is the vector between the ideal constellation point in the I/Q-plane and the actual point received. Its length (or magnitude), defined as the Euclidean distance between the two points, is the EVM. It is a measure of the modulation accuracy. Fig. 16 compares the EVM measurements of upconverted I/Q-modulated signals. One of the signals has been upconverted to microwave using a LO source that offers high spectral purity, i.e. low phase noise (SSB phase noise at 10 GHz is <−115 dBc at a carrier offset frequency of 20 kHz). The measured EVM is small – only 0.37%. If the phase noise of the LO source increases then the EVM also increases. Fig. 16 shows the effect. The high phase noise of the LO signal results in an EVM of 8.80%. Especially when using a high-order modulation scheme, this will result in a high bit error rate. Hence, a high quality LO source is essential.



MODULATION ACCURACY	Result	Peak	atSym	Unit
EVM	0.372	1.185	123	%
Magnitude Err	0.129	0.463	320	%
Phase Error	0.22	-1.24	485	deg
CarrierFreq Err	380.89			Hz
Ampt Droop	0.01			dB
Origin Offset	-62.89			dB
Gain Imbalance	0.00			dB
Quadrature Err	0.00			deg
RHO	0.999986			
Mean Power	-16.24	-9.31	319	dBm
SNR (MER)	48.59			dB

MODULATION ACCURACY	Result	Peak	atSym	Unit
EVM	8.798	21.590	551	%
Magnitude Err	3.995	14.440	598	%
Phase Error	5.75	45.74	422	deg
CarrierFreq Err	101.44			Hz
Ampt Droop	0.02			dB
Origin Offset	-53.48			dB
Gain Imbalance	-0.06			dB
Quadrature Err	-0.25			deg
RHO	0.992259			
Mean Power	-16.19	-9.70	310	dBm
SNR (MER)	21.11			dB

Fig. 16: The influence of LO phase noise on the EVM measurement.

Phase coherence

The phase of the RF signal is given by the phases of the two mixer input signals. For the upper sideband the phases of the IF and the LO signal add up while for the lower sideband the phases subtract (see equation on page 3).

If two IF sources maintain a fixed phase difference $\Delta\varphi_{12}$, then the phase coherence will not be altered by the upconversion process provided that there is no phase difference between the two LO signals driving the mixers (see Fig. 17). Thus, in order to maintain phase coherence one has to make sure that the phases at the mixer LO ports equal.

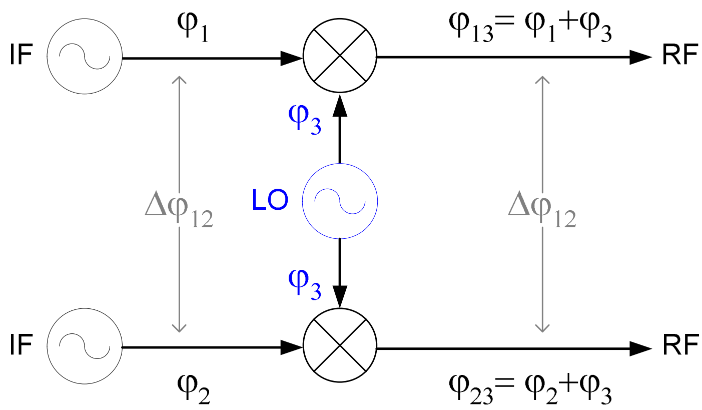


Fig. 17: Example setup for maintaining phase coherence between two upconverted signals (φ denotes the phase of the signal).

Frequency hopping

Hopping of the LO frequency directly translates to the RF output signal. In this way, RF frequency hopping can be implemented to cover a broad frequency range. A system requirement is that the mixer's specified LO and RF operating frequency ranges cover the intended hopping band. If the RF frequency is varied over a broad range, then signal filtering becomes difficult. Using mixers with very good LO-to-RF isolation or single sideband (SSB) mixers could be helpful. SSB mixers offer suppression of the LO and the unwanted sideband. (Note that the device needs to qualify for use as an upconverter.)

