Differential measurements with Spectrum Analyzers and Probes
Application Note

Products:

- R&S®FSU
- R&S®FSV
- R&S®FSW
- R&S®RT-ZS30
- R&S®RT-ZD30
- R&S®RT-ZA9

The constantly decreasing size of components and the available board space form a challenge to place adequate test connection for RF instruments. Recent improvements in the availability and use of high performance differential building blocks in RF circuits intensify the problems of connecting test equipment.

Using oscilloscope probes is a possibility to perform measurements by connecting to printed circuit board lines and chip contacts where only a minimal area is required to make contact.

This application note provides information on how to use oscilloscope probes in RF measurements using spectrum analyzers, and show the results of differential measurements with a spectrum analyzer.

Application Note

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1 Introduction

To verify the performance of each single part, RF circuit design often requires measurements at many stages in a signal path. In the past, most RF designers placed adequate RF test connectors as test points along the RF signal path. As components become smaller and board space is an important constraint, the willingness to provide sufficient space for these RF test connectors is decreasing. In addition, modern high performance circuit designs often use differential signals to interconnect the signal stages, which makes this situation even worse as two connectors are required at each test point.

Surface mounted parts and printed circuit board tracks offer sufficient space to connect an oscilloscope probe tip directly. Probing directly in the circuit overcomes the problem of requiring test connectors at various points in a design. Modern oscilloscope probes offer high impedance, low capacitive loading and a wide bandwidth of several GHz, making them an ideal tool for RF measurements with a spectrum analyzer.

This application note introduces the use of oscilloscope probes in combination with RF spectrum analyzers. Basic capabilities of probes and their influence on RF measurements are explained. A practical section compares probe measurement results to results obtained with traditional direct contacting methods.

2 Overview

A common problem in circuit design and debugging is the availability of test points to perform high quality measurements without affecting the circuit characteristics.

The best solution is to include RF test connectors at the points of interest and route the test signals to these connectors. Previously, conventional methods for the signal routing to the test connector range from jumper resistors to connect the signal either to the next stage or to the test connector, or medium impedance resistors that couple the test port to the signal path.

While this works well with typical 50 ohm line impedance on single ended RF connections, it is becoming more difficult with chips that use higher impedance or even differential interconnections, as it is common with modern RF chipsets and mixers. Their output impedance is often different to the 50 Ohms typically used in RF test equipment such as spectrum analyzers, or cannot be made available on test connectors due to missing space on the board. High impedance probes, like those used with oscilloscopes, offer a solution to overcome the challenge of measuring these signals. The high input impedance and low capacitance of the probe avoids the problem of loading the circuit so that measurements are possible without disturbing the signal path. Variations in impedance can also be accommodated. The variety of probe tips available overcomes the need to dedicate large areas of board space to test connectors, as the tips can be directly connected to any surface mounted parts or existing printed circuit board tracks.

Making accurate measurements with oscilloscope probes in conjunction with spectrum analyzers requires some understanding of the effects at the probing point, as well as correcting for the probe scaling and frequency response effects in the measurements. With the availability of modern high impedance probes which can be connected to spectrum analyzers, an effective, highly accurate, measurement solution is available to solve a tedious problem for RF engineers.

2.1 Probing solutions

There are a wide variety of probes available for oscilloscopes, ranging from simple passive probes to active, high impedance probes. It is important to select a probe that suits the circuit under test and which works well together with the test equipment.

Most passive oscilloscope probes are designed to have an impedance of 1 MOhm at the probe tip and the output connector. While these probes can be used with every oscilloscope that offers this input impedance, they will not work with a typical spectrum analyzer RF input connector, as this uses 50 Ω impedance. There are also oscilloscope probes with 50 Ω input and output impedance available. These probes can be used with spectrum analyzers, but due to their low input impedance they result in a heavy load to the circuit under test and thus may not work on some RF circuits when connected to a signal path. Passive probes have the additional advantages of low price and low distortion to the signal under test at all.

Fig. 2-1: Active oscilloscope probe R&S ® RT-ZS30

Active probes for oscilloscopes offer the advantage of a very high input impedance and low capacitive load, typically achieved by a wide bandwidth FET amplifier. The probe amplifier output often has 50 Ω impedance which matches the spectrum analyzer RF input perfectly.

