Improved Dynamic Range with Noise Correction

Application Note

Products:

- R&S®FSU
- R&S®FSQ
- R&S®FSG

This application note provides information about spectral measurements with noise correction. The basic requirements and the limiting factors of a spectrum analyzer are explained. Dynamic range improvements by means of a noise correction is presented. Measurement examples show the improved performance of TOI measurements with noise correction.

Application Note

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1 Overview

Dynamic range is one of the most important characteristics of a spectrum analyzer. Modern wireless systems generate increasing demands on the existing measurement systems for accurate measurements of unwanted spectrum emissions or spurious signals. These measurements require a very high dynamic range of the spectrum analyzer. The maximum mixer level, the intermodulation products and the noise floor of the analyzer define the available dynamic range. The use of signal processing routines to reduce the noise floor of the analyzer will lead to improved dynamic range and more accurate measurements. Noise correction has been used for many years in ACP (adjacent channel power) measurements, and is now available for all spectrum analyzer measurements like spectrum emission test.

2 Dynamic Range Limitations

The inherent dynamic range available for the measurement is an important factor. A sufficient high dynamic range that leaves enough margin for the DUT (device under test) assures that the test result is minimally affected by the spectrum analyzer. The dynamic range of a spectrum analyzer is determined by the following factors:

- the internal noise floor of the spectrum analyzer
- its phase noise
- its intermodulation distortion.

The phase noise and intermodulation distortion will mainly affect measurements close to a carrier or with more than one carrier signals. The internal noise floor will be an important factor for all measurements, as it limits the capability of the analyzer to perform accurate measurements at low level signals. Using less attenuation or a preamplifier will decrease the internal noise, but both possibilities will lead to higher distortion products and may not increase the available dynamic range for a given input signal level. If the available dynamic range of an existing spectrum analyzer is not sufficient for the requirement, the only solution in the past was to use an instrument of higher performance class or setups with additional filters to suppress the signal.

This application note helps to understand the possibility of reducing the internal noise floor of a spectrum analyzer by means of signal processing routines. This method is called noise compensation or noise correction. It is based on the fact that the internal noise floor of the analyzer can be accurately measured without any additional external hardware or changes in the test setup. The measured internal noise level is subtracted from all subsequent measurement results. This application note gives some information about the noise correction available in the R&S FSU and FSQ spectrum analyzer family and shows the improvement in practical measurement examples.

3 Signal Processing - Noise Correction

The idea of additional signal processing to compensate for the internal noise sources is not new. Modern spectrum analyzers like the R&S FSU family offer this feature as an integrated function, and it has been intensively used to improve the dynamic range in ACP measurements or phase noise measurements. The noise correction in the spectrum analyzer is generally based on a mathematical subtraction of the analyzer´s inherent noise power from the actual power reading, which is a combination of the input signal and the inherent noise of the analyzer. Practical implementation of this procedure is therefore limited to spectral power measurements like signal level, ACP, phase noise, TOI and spurious emission measurements. As the inherent noise is measured as a scalar power value, it is not possible to subtract this from any vector signal based measurement or any demodulation. The noise correction will therefore not improve the EVM reading of a vector signal analyzer measurement.

3.1 Evaluation of the noise level

The quality of the dynamic range improvement based on the noise correction technique is mainly influenced by the accurate knowledge of the inherent noise level under the given operating conditions. The internal noise floor of the spectrum analyzer can easily be measured. The procedure to compensate for the inherent spectrum analyzer noise works in two steps:

- In a first step, the input signal is removed from the spectrum analyzer and the input is terminated. The R&S FSU has an internal switch that selects either the input signal or a termination. In this setup, the inherent noise power at the actual frequencies is measured.
- In the second step, the input is selected and the input signal is measured. The trace mathematic calculates the input power by subtracting the inherent noise power from the measured values.

For best accuracy it is important to perform the calibration measurement of the inherent noise floor with the same hardware settings as the corresponding measurement, because small variations of the noise level will lead to large changes in the compensated noise floor. The R&S FSU will therefore disable the noise correction when hardware settings are changed that would lead to a different inherent noise floor.

