Using Harmonic External Mixers To Extend the Frequency Range

Application Note

Products:

R&S®FSV	R&S®FSU
R&S®FSVR	R&S®FSP
R&S®FSQ	R&S®FSE

This application note gives a short summary on how to use harmonic mixers in combination with Rohde & Schwarz Signal and Spectrum Analyzers. Focus of this application note is the use of conversion loss tables with different R&S analyzers. It also provides a tool to convert different formats of the conversion loss tables.

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Application Note

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1 Using Harmonic Mixers to Extend the Frequency Range

Spectrum analyzers make use of harmonic mixers to increase their frequency range. Every harmonic mixer covers a specified frequency band, whose frequency range is dependent on the dimensions of the waveguide used as a connector to the DUT. Typical frequency ranges are therefore 40 to 60 GHz (U-band), 50 to 75 GHz (V-band), 60 to 90 GHz (E-band) and 75 to 110 GHz (W-band). A list of harmonic mixers available from Rohde & Schwarz is appended in chapter "Ordering information".

A harmonic mixer is placed in the signal path between the DUT and the RF frontend of the spectrum analyzer. It down-converts its specified frequency band to one of the intermediate frequencies (IF) of the analyzer, which is made available via a dedicated input connector. To perform the frequency conversion, harmonic mixers need a so called local oscillator signal (LO), which must be provided by the spectrum analyzer as an output signal.

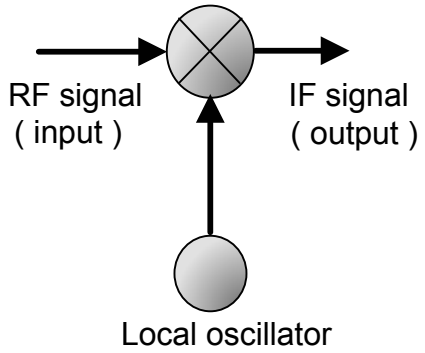

Figure 1: Block circuit of an external mixer

The frequency conversion complies with the following equation

$$f_{IF} = \left| f_{RF} - n \cdot f_{LO} \right|, \qquad (1)$$

where n equals the order of the harmonic of the local oscillator being used.

To cover a complete frequency band this means that the analyzer must provide a sweeping LO signal, which subsequently converts the RF at each frequency of the selected band to the fixed intermediate frequency.

By creating the IF signal directly the harmonic mixer bypasses the inbuilt microwave module of the spectrum analyzer. This is why the external mixing solution lacks a tunable filter and therefore yields image signals. To distinguish true signals from image signals, modern spectrum analyzers provide software algorithms (so called software preselectors), which detect and eliminate the image frequencies before drawing the measured curve on the screen.

For more details on harmonic mixing, see Application Notes 1EF43_0E and 1GP65_0E, references [1] and [2].

1.1 Operating Harmonic Mixers in combination with R&S Spectrum Analyzers

1.1.1 Local Oscillator and IF Frequencies of different Spectrum Analyzer families

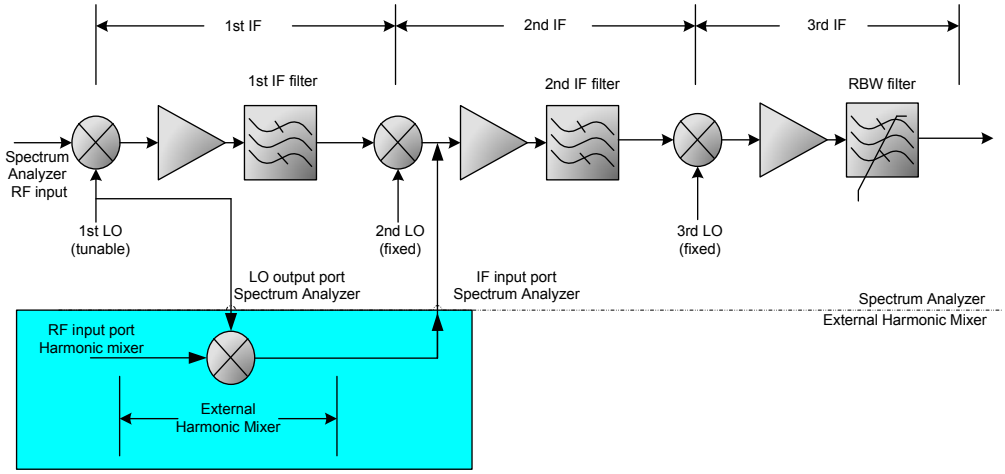

Figure 2: Spectrum Analyzer block diagram with a harmonic mixer attached

Figure 2 shows a block diagram of a modern spectrum analyzer that is operated with a harmonic mixer. Depending on the concept, the IF stages are located at different frequencies. Therefore, the tuning ranges of the local oscillators are also different.