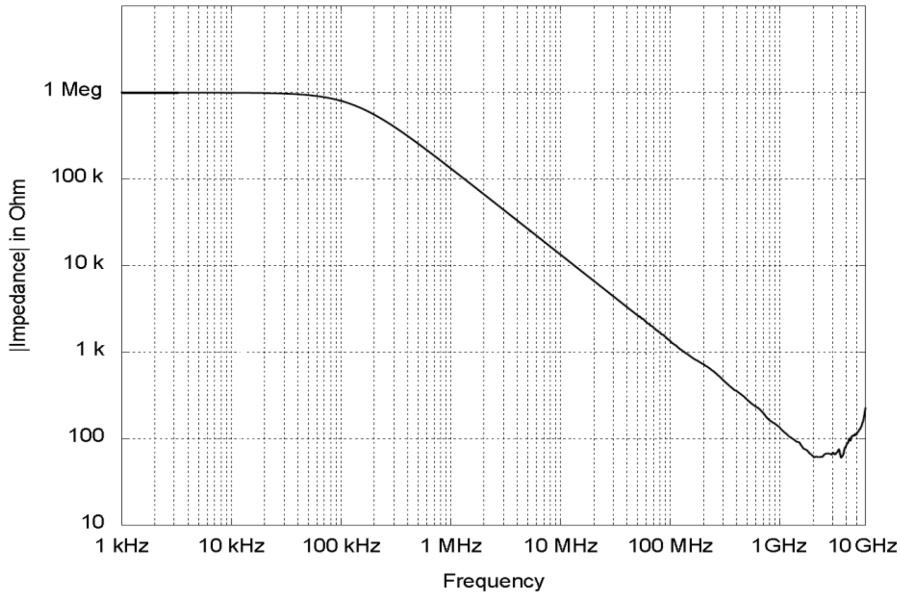

Fig. 2-2: Plot of the Input Impedance versus frequency for active probe R&S RT-ZS30

The disadvantage of the amplifier is that the active probe will add distortion to the test signals that is not present in measurements with direct connections to test points, or with passive probes. However, many modern active probes have excellent amplifiers that match the low distortion levels of high performance spectrum analyzers. Further information on the probe distortion performance is given in a later chapter.

2.1.1 Probe Solutions for R&S Spectrum Analyzers

A difficulty using active probes with spectrum analyzers is that power needs to be supplied to the probe to drive the built-in amplifier.

To connect probes to spectrum analyzers, R&S offers the probe adapter RT-ZA9. The adapter converts the probe plug of an R&S active probe to a standard N-connector. The power and data connection to the spectrum analyzer is done with a USB connection.

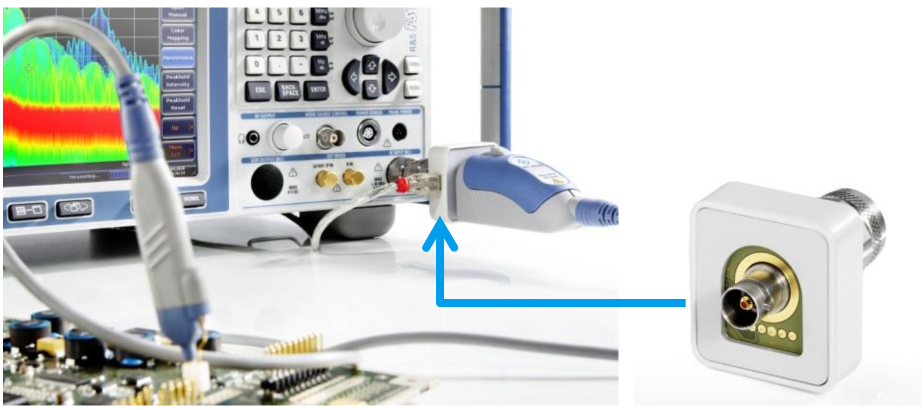

Fig. 2-3: Probe adapter RT-ZA9 connected to the R&S FSV spectrum analyzer

2.1.1.1 Probe interface in the R&S FSW-B71

The R&S FSW High Performance Signal & Spectrum Analyzer does not require an RT-ZA9 to connect active probes, if the optional baseband input R&S FSW-B71 is installed. The baseband input consists of 4 BNC connectors (I/Q and inverted I/Q) on the front panel of the FSW, each with 50 Ω input impedance.

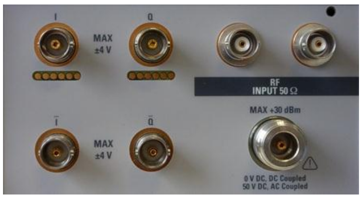

Fig. 2-4: Baseband and Probe inputs on the R&S FSW spectrum analyzer

The baseband inputs of the spectrum analyzer are normally used to connect I/Q baseband signals for any kind of signal demodulation and evaluation. In baseband mode the inputs have 160 MHz analysis bandwidth.