Very important for the successful noise correction is a repeatable power measurement. The most accurate and stable power measurement is possible using the RMS detector. The stability of the power measurement is controlled by the sweep time, since this has a direct influence on the amount of samples available to calculate the average value. A long sweep time will give more stable results and thus leads to better compensation of the inherent noise power.

The linearity of the receiver has a great impact on the accuracy of the noise power measurement. The FSU is using digital filtering for RBW settings up to 100 kHz, thus providing an excellent linearity. This is important because the inherent noise power measurement must be performed with the same instrument setting which is used for the input signal measurement, but only internal noise is measured.

Since the noise compensation measures the inherent noise power of the spectrum analyzer with the actual setting, any change of the spectrum analyzer setting must be avoided (especially settings of Frequency, RF ATT, RBW, ...). Otherwise it requires a new measurement of the inherent noise by reactivating the Noise Correction.

3.2 Details of the noise correction

For a better understanding of the noise correction it is very helpful to investigate the mathematical background of the subtraction routine that is used to reduce the inherent noise floor of the spectrum analyzer.
For any spectral measurement, the spectrum analyzer will allways measure the input signal level together with the inherent analyzer noise level. The noise of the analyzer will be incoherent to the input signal. For power measurements using the RMS detector, the spectrum analyzer measurement will show the sum of the input signal power and the inherent noise power. The mathematical expression of this in linear power terms is:

$$P_{MEAS} = P_{SIGNAL} + P_{NOISE}$$

The graphical plot of this relationship helps to understand this equation. In the figure below the input signal power, the noise power and the measured total power are shown in a log scale like it is typically used on a spectrum analyzer:

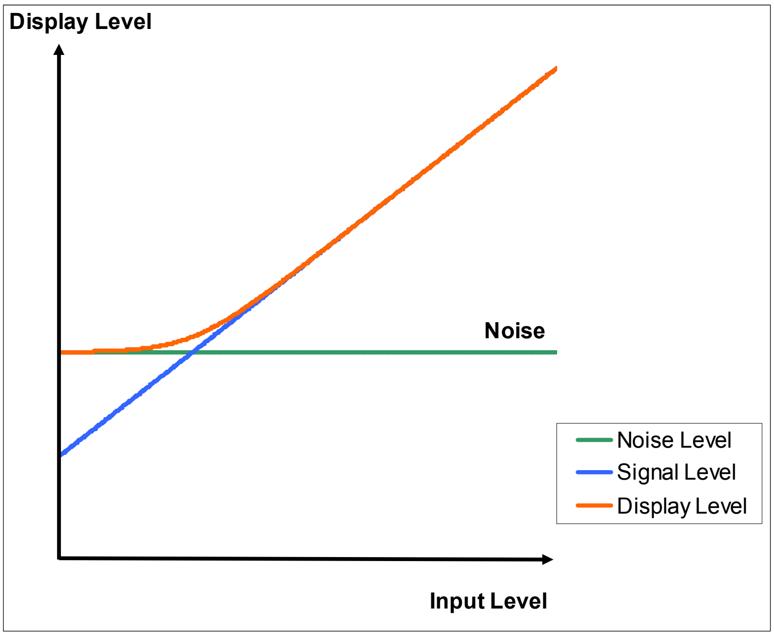

Figure 1: Dependancy of the displayed signal power and the input signal power

The plot shows the effect that the spectrum analyzer will show the sum of the input signal power and the inherent noise power when both are very close. For input levels much higher than the inherent noise there is almost no influence on the total power. Input levels below the noise floor cannot be measured and the analyzer will display the inherent noise power.
With the above formula solved for the input signal power, we can see that the signal power can be recovered from the measured signal power by subtracting the inherent noise power of the analyzer.

$$P_{SIGNAL} = P_{MEAS} - P_{NOISE}$$

The formula turns the whole concept of noise correction into a fairly simple process of subtracting a fixed, known value for the inherent noise power from any measurement value. However, in practice the normal view on the spectrum analyzer uses a log scale. With activated noise correction and no input signal connected, the measured values and the inherent noise power of the spectrum analyzer are almost equal.

As a consequence the subtraction of the inherent noise from the input signal might generate negative power values, which would cause infinite negative numbers on the typically used logarithmic scaling. To avoid this, the R&S spectrum analyzers only subtracts a major part of the inherent noise power from the measured power values. This leads to a partially compensated inherent noise floor with a noise reduction of about 13 dB. For measured signal values below the inherent noise floor level, a special mathematical approach limits the displayed noise level to prevent infinite negative values on the logarithmic scaling.