The local oscillator frequency ranges for R&S spectrum analyzers are

- 7.73 GHz to 15.23 GHz for the R&S FSV and R&S FSVR
- 7.00 GHz to 15.50 GHz for the R&S FSU/FSQ family
- 7.00 GHz to 13.20 GHz for the R&S FSP family.

The fundamental frequency of the local oscillator is too low to directly down-convert frequencies at 40 GHz or above. The conversion therefore uses the n-th harmonic of the LO frequency, with n being the necessary factor to reach the desired frequency range. The R&S FSV for example uses the 6^{th} harmonic for down-conversion of the E band (60 to 90 GHz).

Depending on the LO frequency range a single harmonic might not be sufficient to fully cover the frequency range of a microwave band. Modern spectrum analyzers, like the R&S FSV, therefore offer the possibility to switch the harmonic number within the microwave band.

The required IF frequency depends on the frequency concept of the spectrum analyzer. For R&S spectrum analyzers, it is

- 729.9 MHz for R&S FSV and FSVR
- 404.4 MHz for R&S FSU/FSQ and FSP families.

From the different LO frequency ranges and the different IFs available in these instrument models, it is obvious that the number of the LO harmonic used for down-conversion of a microwave band is different for the individual spectrum analyzer families.

In order to use an external harmonic mixer, it is necessary to access the local oscillator (LO) and intermediate frequency (IF) signals of the spectrum analyzer. Therefore the options R&S FSP-B21, R&S FSU-B21, and R&S FSV-B21 provide access to the 1st LO and 2nd IF by means of two female SMA connectors.

1.1.2 Support of 3 port and 2 port mixers

As shown in figure 1, a harmonic mixer basically has 3 ports: RF input, LO input and IF output. As the LO frequency range is much higher than the IF frequency used, some external mixers combine these two signals at one port. These mixers are therefore only two port devices, i.e. they have an RF input port and a combined LO in / IF out port.

To support both types of mixers, the LO out port of all B21 options can also be used as a combined LO out / IF in port. This means that all B21 options are suitable for 2- as well as 3-port mixers.

1.1.3 Signal identification (Image suppression)

The absolute value function in equation (1) indicates that there are always two RF frequencies – the real frequency and its image frequency - which will be converted to the same IF frequency. To distinguish between the real signal and its image, modern spectrum analyzers use a mechanism called Signal Identification (see AppNote 1EF43_0E).

The principle of the Signal Identification algorithm is simple. According to equation (2) the same RF frequency is converted to a given IF frequency by two LO frequencies at a distance of twice the IF frequency:

$$f_{RF} = n \cdot f_{LO} \pm f_{IF}\,, \qquad (2)$$

If the spectrum analyzer performs two sweeps with LO frequencies at a distance of twice the IF, the wanted RF signals will remain at the same position in the resulting trace, whereas the image signals will be shifted in frequency. With this knowledge, it is easy to eliminate the image signals from the displayed trace. More details can be found in reference [1].

2 Characteristics of an External Mixer: Conversion Loss

2.1 Overview

The conversion loss of a mixer specifies how efficiently a mixer converts the signal energy from the input frequency (RF) to the output frequency (IF). It is defined as the ratio of the input power to the output power of one sideband, measured in dB at a given LO level. As the conversion loss of a mixer is frequency dependent, it is usually specified in tables which contain a list of frequencies and the corresponding conversion loss values. When loaded into a spectrum analyzer the conversion loss table increases the level accuracy of the results obtained from the harmonic mixer, as it allows the analyzer to take the frequency characteristics of the mixer into account.

2.2 Conversion Loss Definition

An inherent conversion loss results from the mixing principle, which is 3 dB for each sideband. A passive mixer, which 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.

As the frequency of the IF signal (mixer output) is different from the RF signal frequency (mixer input) as described in section 1, both frequencies appear in the conversion loss definition. A conversion loss is specified as

$$K(f_{RF}) = -10\log_{10}\left(\frac{P_{RF}(f_{RF})}{P_{IF}(f_{IF})}\right)\Bigg|_{P_{LO}} , \qquad (3)$$

with K being the conversion loss, which is dependent on the input frequency.