The upper two connectors include the power and data interface for R&S RT-Zxx active probes. Once a probe is connected, the FSW will automatically identify the probe type and apply correction factors for accurate readings.

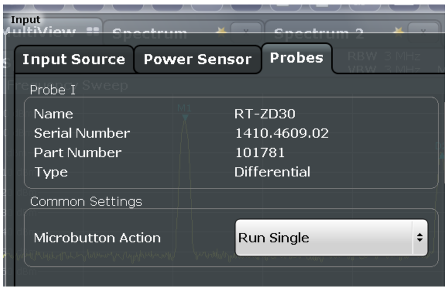

Fig. 2-5: RF input and Probe configuration on the R&S FSW spectrum analyzer

As an additional feature, the R&S FSW can use the baseband input directly as a second RF input. This feature is implemented with an internal RF switch between the I-input and the RF input. The input is selected in the Input dialog.

Fig. 2-6: RF input selection dialog on the R&S FSW spectrum analyzer

A probe connected to the baseband input can be used for RF measurements up to 6 GHz. The loss of the probe and the switch are automatically taken into account for the measurement results.

2.2 Differential versus single-ended

The typical RF design was for a long time dominated by single ended, coaxial circuits throughout the signal path. The availability of high performance, differential RF components today makes the use of differential circuit architectures possible. Good examples for this technology are A/D and D/A converters; mixers and amplifiers are also available. There are a couple of reasons for this trend:

- The RF emission from differential lines is significantly lower than from a single line. The reason is that the signal level on both lines is equal, but the signal on one line is 180 degree phase shifted. When both lines are placed close together, the RF emissions from both lines cancel out in the far field.
- Another advantage is that the available signal level on a differential line is twice as large as on one of the single lines, which increases the signal to noise ratio.
- An important feature of differential signals is that the distortion products are lower compared to single ended designs, either because lower levels are used in each of the two signal lines, or by the inherent cancellation of the even order harmonic products in balanced circuits.

While differential circuits outperform any single ended design, the technology creates a problem for making accurate measurements. Most RF test instruments, such as spectrum analyzers, use a single ended RF connector. The two parts of a differential signal need to be combined into a single line before they can be connected to a spectrum analyzer. A BALUN (BALanced/Unbalanced) circuit was previously often used to make the combination. The disadvantage of a BALUN is that the frequency range is limited, and the impedance must be matched to the test point.

Active differential probes are a commonly used with oscilloscopes. The positive and negative inputs of these probes are connected to a high performance differential amplifier, which converts the inputs to a single-ended coaxial output signal. Most oscilloscope probes offer a typical input resistance of 1 MOhm and very low input capacitance (typically below 1 pF).

The high input impedance puts a very low load on the signal test point and can consequently be directly connected to a differential signal line or a high impedance output of an integrated circuit. With the availability of active, differential probes and methods to use these probes together with a spectrum analyzer, a big obstacle is solved that made measurements difficult to perform in the past.

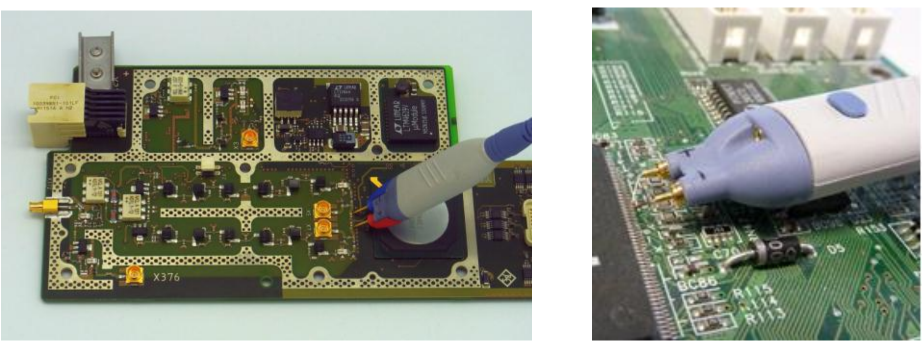

Fig. 2-7: Examples for a differential probe directly connected to a circuit

3 Probe Performance Results

This chapter provides results from tests on an RF circuit board designed for the evaluation of probes. The board can be used to both directly connect the test equipment at test connectors, and has dedicated test points which to connect a probe

