Group Delay measurements with Signal and Spectrum Analyzers

Application Note

Products:

- R&S®FSW
- R&S®FSW-K17

Phase distortions in a transmission channel are determined using group delay measurements, they must be as low as possible to maintain good signal quality. Vector network analyzers are normally used to characterize the group delay variations as a measure of phase distortion.

This application note provides basic information about the concept of a group delay measurement with spectrum analyzers and signal generators, and how this method simplifies the test setup and improves the measurement speed.

Measurement examples show the limiting factors of this approach and help the user to understand and avoid some limitations of this method. In addition the test results are compared to those generated with vector network analyzers.

Application Note

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8.2017 – 1EF98-1E

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1 Introduction

Detecting amplitude flatness and phase distortion is crucial in characterizing the quality of a transmission channel, as both lead to a limited signal quality at the receiver. In most cases the usable bandwidth of a communication channel shall be maximized in order to get the best throughput with minimal signal distortions. The available bandwidth of a RF channel is typically limited by the bandpass characteristic of filters, amplifiers and mixers. The bandpass characteristic is easily visible as frequency response of the channel, and the amplitude flatness within the used bandwidth may have an influence on the signal quality. The most important characteristic that limits the bandwidth of the RF signal path is the phase distortion or group delay variation, as this parameter leads to distortion of the signal passing the RF channel. The knowledge about phase distortion is essential to maintain low bit error rates in data transmissions.

VNAs (**V**ector **N**etwork **A**nalyzer) commonly performs amplitude flatness and phase distortion measurements. The principle of a VNA limits the test to a single frequency point per time, and the VNA steps through the frequency range of interest with a given (user-settable) number of measurement points. A basic description of this measurement is given in the next section.

This application note describes a different technique for this measurement. The R&S®FSW-K17 multicarrier group delay measurement application performs this important measurement with a signal and spectrum analyzer. The option uses a multicarrier method, and besides evaluating the group delay, the option also displays the amplitude flatness. Key for this technique is a signal generator that stimulates the device under test with a multicarrier signal with the full channel bandwidth. A signal and spectrum analyzer captures the full bandwidth of the output signal from the device and uses digital signal processing to determine amplitude and phase for each tone of the multicarrier signal. By calculating the phase differences between two adjacent carriers, the spectrum analyzer calculates the phase transfer function or the group delay of the device under test. Further details are explained in the next sections.

2 Group Delay measurement process

2.1 Theoretical background of Group Delay

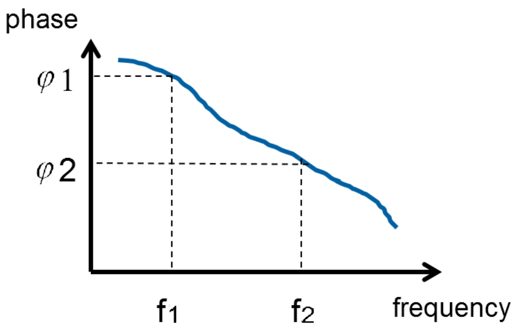
Group delay measurements are usually based on phase measurements. The measurement procedure corresponds to the definition of group delay τ_{gr} as the negative derivative of the phase φ (in radian) with respect to frequency f:

$$\tau_{\text{gr}}(f) = -\frac{1}{2\pi}\frac{d\varphi}{df}$$

Equation 2.1: Definition of group delay

2.2 Vector Network Analyzer measurement

For practical reasons VNA measure a difference coefficient of the transmission parameter S_{21} instead of the differential coefficient, which yields a good approximation to the wanted group delay τ_{gr} if the variation of phase φ is almost linear in the observed frequency range Δf which is also called the aperture.



$$\tau_{\mathrm{gr}}(f) = -\frac{1}{2\pi}\frac{\Delta\varphi}{\Delta f}$$

Fig. 2.2: Definition of phase difference and aperture

Fig. 2.2 shows the terms $\Delta\varphi = \varphi 2 - \varphi 1$ and $\Delta f = f_2 - f_1$ for linearly decreasing phase response, e.g. of a cable.