Clearly, the equation also shows a dependency on the intermediate frequency, but with the local oscillator characteristics known, the IF can be derived from the RF signal. The conversion loss is specified at a certain power level of the LO signal, the drive level, as this determines the operating point of the mixer.

During production of the harmonic mixer, the conversion loss is measured for the complete frequency range of the mixer. The resulting tables contain the frequency response characteristics of the mixer.

To avoid the need for conversion loss tables, spectrum analyzers with an external mixer option also allow the usage of an average conversion loss, i.e. a number for the conversion loss that is constant over the entire frequency range. Usage of an average conversion loss number yields the advantage of easier handling, i.e. there is just one number to enter, at the cost of reduced level measurement accuracy.

2.3 How to measure the Conversion Loss of a Mixer

To characterize a mixer, a measurement of the device specific conversion loss needs to be performed. For conversion loss measurement, a sinusoidal input signal with known power level over frequency is required at the mixer input. Furthermore, the measurement requires the local oscillator to be operated at the power level which will be used later in the environment the conversion loss table is dedicated to. With these prerequisites, the RF signal is tuned over the frequency band limits in k discrete steps. For each step, the IF power at the mixer output is measured and normalized to the RF input power. The result is a conversion loss table, e.g. for the U band (40-60 GHz):

RF Frequency	Conversion Loss
40 GHz	17.4 dB
…	…
60 GHz	18.6 dB

3 Using Conversion Loss Tables with R&S Analyzers

3.1 Formats in Use for R&S Spectrum Analyzers

3.1.1 ASCII Format

All R&S spectrum analyzers of the R&S FSP, FSU, FSV, and FSVR families require ASCII format conversion loss tables for the external mixer operation mode. The tables can be read using any text editor and may also be edited, but it is strongly recommended to use the edit function of the analyzer firmware, as explained in section 3.2.

3.1.2 Binary Format

A binary format of the conversion loss table was used with R&S FSE family spectrum analyzers. External mixers sold as accessory to FSE family spectrum analyzers were delivered with conversion loss tables in binary format.

To make these tables available for newer R&S spectrum analyzers that require ASCII format tables, a conversion tool comes with this application note, see section 3.4.

3.2 Setting up an R&S Spectrum Analyzer for External Mixer operation

3.2.1 R&S FSV

To open the configuration dialog on a R&S FSV with option FSV-B21, press

- FREQ
- External Mixer
- External Mixer Config

to open the configuration dialog.

Select the band that the mixer was designed for – or “USER” if none of the displayed bands fits.

Having selected the frequency band also determines the RF start and stop frequencies. For all predefined bands, these are the band limits, whereas for the user defined band, it is the maximum range that can be covered using the LO range of the R&S FSV in combination with the selected harmonic.

The checkbox RF Overrange allows the usage of a mixer beyond the frequency limits of the selected band. In this case, the settable RF frequency is limited by the LO range and the selected harmonic, as is the case for the “USER” band.

For further configuration, select the Harmonic Type. For double diode mixers, such as the R&S FS-Z60, Z75, Z90, and Z110, it will in general be an even harmonic only, i.e. select Even.

Finally the conversion loss can be set for a single range. If two different harmonics are used to cover the band, Range 2 has to be set up in the same way for the other harmonic in use.

To use an external mixer with the 6^{th} harmonic of the LO and a conversion loss table named “table.cvl”:

- Check Range 1
- Set the Harmonic Type to Even
- Set the Harmonic Number to 6
- Press the Table Button
- Select IMPORT TABLE from the dropdown box
- Navigate to the directory of “table.cvl”, select the file
- Press Select
- Select “table.cvl” from the dropdown box.