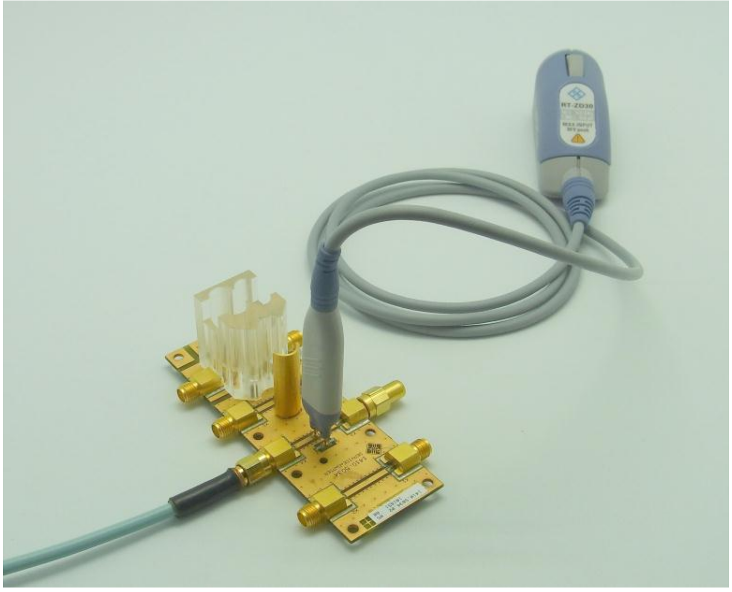

Fig. 3-1: Probe test adapter used for performance evaluation

As shown on Figure 3-1 above, the test board consists of straight 50 Ω connection lines between two SMA connectors. With the test pins placed directly on these connection lines R&S probes can be connected to the board.

As probes are developed for applications with oscilloscopes, typical parameters for RF circuits like distortion or intermodulation are not specified in a probe data sheet. To verify the performance of probes with respect to these important parameters for RF applications, RF measurements are performed using the test circuit above.

3.1 Distortion performance of probes

The two most common measurements for distortion are TOI (Third Order intermodulation) and Second Harmonic Distortion. Testing for distortion is one of the most demanding measurements. It requires a spectrum analyzer with high dynamic range. Normally additional equipment like a filter is necessary to suppress unwanted harmonics from other test equipment like the signal generator.

The probe test board is used to perform the distortion measurements on a single ended, active probe model RT-ZS30 (3 GHz, 10:1 probe), and the differential active probe model RT-ZD30. The probe test board includes a simple RF line; the probe tips can connect to the 50 ohm line and the ground.

The distortion test on the differential probe was performed with the probe in single ended mode, by connecting the unused probe tip to a 50 ohm load. Both probes were connected to the R&S FSW spectrum analyzer baseband input, with the internal signal path connecting the probe to the RF input.

3.1.1 3rd order intermodulation performance of the probe

The intermodulation distortion of the probe is tested with two signal generators; the outputs of the generators are combined with a hybrid power combiner that offers a good isolation between the generator ports, to avoid any intermodulation between the output amplifiers of the generator. The output signal of the power combiner is connected to the RF input of the spectrum analyzer via a probe test adapter.

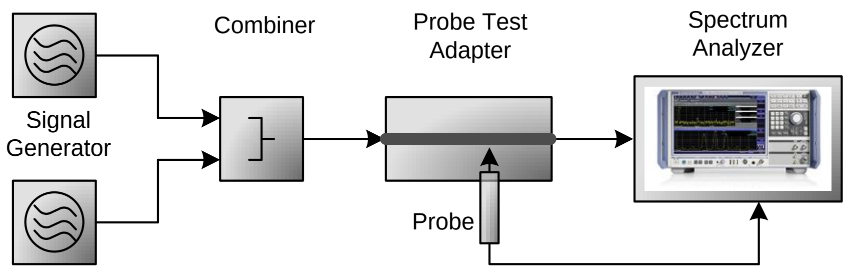

Fig. 3-2: Block circuit of intermodulation distortion test setup

The Figure 3-3 (below) shows the test setup and result on the screen of the FSW with the single ended probe.