For non-frequency converting devices like cables, filters or amplifiers, the measurements of S_{21} at two different frequencies can happen in sequence. The VNA delivers the test signal with known amplitude and phase, and the received signal is compared to the stimulus signal.

A key measurement is the relative and/or absolute group delay for frequency up- or down-converters. With frequency converting devices like mixers, the phase between the input and output signal cannot be measured directly, because the frequencies are different. Also the phase is not only influenced by the component itself, but also by the phase of the local oscillator. One possible solution is to use the so-called reference mixer technique, where an additional mixer uses the same local oscillator as the device under test to reconvert either the RF or IF signal in order to get identical frequencies at the reference and measurement receiver of the VNA.

If the LO of the device under test is not accessible, group delay measurements are not possible with a reference mixer. In this case a very common method in the past was to use AM or FM modulated signals and measure the delay of the modulation signal. Other methods try to reconstruct the LO. They use an external signal generator as LO for the reference mixer and try to tune the generator frequency until the phase drift versus time of the IF is minimized. These techniques have limitations in terms of dynamic range, measurement accuracy and speed.

Another technique is to stimulate the device under test with a two tone signal. By measuring the phase differences between the two signals at the input and the output, the network analyzer calculates the phase transfer function or the group delay of the device under test. The measurement accuracy does not depend on the embedded

LO's frequency stability as long as the deviation is within the measurement bandwidth of the network analyzer receivers. To measure the phase difference of two carriers the VNA must provide a two-tone source and two receivers that measure both signals simultaneously.

2.3 Multi-Carrier group delay measurement

Most group delay measurements today are performed with sinewave signals whose frequencies are swept (stepped) over the frequency range of interest. For a full characterization one needs to measure the response at many frequency points. For each measurement point, the source and the receiver frequency need to be stepped and the measurement filters have to settle before readings can be taken. In addition, the delay through the DUT needs to be taken into account, which can be up to 230 ms for a satellite in orbit.

In contrast to a single sinewave, a multi-carrier signal contains several sinewaves, each having a specific frequency and phase. This approach can have significant advantages compared to the stepped approach, especially with large delays or many test points. A multi-carrier signal is most often created with an integer number of cycles of each individual sinewave in the signal, these signals are also called orthogonal signals. A simple example of such a signal is shown in the following figure.

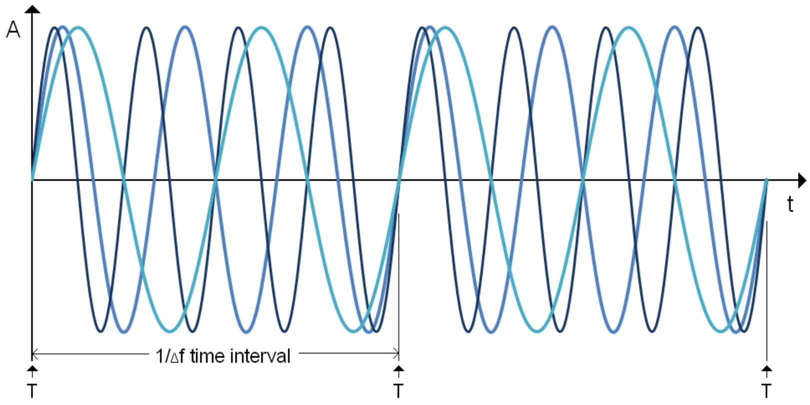


Fig. 2.3-1: Waveform with orthogonal multicarrier sinewaves and trigger points

In this example three sinewaves are used to illustrate the most important criteria for an orthogonal multicarrier waveform. The frequencies of the single tones are selected in such a way that the tones are using an equal frequency spacing Δf. As a result of this common spacing, each sinewave is presented with an integer number of periods in the combined signal when a time interval of 1/ Δf is observed. In the above example the common time interval for the tree sinewaves is marked, and the integer waveform for each sinewave can be recognized. It shall be noted that the relative phase of each sinewave can be adjusted in order to optimize the crest factors of the total signal. In the above example with all carriers starting at zero degree the signal becomes an impulse and the crest factor of the signal is very high. The crest factor can be lowered by using arbitrary phases or following special rules for each tone, like quadratic ally varying phase from tone to tone.