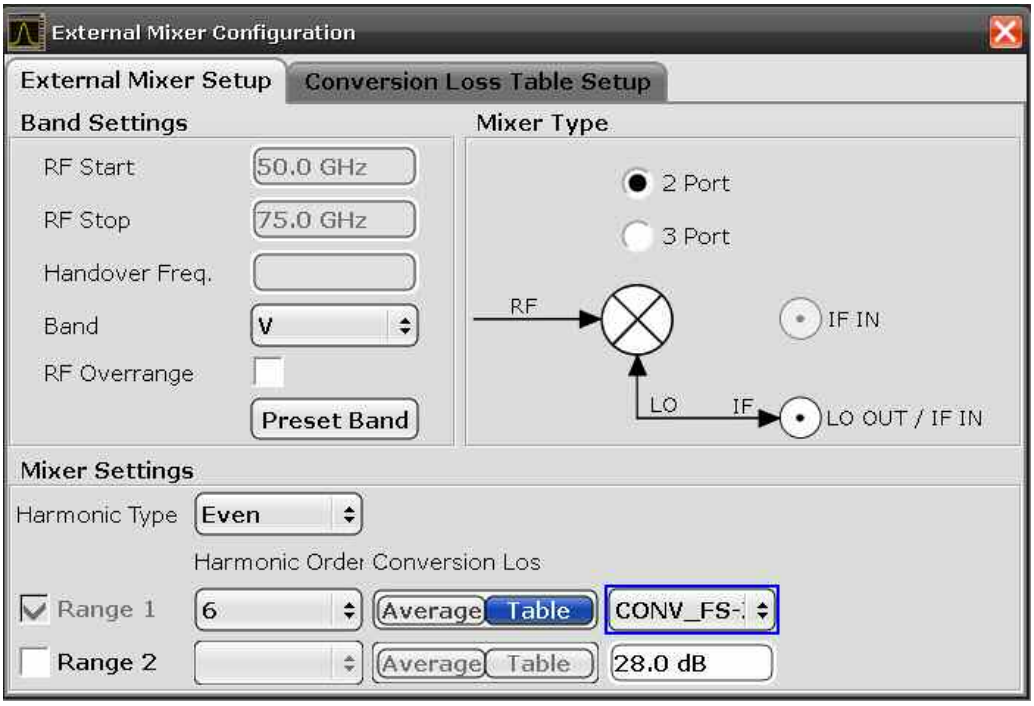

Figure 3: R&S FSV External Mixer Configuration dialog

Alternatively, the conversion loss table can also be imported in the “Conversion Loss Table Setup” tab. Instead of importing, a conversion loss table can also be generated if the conversion loss values are known.

- Switch to the “Conversion Loss Table Setup” tab
- Press New Table
- Fill in the File Name, the Band, Harmonic Order, Bias, and the Mixer Type (2- or 3-port). Optionally, the fields Comment, Mixer Name, and Mixer S/N may be used for additional data.
- For each conversion loss value
  - Press Insert Value
  - Enter Position (frequency)
  - Enter Value (conversion loss)
- Press Save

After having pressed Save, the generated conversion loss table is available for selection in the Conversion Loss dropdown box.

As mentioned in section 2.2, an average conversion loss for the entire band may be used. The setup is identical to the above, except that “Average” is chosen instead of “Table” and a single value is specified instead of a conversion loss file.

3.2.2 R&S FSU

To open the configuration settings for external mixer operation on an R&S FSU or R&S FSQ with option FSU-B21, press

- FREQ
- EXTERNAL MIXER
- EXT MIXER ON
- SELECT BAND

to open the band selection dialog. To use an external mixer with an average conversion loss for the entire band

- Check the appropriate band
- Specify the mixer specific values, such as harmonic, number of ports, and bias in the respective columns
- Modify the value in column AVG CONV LOSS/dB.

To configure an external mixing setup using a conversion loss table as shown in Figure 4, the table must be imported first.