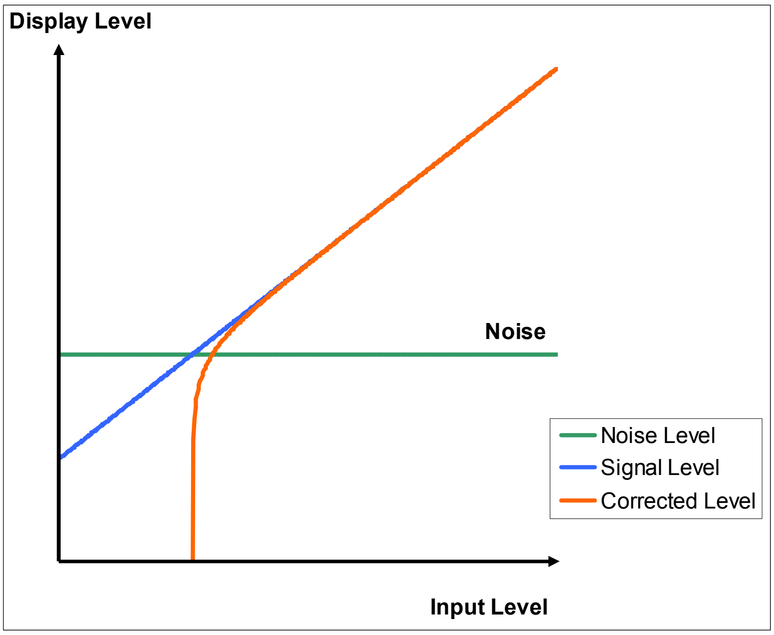

Figure 2: Noise subtraction leading to negative infinite numbers

Another very important effect is shown in the above figure. Due to the fact that the result of the noise power subtraction is almost zero, even small changes in the measured signal level will cause large variations of the corrected noise floor trace. This effect can be seen in the above figure in the region where the measured signal level is close to the inherent noise level. The slope of the calculated signal after the subtraction procedure gets very steep, which will lead to large variations for small level changes. This will lead to large variations of the displayed noise level if the measured noise level is not sufficiently averaged. For practical measurements the time to perform the required number of averages may be a limiting factor to use the noise correction feature.

4 Measurement Examples

4.1 Extended dynamic range with noise correction

Improving the dynamic range can be a difficult task. This example shows the result for an intermodulation measurement on a multi carrier signal. These measurements are commonly performed on power amplifiers or base stations and require very high dynamic range. The measurement bandwidth is typically defined by the type of signals used in the system and can therefore not be reduced to improve the available dynamic range. The use of a preamplifier will in most cases not increase the dynamic range as it would lead to increased intermodulation in the spectrum analyzer.

The following measurement result shows the improvement of the dynamic range of a measurement with noise correction. A signal generator is used to generate a GSM-like multi-carrier signal with an output level close to the maximum input level of the spectrum analyzer without overloading the analyzer.