Subsequent RF amplifier

Typically, the power level at the RF port of a passive mixer is rather low due to conversion loss and input power restrictions. If a high RF level is required, the signal power can be increased using a RF amplifier. Similar to the mixer specifications, there are certain amplifier characteristics that have to be considered, such as frequency operating range, gain, 1dB compression point, noise and third-order intercept point. An amplifier will add to the noise in the system and cause further distortion of the signal. In order to minimize intermodulation, the mixer's RF signal should be filtered adequately to suppress the unwanted spectral components before it is fed into the amplifier.

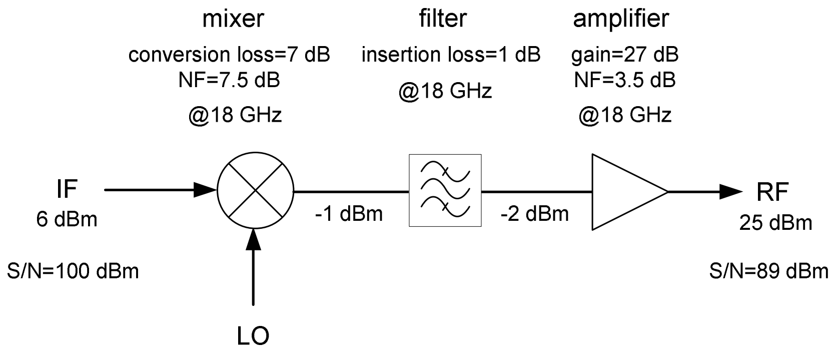


Fig. 18: Schematic of signal amplification using a subsequent bandpass filter and an amplifier.

8 Conclusion

This Application Note has described the generation of I/Q-modulated microwave signals achieved by external upconversion using a mixer and the R&S®SMF100A microwave signal generator.

The R&S®SMF100A in combination with an external mixer is a flexible solution, since the performance of the mixer can be adapted to individual applications. The R&S® SMF100A itself is an ideal LO source. It offers excellent performance, which is required to attain high signal quality. Furthermore, the presented test setup consisting of an R&S®SMBV100A vector signal generator, an R&S®SMF100A microwave generator and an external mixer is a powerful and cost-efficient setup for vector signal generation at microwave frequencies.

9 Abbreviations

ACLR	adjacent channel leakage ratio
CW	continuous wave
EVM	error vector magnitude
IF	intermediate frequency
IIP3	input two-tone third-order intercept point
LO	local oscillator
NF	noise figure
OIP3	output two-tone third-order intercept point
P1dB	1dB compression point
PEP	peak envelope power
QAM	quadrature amplitude modulation
RF	radio frequency
S/N	signal to noise ratio
SSB	single sideband
UUT	unit under test
VSWR	voltage standing wave ratio

10 References

[1] Mini-Circuits, AN-70-001 Rev OR (M79277), "Fixed attenuators help minimize impedance mismatches"

11 Ordering Information

Type of instrument

R&S®SMF100A	Microwave Signal Generator	1167.0000.02
R&S®SMF-B122	Frequency Range 1 GHz to 22 GHz	1167.7004.02
R&S®SMF-B144	Frequency Range 1 GHz to 43.5 GHz	1167.7204.02
R&S®SMF-B1	OCXO Reference Oscillator	1167.9159.02
R&S®SMF-B2	Frequency Extension 100 kHz to 1 GHz	1167.4005.02
R&S®SMF-B20	AM/FM/φM/LOG AM Modulator	1167.9594.02
R&S®SMF-B26	Step Attenuator 100 kHz to 22 GHz	1167.5553.02
R&S®SMF-B27	Step Attenuator 100 kHz to 43.5 GHz	1176.5776.02
R&S®SMF-B31	High Output Power 1 GHz to 22 GHz	1167.7404.02
R&S®SMF-B81	Rear Connectors 22 GHz	1167.5999.02
R&S®SMF-B82	Rear Connectors 43.5 GHz	1167.6208.02
R&S®SMF-B83	Removable GPIB	1167.6408.02
R&S®SMF-B84	Removable USB	1167.6608.02
R&S®SMF-B85	Removable Flash Disk	1167.6808.02
R&S®SMF-K3	Narrow Pulse Modulation	1167.7804.02
R&S®SMF-K4	Ramp Sweep	1167.7604.02
R&S®SMF-K23	Pulse Generator	1167.7704.02
R&S®SMBV100A	Vector Signal Generator	1407.6004.02
R&S®SMBV-B103	9 kHz to 3.2 GHz	1407.9603.02
R&S®SMBV-B106	9 kHz to 6 GHz	1407.9703.02