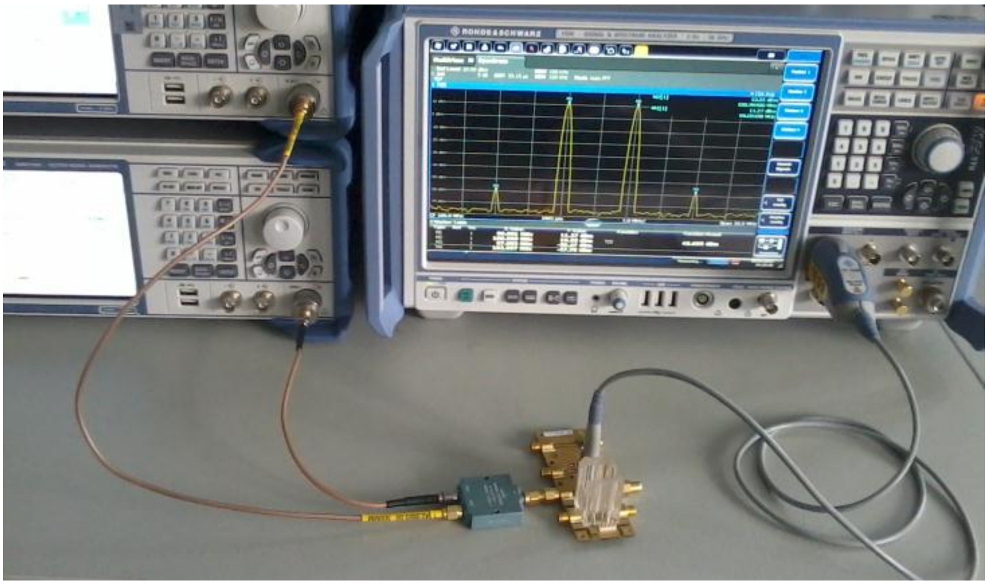

Fig. 3-3: Test setup for intermodulation distortion test of the RT-ZS30 at 500 MHz

The test of intermodulation distortion was performed from 100 MHz to 1 GHz, with +15 dBm input level into the single ended, active probe and the differential active probe. Both probes have a similar amplifier characteristic and therefore show similar performance for intermodulation distortion.

Test results for 3rd order intercept point (TOI)		
Frequency	**RT-ZS30**	**RT-ZD30**
100 MHz	~ 44 dBm	~ 43 dBm
500 MHz	~ 47 dBm	~ 45 dBm
1000 MHz	~ 45 dBm	~ 41 dBm

Table 3-1: Intermodulation Distortion Test Results

The R&S active probes used in this test are both 10:1 probes, which means that the input signal is divided by a factor of 10 to 1. Only a tenth of the input signal at the tip is used to drive the probe amplifier and the connected test instrument (either the oscilloscope, or the spectrum analyzer).

The 10:1 ratio is equal to 20 dB of signal loss before the probe amplifier. The signal loss of the 10:1 divider has the same effect as the RF attenuator in the spectrum analyzer and shifts the TOI result by the amount of attenuation. Taking the 20 dB signal loss into account, the TOI of the probe amplifier is similar to a high performance spectrum analyzer´s typical TOI specification of about 25 dBm.

3.1.2 2nd order harmonic distortion performance of the probe

The harmonic distortion of the probe is tested using just one signal generator, the output of the generator is low-pass filtered to assure a good suppression of the distortion from the generator output amplifier. The output signal of the filter is connected to the RF input of the spectrum analyzer via a probe test adapter.

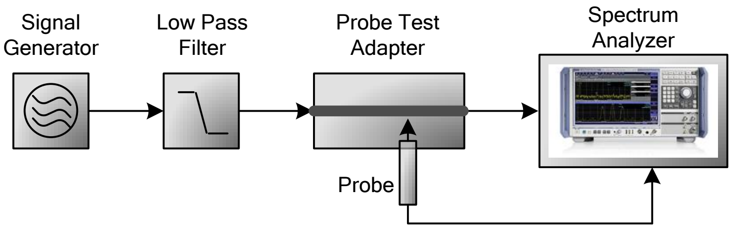

Fig. 3-4: Block circuit of harmonic distortion test setup

The test setup with the filter and the probe test board is shown below in figure 3-5.