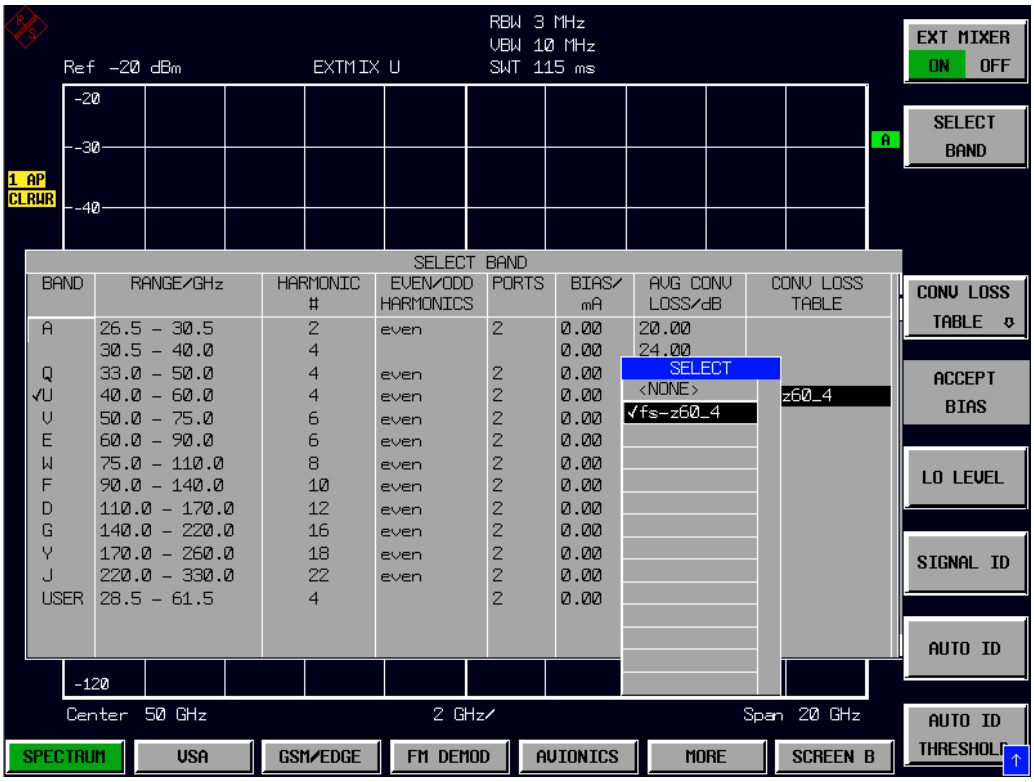

Figure 4: Selecting a U band external mixer and the corresponding conversion loss table

If the table is available in the “acl” ASCII format, it can be imported to the R&S FSU from any other storage medium, such as a USB stick. A table cannot be selected if it was not imported. To import a table

- Press CONV LOSS TABLE in the external mixer softkey menu
- Press LOAD TABLE
- Select the respective file in the open dialog
- Press Open.

The table will now be available for selection. Alternatively, a new table can be generated. To generate a new table, stay in the conversion loss table dialog and

- Press NEW TABLE
- Enter a suitable name
- For each conversion loss value
  - Press INSERT LINE
  - Enter Position (frequency)
  - Enter Value (conversion loss)
- Press SAVE

Please note: The name of the conversion loss table is automatically extended by an underscore and an integer value, e.g. "_4". The integer value corresponds to the harmonic order of the LO signal being used. A file without this extension cannot be selected later on. It is also important to have exactly the band start frequency as the first value in the conversion loss table and exactly the band stop frequency as the last value in the table. If these criteria are not fulfilled, the table cannot be selected. Figure 5 shows the conversion loss edit dialog, including the filename extended by "_4" and the first value in the table being at 40 GHz, exactly the band start frequency.