The R&S®SMW200A vector signal generator with build-in wideband ARB waveform generator and I/Q modulator offers a comfortable solution to create these test signals. The signal generator creates a test signal with up to 2 GHz bandwidth and with thousands of carriers covering the frequency range of interest.

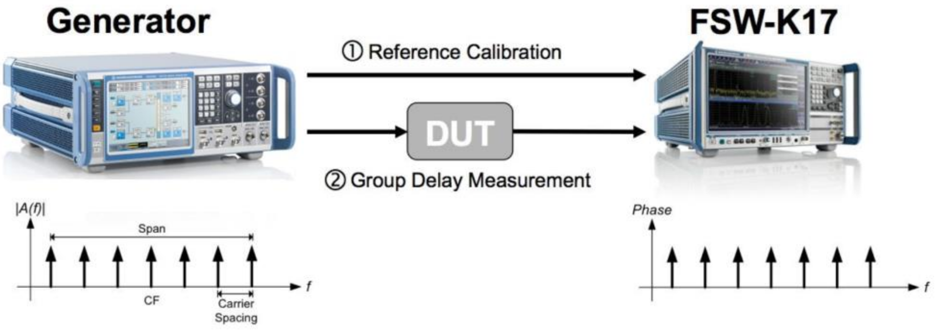


Fig. 2.3-2: Test setup for group delay measurements

The R&S®FSW signal and spectrum analyzer allows to capture these wideband signals into I/Q-memory, with instantaneous bandwidth of up to 512 MHz or even more. A subsequent signal processing based on FFT algorithms allow to recover the amplitude and phase of each individual tone of the applied multi-carrier signal.

Figure 2-3 shows the test setup for determining the group delay: A signal generator generates a multicarrier signal, which is defined by the center frequency, the carrier spacing and the number of carriers. The use of wideband multicarrier signals makes it possible to quickly determine the group delay over the entire frequency range of interest.

In a first step a calibration (1) without the device under test (DUT) is carried out, in order to determine the reference phase and amplitude of the individual carriers. During calibration the signal is fed directly to R&S®FSW without a DUT. The calibration data can be easily and conveniently saved in a file and retrieved again at any time. This saves time during subsequent measurements, and makes it possible to quickly switch between different measurements.

In order to determine the group delay, the multicarrier signal is then measured at the output of the DUT (2). The R&S®FSW-K17 option can determine the group delay over the frequency range of the carriers from the phase difference between the reference measurement and the current measurement results.

Because the phase relation between the reference calibration and the measurement is the only thing that is important for analysis, it is possible to work with crest factor optimization on the generator. A multicarrier signal with a low crest factor improves the SNR for the group delay analysis and protects the DUT.

2.3.1 Absolute versus relative group delay

Electrical signals experience a delay while passing through a transmission medium. In the best case, the delay is equal for each frequency. In practical RF circuits like a cable, the velocity of the signal is lower than in vacuum, and the delay due to the electrical length is higher than one would expect based on the length of the cable. The measurement of this delay can be performed by calculating the derivative of the phase versus frequency as explained earlier. This delay is called the absolute group delay, and it applies to the group of signals (at least two) that were used to calculate the delay. In practice the absolute group delay is important in ranging applications where the distance between two points shall be measured. For RF signals used in communication applications, the group delay variation is more important.

The electrical delay of a RF circuit often changes over the frequency. In practical applications most signals cover a known, limited bandwidth, or consist of a group of spectral lines like a pulse modulated carrier. If the components of such a signal suffer different delays for each signal component, the combination of all components lead to a distorted signal. This is the reason why the measurement of group delay variation is very important for any kind of RF circuit. This measurement is sometimes also called group delay distortion or relative group delay. Relative group delay measurements ignore the constant delay caused by the DUT. This delay affects all frequency components in the same way and does not lead to a change in the signal shape. However, the absolute group delay may be significant.