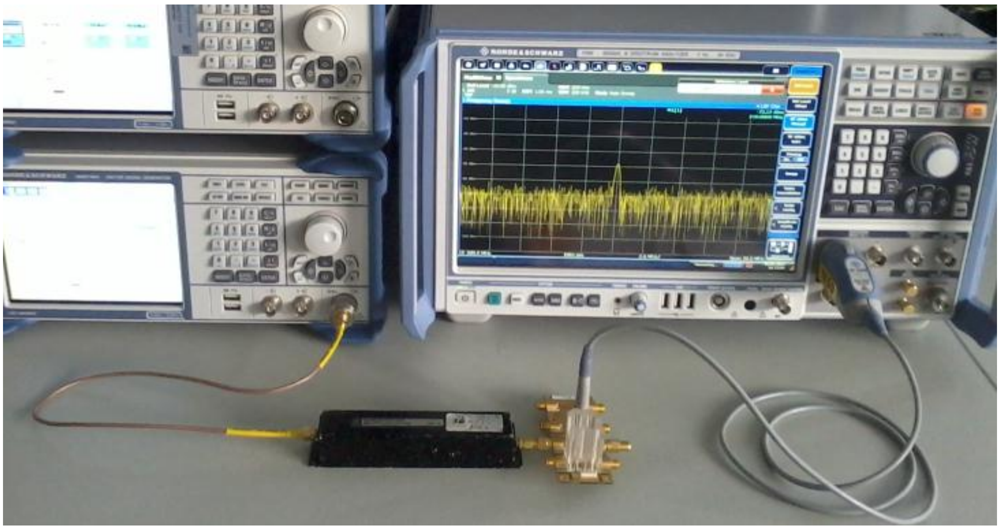

Fig. 3-5: Test setup for harmonic distortion test for RT-ZS30at 100 MHz

The test of harmonic distortion was performed at 100 MHz and 250 MHz and +15 dBm input level into both types of probes.

Test results for 2nd order harmonic distortion				
Frequency	**RT-ZS30**		**RT-ZD30**	
	Distortion	**SHI**	**Distortion**	**SHI**
100 MHz	-59 dB	74 dBm	-58 dB	73 dBm
250 MHz	-60 dB	75 dBm	-59 dB	74 dBm

Table 3-2: Harmonic Distortion Test Results

As explained for the intermodulation distortion test results, the 20 loss at the input of the probe is also improving the performance for harmonic distortion. Taking the 20 dB signal loss into account, the result of the probe is again similar to the typical SHI specification of about 55 dBm for high performance spectrum analyzers.

4 Measurements with differential probes

In the previous chapters some fundamental performance tests were performed on R&S active probes to show their capabilities in RF test scenarios. This section describes using an RT-ZD30 active differential probe to perform measurements on a true differential amplifier and shows the test results achieved.

4.1 Differential Amplifier measurements

In a differential circuit the RF signal is normally divided into two components with equal level and 180 degree phase shift. The main signal of interest is the difference between these two signals. Each signal may contain other components that may be ignored as long as their difference is small or zero. This is for example true for any signals that appear on both lines with equal level and equal phase. These signals are so called "Common mode signals" and will be suppressed by the subsequent stage in a true differential signal path. Measurements on differential signals are therefore not possible with a normal spectrum analyzer, as only one RF input is available. Two measurements one after the other with the same analyzer do not keep the phase relationship and are therefore not a solution for this task. A typical work-around is to use a transformer like a BALUN (**B**alanced/**Un**balanced) to combine the differential signal into a single line signal. The drawback of this solution is the size and limited frequency range of the transformers, which in many cases prevents putting them directly into the circuit at the test points.

4.1.1 Test Setup for differential amplifier measurements

The following simple test setup is used to show practical test results for differential measurements with spectrum analyzers and probes.

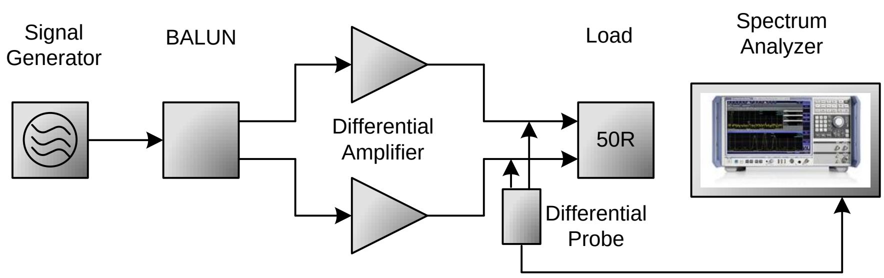

Fig. 4-1: Block circuit of the differential amplifier test setup

The circuit consists of a signal generator that drives a BALUN to generate a differential test signal. The differential signal paths are connected to two identical amplifiers. Depending on the test, the outputs of the amplifier are directly connected to the spectrum analyzer (single amplifier result) or they are combined again with a BALUN to measure the overall differential performance of the amplifiers. For the test with the probe the outputs are terminated with a 50 Ω load.

4.1.1.1 Test Results for direct connection to the amplifier

Before measurements on the amplifiers are performed with the differential probe, a simple test of the characteristics of each single amplifier and the differential amplifier is done.

For this test the amplifier is used as a power amplifier and operated close to its maximum output level. The available output level and the distortion of the second order harmonic are measured with the spectrum analyzer connected directly to the amplifier output. In a second step, both amplifier outputs are combined with a BALUN to form a differential amplifier. The combined output signal of the BALUN is connected to the spectrum analyzer to measure the performance improvement. The inherent loss of the BALUN is compensated in the spectrum analyzer as a reference level offset.