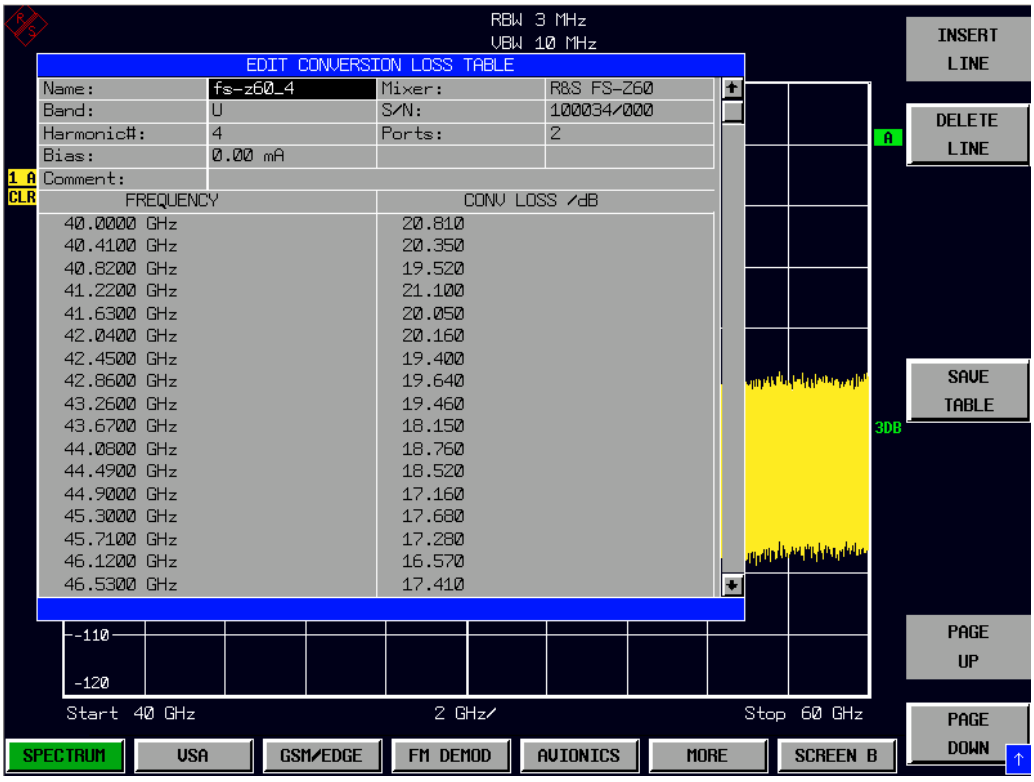

Figure 5: Editing a conversion loss table on an R&S FSU

Back in the band selection dialog, the newly generated or loaded tables can now be selected for use by

- Pressing Enter in the corresponding line of column CONV LOSS TABLE
- Selecting the appropriate conversion loss table from the list of available tables

as shown in Figure 4.

Please note: Pressing Enter in the CONV LOSS TABLE column lists only those tables for selection that match the conditions mentioned above. These are:

- Tables need to have the harmonic order in the file name

- Tables need to have the band start frequency as the first value and the band stop frequency as the last frequency value.

3.3 A sample Conversion Loss Table

Although it is not recommended to set up a table manually, a sample conversion loss table in ASCII format is shown here. The table below is a table, with only six entries for a U band mixer that was generated on an R&S FSV.

```
# Mixer Name
My U band mixer
# Serial Number
123456
# Band
U
# Number of Harmonic
4
# Bias
0.000000
# Ports
2
# Comment

# Date
1.JUN.10
# Calibration data
(40000000000.000000, 18.000000)
(45000000000.000000, 19.000000)
(50000000000.000000, 20.000000)
(55000000000.000000, 21.000000)
(59000000000.000000, 22.000000)
(60000000000.000000, 23.000000)
```

3.4 Conversion Tool

This application note comes with a conversion tool which allows the conversion of binary conversion loss tables from the R&S FSE family into ASCII conversion loss tables for the R&S FSP, R&S FSU, and R&S FSV families. The program is not only capable of converting binary data in to ASCII data, but also calculates the correct harmonic order for the given mixer and spectrum analyzer. The program is called with two parameters

ConversionTool *-TargetFamily FileName*

Where *-TargetFamily* is one out of *-fsp,-fsu,-fsv*. It specifies the target spectrum analyzer. *FileName* is the filename of the original file. The file extension tells the program whether to read it in binary or text form. A file with extension “cl” is read binary, all others as ASCII files.

4 Literature

[1] Rauscher, Christoph. Frequency Range Extension of Spectrum Analyzers with Harmonic Mixers. Application Note 1EF43_0E. Rohde & Schwarz.

[2] Tröster, C., Thümmler, F., and Röder, T. Upconverting Modulated Signals to Microwave with an External Mixer and the R&S SMF100A Microwave Signal Generator. Application Note 1GP65_0E. Rohde & Schwarz.

5 Ordering Information

R&S FS-Z60	Harmonic mixer 40 GHz to 60 GHz	1089.0799.02
R&S FS-Z75	Harmonic mixer 50 GHz to 75 GHz	1089.0847.02
R&S FS-Z90	Harmonic mixer 60 GHz to 90 GHz	1089.0899.02
R&S FS-Z110	Harmonic mixer 75 GHz to 110 GHz	1089.0947.04
R&S FSV30	Signal and Spectrum Analyzer 9 kHz to 30 GHz	1307.9002.30
R&S FSV40	Signal and Spectrum Analyzer 9 kHz to 40 GHz	1307.9002.40
R&S FSV-B21	LO/IF connections for external mixers for R&S FSV and R&S FSVR	1310.9597.02
R&S FSVR30	Real-Time Spectrum Analyzer 10 Hz to 30 GHz	1311.0006.30
R&S FSU26	Spectrum Analyzer 20 Hz to 26.5 GHz	1166.1660.26
R&S FSU46	Spectrum Analyzer 20 Hz to 46 GHz	1166.1660.46
R&S FSU50	Spectrum Analyzer 20 Hz to 50 GHz	1166.1660.50
R&S FSU67	Spectrum Analyzer 20 Hz to 67 GHz	1166.1660.67
R&S FSQ26	Signal Analyzer 20 Hz to 26.5 GHz	1166.1660.26
R&S FSQ40	Signal Analyzer 20 Hz to 40 GHz	1166.1660.40
R&S FSU-B21	LO/IF connections for external mixers for R&S FSU and R&S FSQ	1157.1090.02

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