The multi-carrier group delay measurement allows to test relative and absolute group delay. In case of relative measurements only the RF signal is connected between the generator and the spectrum analyzer or DUT. The calculation of the relative group delay is only performed between two adjacent tones. While both tones may suffer a large absolute delay, the delay difference is the only limitation and needs to stay within the inverse of half the tone spacing. This is the same limitation that applies to a VNA, and is commonly known as under-sampling for devices with long electrical length.

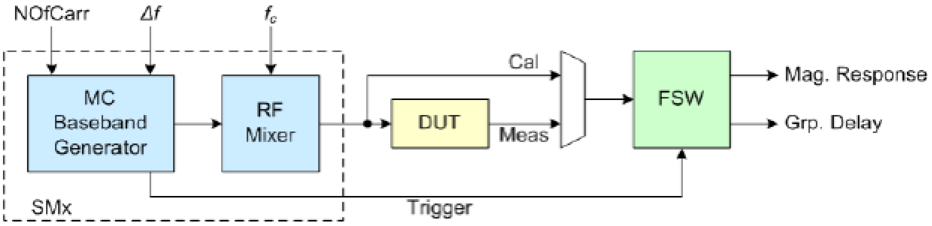


Fig. 2.3.1: Trigger connection for absolute group delay measurements

Absolute group delay measurements use an additional trigger or timing signal. The multicarrier signal consists of a finite number of single tone signals with equal spacing. The spacing defines the length of the signal waveform, which is exactly 1/spacing in case of orthogonal signals. The timing signal marks the start of each waveform segment and is used as a trigger for the spectrum analyzer. The repeating behavior of the signal is a limiting factor in this approach. The signal structure repeats with 1/ Δf and creates an ambiguity in the group delay calculation. This repetition limits the absolute group delay measurement to a maximum of 1/ carrier spacing.

3 Comparing the measurements

This chapter provides a comparison of test results for absolute group delay between a VNA and the Signal Analyzer with the multi-carrier setup.

A bandpass filter is used as DUT to reflect the most typical measurement scenario of a transmit channel. The typical behavior of a bandpass filter is a decent frequency range with flat group delay response in the passband, and steep changes of passband loss and group delay at the band edges.

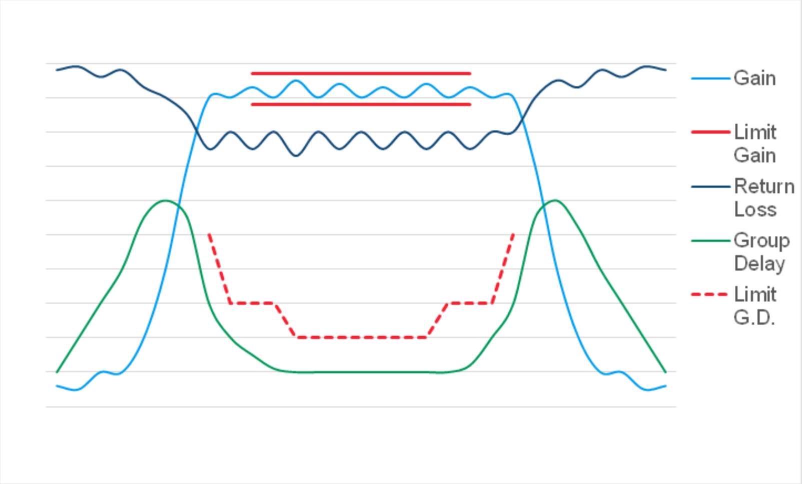


Fig. 3-1: Typical band pass filter shape with test limits

In a practical test scenario it is important to verify the gain flatness and the group delay response in the passband. The usable range of a band limited signal path is most often limited by the group delay changes at the band edges. It is important to be able to perform accurate measurements with sufficient frequency resolution to determine the available bandwidth of the DUT.