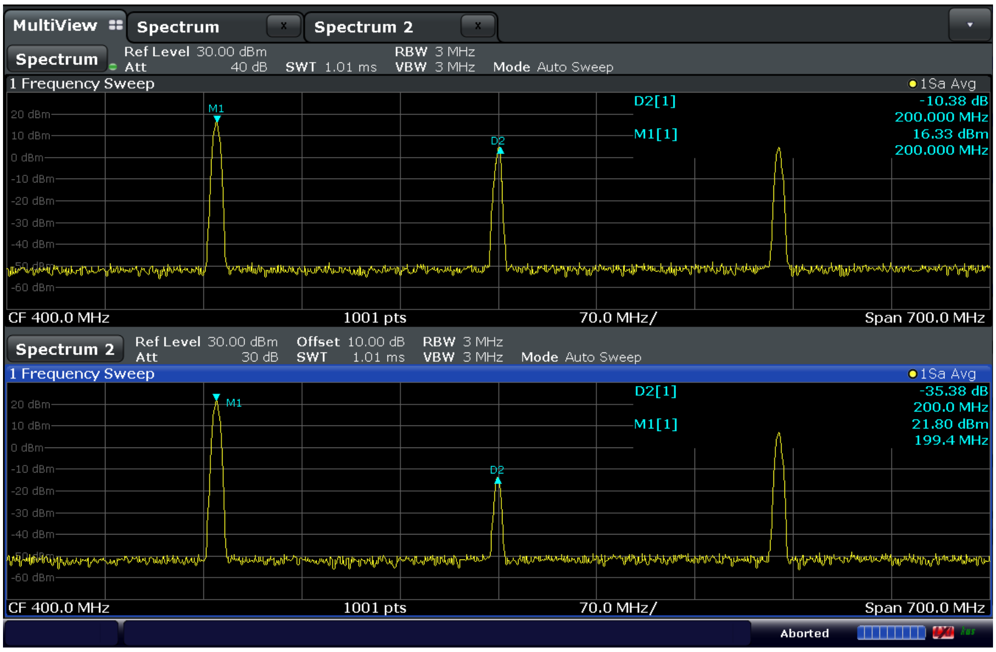

Fig. 4-2: Test result of the differential amplifier connected to the spectrum analyzer

In the above figure (Fig 4-1) the upper screen shows the performance of a single amplifier directly connected to the RF input of the FSW. The lower screen shows the result of the differential circuit built from two of these amplifiers.

From this result one of the important advantages of differential circuits can be easily identified: the inherent cancellation of the even order harmonic products. While the single amplifier offers only about 10 dB harmonic suppression, the same amplifier reaches about 35 dB in the balanced design, while providing 6 dB more output level. This is one of the reasons why differential circuits are used a lot in high performance signal path designs.

The above measurements have been performed on a test circuit that offers test points at all signal connections between the stages. In a real circuit this is often not the case, and the test engineer needs to find a solution to perform measurements. With probes connected to the spectrum analyzer these measurements can now be performed at any existing contact point like surface mounted parts.

4.1.1.2 Test Results for probes connected to the amplifier output

The following picture shows how the R&S RT-ZD30 differential probe used to measure the differential output signal from the amplifiers in the example test setup. In this case the probe tips are contacted to the soldering pads of a surface mounted connector.

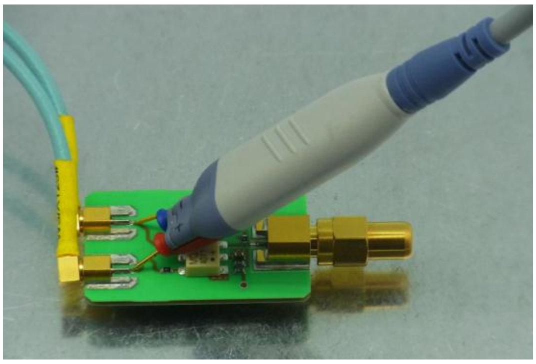

Fig. 4-3: Differential Probe connected to output circuit

The probe cable is connected to the R&S FSW baseband input and the spectrum analyzer is configured to route the signal from the baseband input to the RF signal path. The spectrum analyzer is operated the same way as with a signal connected to the RF input. The 10:1 ratio of the probe and the internal cabling is automatically corrected with a transducer factor on the R&S FSW (marked on the screen with the label TDF).