Ordering Information

R&S®SMBV-B1	Reference Oscillator OCXO	1407.8407.02
R&S®SMBV-B90	Phase Coherence	1407.9303.02
R&S®SMBV-K22	Pulse Modulator	1415.8019.02
R&S®SMBV-K23	Pulse Generator	1415.8025.02
R&S®SMBV-B10	Baseband Generator with Digital Modulation (realtime) and ARB (32 Msample), 120 MHz RF Bandwidth	1407.8607.02
R&S®SMBV-B50	Baseband Generator with ARB (32 Msample), 120 MHz RF bandwidth	1407.8907.02
R&S®SMBV-B51	Baseband Generator with ARB (32 Msample), 60 MHz RF bandwidth	1407.9003.02
R&S®SMBV-B55	Memory Extension for ARB to 256 Msample	1407.9203.02
R&S®SMBV-B92	Hard Disc (removable)	1407.9403.02
R&S®SMBV-K18	Digital Baseband Connectivity	1415.8002.02
R&S®SMBV-K6	Pulse Sequencer [1]	1415.8390.02
R&S®SMU200A	Vector Signal Generator	1141.2005.02
R&S®SMU-B102	Frequency option 2.2 GHz, 1^{st} RF path	1141.8503.02
R&S®SMU-B103	Frequency option 3 GHz, 1^{st} RF path	1141.8603.02
R&S®SMU-B104	Frequency option 4 GHz, 1^{st} RF path	1141.8603.02
R&S®SMU-B106	Frequency option 6 GHz, 1^{st} RF path	1141.8803.02
R&S®SMU-B202	Frequency option 2.2 GHz, 2^{nd} RF path	1141.9400.02
R&S®SMU-B203	Frequency option 3 GHz, 2^{nd} RF path	1141.9500.02
R&S®SMU-B13	Baseband Main Module	1141.8003.04
R&S®SMU-B9	Baseband Generator with ARB (128 Msample)	1161.0866.02
R&S®SMU-B10	Baseband Generator with ARB (64 Msample)	1141.7007.02
R&S®SMU-B11	Baseband Generator with ARB (16 Msample)	1159.8411.02
R&S®SMJ100A	Vector Signal Generator	1403.4507.02
R&S®SMJ-B103	Frequency option 3 GHz	1403.8502.02
R&S®SMJ-B106	Frequency option 6 GHz	1403.8702.02
R&S®SMJ-B13	Baseband Main Module	1403.9109.02
R&S®SMJ-B9	Baseband Generator with ARB (128 Msample)	1404.1501.02
R&S®SMJ-B10	Baseband Generator with ARB (64 Msample)	1403.8902.02
R&S®SMJ-B11	Baseband Generator with ARB (16 Msample)	1403.9009.02
R&S®SMATE200A	Vector Signal Generator	1400.7005.02
R&S®SMATE-B103	Frequency option 3 GHz, 1^{st} RF path	1401.1000.02
R&S®SMATE-B106	Frequency option 6 GHz, 1^{st} RF path	1401.1200.02
R&S®SMATE-B203	Frequency option 3 GHz, 2^{nd} RF path	1401.1400.02
R&S®SMATE-B206	Frequency option 6 GHz, 2^{nd} RF path	1401.1600.02
R&S®SMATE-B13	Baseband Main Module	1401.2907.02
R&S®SMATE-B9	Baseband Generator with ARB (128 Msample)	1404.7500.02
R&S®SMATE-B10	Baseband Generator with ARB (64 Msample)	1401.2707.02
R&S®SMATE-B11	Baseband Generator with ARB (16 Msample)	1401.2807.02

[1] Pulse Sequencer requires an external PC

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