The group delay measurement comparison is performed between the R&S ZNB (traditional VNA) and the combination of the R&S SMW signal generator + R&S FSW spectrum analyzer using the multi-carrier method.

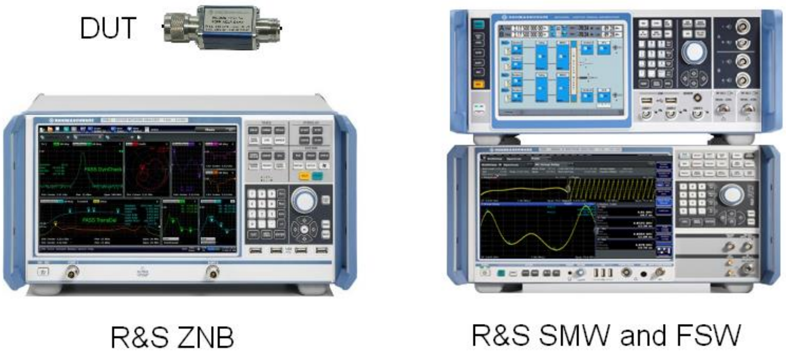


Fig. 3-2: Instruments used for the Group delay measurement comparison

3.1 Measurement result comparison

The test is performed on a bandpass filter at a center frequency of 950 MHz and 50 MHz bandwidth, and about 20 dB stopband attenuation at 80 MHz bandwidth. The test was performed on 1000 points over 100 MHz span, thus resulting in 100 kHz aperture or frequency resolution.

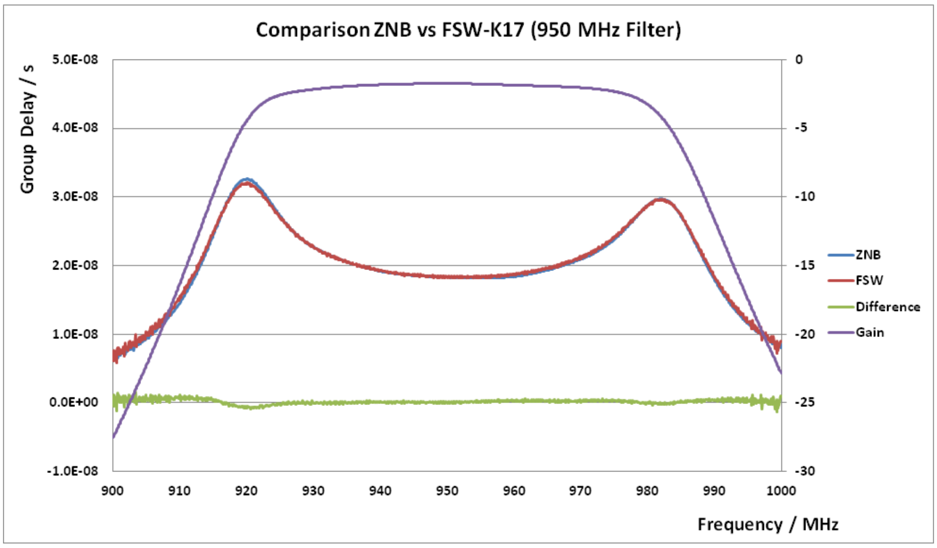


Fig. 3.1-1: Group delay measurement results for the VNA and the SA

Figure 3-3 shows the results for group delay of both test setups as an overlaid plot in a single diagram. The bandpass characteristic of the filter can be easily recognized on the insertion loss trace (shown in violet, scaled on the right axis in dB).

The absolute group delay results for the VNA (blue trace) and the spectrum analyzer measurement (red trace) show excellent agreement between the two different test solutions. For better clarity the green trace shows the difference between the two results for group delay. This trace remains close to zero for the whole passband and the stopband.

A small difference between the results appears at the band edges where the group delay has its peak. While the passband of the filter has good matching to the test instrument, high reflection happens in this frequency range. Since the test instruments also have limited matching at their test ports, the reflected signals are adding to the test signal and thus lead to a measurement error. This effect was minimized in this test by using short, good quality cables and adding matching pads to the source and the spectrum analyzer (10 dB pad). These matching pads are not required for the VNA as it offers a better port matching than a spectrum analyzer or signal source, and it further improves the measurement by applying a full error correction model.