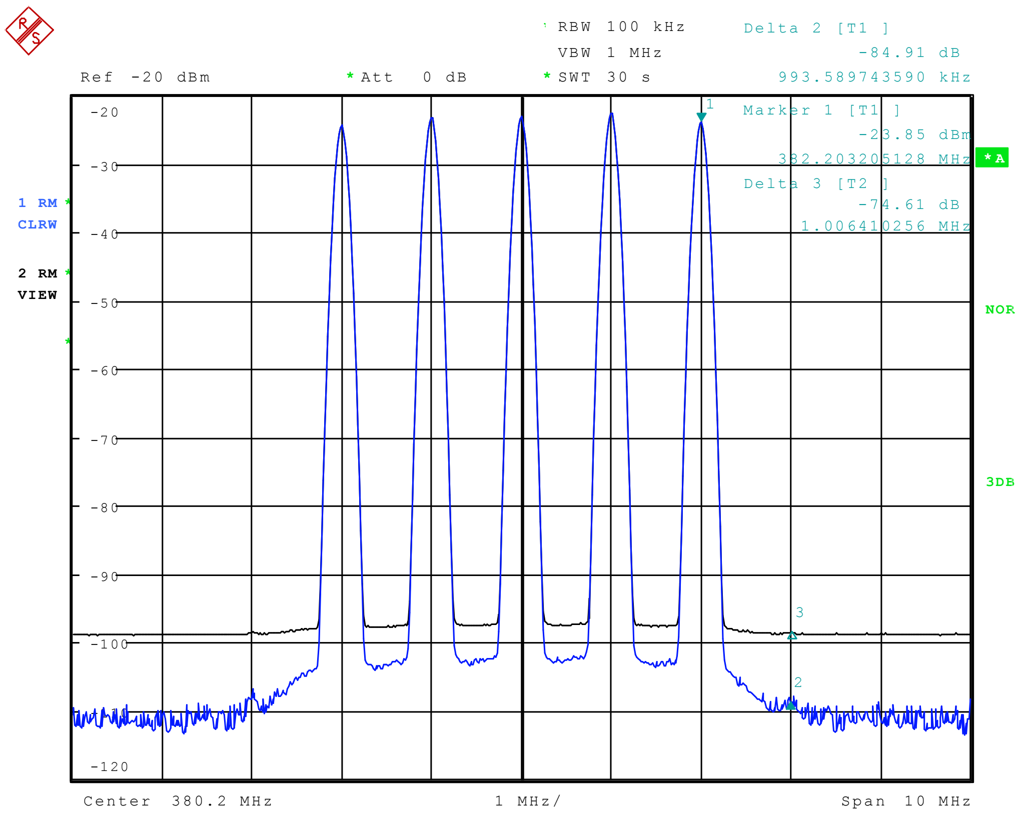

Figure 3: Improved dynamic range on a multi-carrier measurement with noise correction

The uncorrected spectrum analyzer measurement result is shown with the black trace. The marker Delta3 at the position of the first intermodulation product shows about 75 dB dynamic range.

Enabling the noise correction in the spectrum analyzer reduces the internal noise floor by about 13 dB. The corrected measurement result is shown in the above plot in blue. The dynamic range is now 85 dB and the intermodulation signal can be observed.

► Note:

In dynamic range measurements with noise correction it might be necessary to increase the RF attenuation setting by about 5 dB for best performance.
The highest dynamic range is achieved when the level of the intermodulation product is close to the noise level. Due to the reduced noise floor after noise correction, the intermodulation products generated within the spectrum analyzer itself would remain at the same level and may limit the performance. In this case the available dynamic range can be easily improved by 10 dB when the RF attenuation setting is increased by 5 dB. This change will reduce the intermodulation signals by 10 dB and thus increase the available dynamic range.

4.2 Low level measurements on noise-like signals

This section shows the result for low level measurements of a typical communication signal. As described before in this application note, the measurement of low level signals that are close or even below the noise floor of the spectrum analyzer will lead to large measurement errors, as the sum of the signal power and the noise power is displayed. For an input signal with a level equal to the analyzer's noise floor, this results in a measurement error of 3 dB. In case of a CW signal a reduction of the resolution bandwidth would lead to a reduced noise floor and thus a more accurate measurement because the signal-to-noise ratio would increase. In case of a noise-like signal as a W-CDMA signal that is used in many communication systems, the reduction of the bandwidth will not lead to better accuracy as the signal is noise-like. The signal as well as the internal noise will be reduced by the same amount and the signal-to-noise ratio remains constant. The improvement of the level accuracy is possible with a preamplifier or with noise correction.

The following measurement example shows the comparison of a measurement result with noise correction and a preamplifier. A signal generator is used to generate a W-CDMA signal with an output level about 5 dB below the noise floor of the spectrum analyzer without preamplifier.