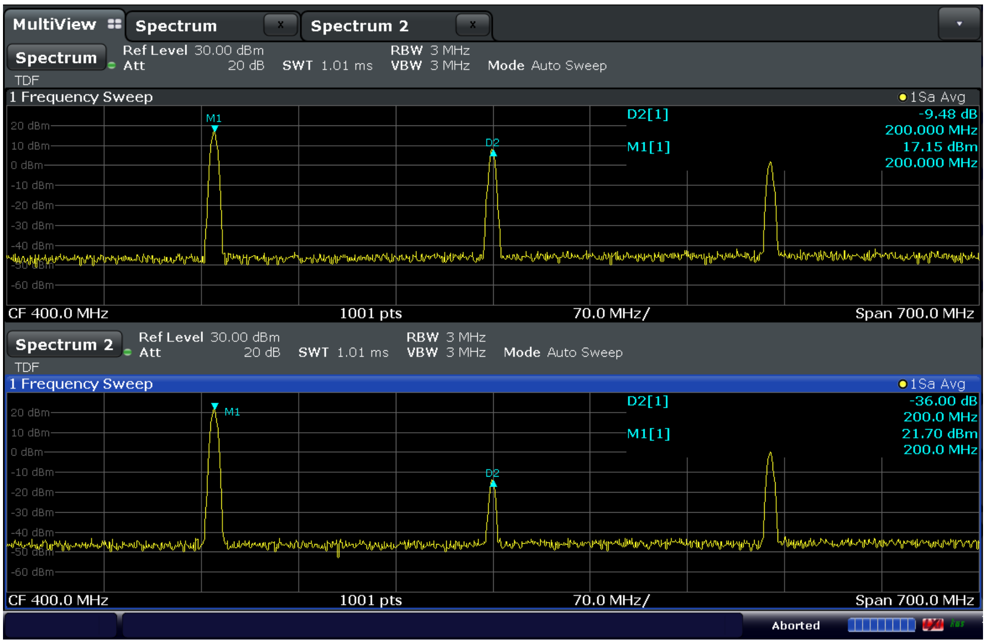

Fig. 4-4: Test result of the differential amplifier connected to the spectrum analyzer

The above figure shows the test results from the single (upper screen) and differential amplifier (lower screen). The test results using the probe are comparable to the test results with direct connection. Oscilloscope probes, especially differential probes, simplify measurements with spectrum analyzers that have been difficult or impossible before.

5 Conclusion

Active probes for oscilloscopes offer new possibilities for spectrum analyzer measurements. Compared to previous setups with additional test connectors or additional special test circuits like a BALUN, the use of active differential probes make quick, accurate measurements possible on signals over a wide frequency range with a spectrum analyzer at any point within a printed circuit board.

In probing situations with limited access to the test point, the micro-button on the RTO active probes from R&S helps the user to keep his fingers on the probe and initiate a sweep on the spectrum analyzer without the requirement to move his hand away from the probe, which helps to capture exactly the result screen of interest.

6 Ordering Information

R&S FSV3	Signal- and Spectrum analyzer 10 Hz to 3.6 GHz	1307.9002.03
R&S FSV7	Signal- and Spectrum analyzer 10 Hz to 7 GHz	1307.9002.07
R&S FSV13	Signal- and Spectrum analyzer 10 Hz to 13.6 GHz	1307.9002.13
R&S FSV30	Signal- and Spectrum analyzer 10 Hz to 30 GHz	1307.9002.30
R&S FSV40	Signal- and Spectrum analyzer 10 Hz to 40 GHz	1307.9002.40
R&S FSW8	Signal- and Spectrum analyzer 2 Hz to 8 GHz	1312.8000.08
R&S FSW13	Signal- and Spectrum analyzer 2 Hz to 13.6 GHz	1312.8000.13
R&S FSW26	Signal- and Spectrum analyzer 2 Hz to 26.5 GHz	1312.8000.26
R&S FSW43	Signal- and Spectrum analyzer 2 Hz to 43.5 GHz	1312.8000.43
R&S FSW50	Signal- and Spectrum analyzer 2 Hz to 50 GHz	1312.8000.50
R&S RTO-ZD20	1.5 GHz Active Voltage Probe, differential	1410.4409.02
R&S RTO-ZD30	3 GHz Active Voltage Probe, differential	1410.4609.02
R&S RTO-ZD40	4.5 GHz Active Voltage Probe, differential	1410.5205.02
R&S RT-ZA9	Probe Box to N/USB Adapter (Adapter to N connectors)	1417.0909.02

About Rohde & Schwarz

Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established more than 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

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