This short comparison shows similar test results for group delay measurements performed with a spectrum analyzer instead of a VNA. In case of a DUT with high input or output reflections it is important to maintain the matching to the test instruments by adding attenuation pads, the loss can be compensated by increased power levels if required.

3.2 Measurement speed advantage

The measuring speed plays an important part in any RF test system. The measurement time for a group delay measurement is influenced by a large amount of parameters like the number of test points or the required accuracy. There is one important area that has direct and huge impact on the test time for group delay measurements, which is the absolute delay through the DUT.

The influence of the DUT on the test time is easy to understand with knowledge of the measurement process. For a DUT with a long delay, the test instrument must wait for the signal to pass through the DUT before it can be measured. For many cases this is not of interest, as the DUT has a direct connection to the test instrument and contains typical RF circuits like filters, amplifiers and mixers with delay times in the region of some ns to several hundred µs. This measurement may also be performed on a long distance link like a satellite in orbit, where the delay can be as much as 240 to 280 ms (depending on the location). When the group delay measurement is performed in sequence like in a traditional VNA (frequency point by point) this delay will have huge influence and can lead to several minutes of test time, as the instrument needs to wait after each frequency step for the signal to pass through the DUT and return.

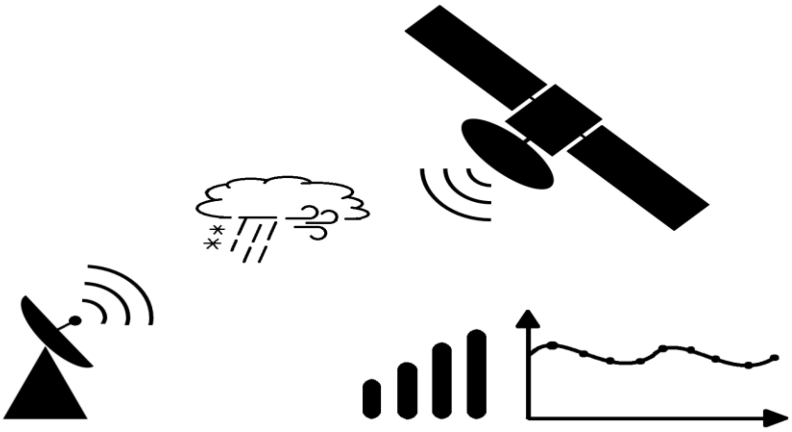


Fig. 3.1-1: Measurement influence from the signal path

In case of a long lasting measurement of gain flatness and group delay (like a long distance link or satellite in-orbit) the test results are suffering from signal path changes. A typical example is the loss variation due to moving clouds, which overlays the gain flatness response and may lead to wrong results. The group delay distortion measurement is very difficult as changes of the distance (moving satellite) influence the relative group delay measurement and complicate the measurement.

The multi-carrier group delay measurement option available in the R&S®FSW spectrum analyzer has an important advantage in this test scenario: as the test signal covers the full bandwidth of the channel at once, only one single measurement is required to get all measurement points. For a wideband, relative group delay analysis over a span of 160 MHz with a carrier spacing of 200 kHz (800 carriers), the option only needs 350 ms, and a mere 80 ms with a carrier spacing of 1 MHz (160 carriers). Besides the group delay result, the option also displays the amplitude flatness within the same test time.

4 Measurement challenges

In the past sections of this application note the fundamentals and the different concepts for group delay measurements have been discussed.

The measurement using a multi-tone stimulus with signal generators and spectrum analyzers provides similar performance levels as the traditional method using a VNA and stepped frequency measurement. While the measurement with the spectrum analyzer offers a speed advantage in some cases like a DUT with long delay, it is also very important to be aware of some limitations that this method suffers from.