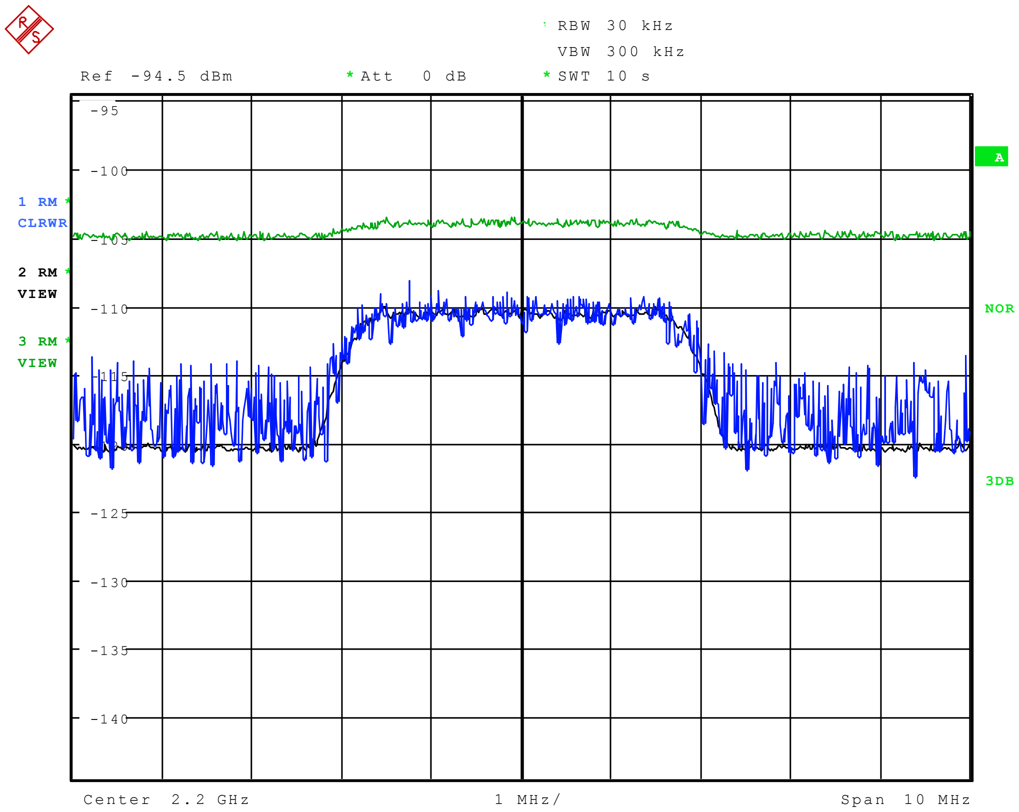

Figure 4: Measurement of W-CDMA signal with Preamplifier or with Noise Correction

The uncorrected spectrum analyzer measurement result is shown in the green trace. At the position of the signal the noise floor increases by about 1 dB, the level error would be about 6 dB. The signal can just be identified.
Enabling the preamplifier in the spectrum analyzer reduces the internal noise floor by about 15 dB. The measurement result is shown in the above plot in the black trace. The signal level is now 10 dB above the noise floor and the signal level can be measured with good accuracy.

The noise correction is a very effective tool to reduce the noise floor of the spectrum analyzer and increase the accuracy of a low level signal measurement. With the same settings as used above, the noise correction is used to measure the input signal.
The spectrum analyzer measurement result is shown in the blue trace. Enabling the noise correction effectively reduces the noise floor of the spectrum analyzer by about 13 dB. In the R&S spectrum analyzer the reduction is limited to this value to avoid negative noise level results and spikes in the noise floor. The average signal level is the same as shown in the black Trace measured with the preamplifier, which is a proof of the measurement accuracy with noise correction. As a consequence of the noise correction, the trace has a wider variation of the noise level. This effect can be improved by selecting a longer sweep time for better averaging.

4.3 Measurements at the theoretical limits

The R&S spectrum analyzers do not just use mathematical models to describe the expected noise level for a given measurement. For improved accuracy the exact noise level is measured with high accuracy and the same settings as the measurement of the input signal. When the full amount of internal noise level is subtracted, this procedure would theoretically allow to create a noise-free spectrum analyzer that measures well below the theoretical limit of -174 dBm per 1 Hz bandwidth and 50 ohms impedance at room temperature. Such a measurement will lead to a valid result even for an input signal below this theoretical limit. For practical considerations the noise correction in the R&S spectrum analyzers has been limited to the reasonable value of -174 dBm per 1 Hz bandwidth, as most users would doubt a result that is below the noise floor of a terminated input connector.

The following measurement example shows the measurement result with noise correction without input signals. The result of the noise corrected measurement is compared to the uncorrected measurement.

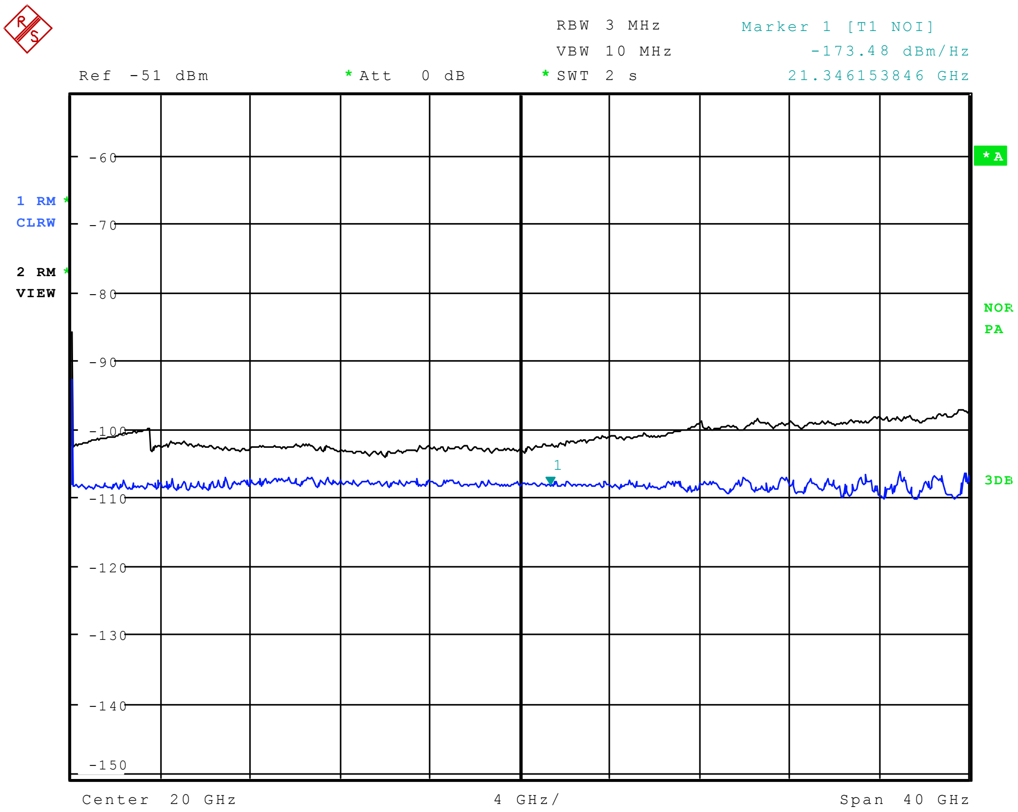

Figure 5: Noise Floor limitation with Preamplifier and active Noise Correction

The black trace shows the spectrum analyzer measurement result with the preamplifier enabled. The measurement result with activated noise correction is shown in the blue trace. A noise marker on the corrected trace shows a noise level close to the limit at -174 dBm(1 Hz) that is used in the R&S spectrum analyzers to avoid unreasonable noise level results.

5 Literature

- [1] Application Note 1EF45_E, Spurious Emission Measurement on 3GPP Base Station Transmitters
- [2] Rohde & Schwarz FSU Operating Manual

6 Ordering Information

R&S®FSU3	Spectrum Analyzer 20 Hz to 3.6 GHz	1166.1660.03
R&S®FSU8	Spectrum Analyzer 20 Hz to 8 GHz	1166.1660.08
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®FSQ3	Signal Analyzer 20 Hz to 3.6 GHz	1155.5001.03
R&S®FSQ8	Signal Analyzer 20 Hz to 8 GHz	1155.5001.08
R&S®FSQ26	Signal Analyzer 20 Hz to 26.5 GHz	1155.5001.26
R&S®FSQ40	Signal Analyzer 20 Hz to 40 GHz	1155.5001.40
R&S®FSU-B24	30 dB Preamplifier, 100 kHz to 50 GHz	1157.2100.50
R&S®FSU-B25	Electronic Attenuator, 0 dB to 30 dB, and 20 dB Preamplifier (3.6 GHz)	1144.9298.02

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