4.1 Multi-tone signal level and noise

Like with most other test results, the accuracy of a group delay measurement is influenced by the signal to noise ratio (SNR) at the receiver. In traditional group delay measurements with a VNA the test signal consist of a single CW carrier that is stepped across the frequency range of interest. The carrier level is either known or very easy to measure with the network analyzer. In case of the multicarrier group delay measurement method, the level of each individual tone might not be known. The carrier power is most often set on the generator as the average power of the complete signal. The carrier power on each tone can be calculated from the average power divided by the number of tones. It is important to limit the number of tones to a decent value that is required to get enough frequency resolution, as the available SNR is decreasing with the number of carriers. The effect of the SNR on the phase measurement can be best understand with this simplified drawing:

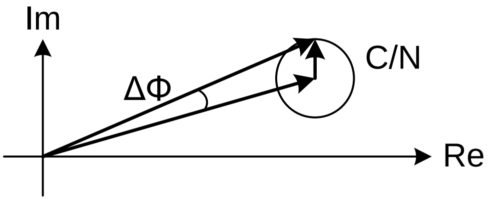


Fig. 4.1-1: performance evaluation

For each group delay measurement point the phase between two adjacent tones is calculated. The phase measurement accuracy is directly influenced by the ratio of tone level to the amount of noise level. The resulting group delay uncertainty for each measurement point within a multicarrier signal can be calculated with the following formula:

$$std(\tau) = \frac{1}{2\pi\Delta f} \cdot 10^{-\frac{C/N\,(\mathrm{dB})}{20}} \cdot \sqrt{\frac{1}{\text{Number of Averages}}}$$

Equation 4.1: Calculation of group delay uncertainty due to SNR

With:

Δf: frequency spacing

C/N: carrier to noise ratio in dB

As the above formula shows, besides the signal to noise ratio there are two other important parameters that have direct influence on the measurement accuracy. The frequency spacing between the tones has a direct impact on the accuracy of a group delay measurement. The reason is in the definition of group delay as the derivative of phase change over the observed frequency interval, as explained in the beginning of this paper. For a given signal to noise ratio the stability of the group delay reading can be improved by using a wider tone spacing (= larger aperture).

In cases where the tone spacing cannot be increased, the best way to improve the quality of the measurement is to perform several measurements in sequence and average the results. In case of the multicarrier group delay measurement this is a very effective way, as each single measurement is extremely short and takes typically only some µs (1/ Δf, see fundamental section in this paper). The measurement application on the R&S FSW signal analyzer performs 5000 averages in the default setting. The average process is implemented as part of the signal processing and increases the capture time of the waveform. This increase of captured data and subsequent average can be best understood as processing gain, in this case the SNR is effectively increased by 37 dB.

While the average of the signal has an effect on the noise floor of the measurement, there is one important aspect on the carrier level that shall be mentioned here. The relative phase relationship of adjacent tones within the multicarrier signal between the reference calibration and the measurement is important for the group delay distortion measurement. Since the absolute phase of each tone is not important, it is possible to work with crest factor optimization to improve the performance. The crest factor is defined as the ratio of the peak level to the average level of the complete test signal. The crest factor of a multi tone signal can be influenced by the phase of the tones in the signal. A signal with a high crest factor will have reduced total power and energy in each tone, as the peak power is most often limited by the DUT. To avoid any compression, the maximum level of the multicarrier signal should stay within the capabilities of the tested hardware. A multicarrier signal with a low crest factor improves the SNR for the group delay analysis and protects the DUT. With proper selection of the phases for each tone the crest factor can be minimized. The R&S signal generators SMBV and SMW offer build-in functions to create multicarrier signals with minimum or selectable crest factors for the given number of tones.

To summarize the above described effects, here is an example for the typical measurement accuracy of the multicarrier group delay due to SNR:

Test results for different SNR values and Δf = 250 kHz	
SNR	**Stand Dev.**
10 dB	2.8 ns
20 dB	0.90 ns
30 dB	0.28 ns
40 dB	0.09 ns

Table 4.1: Group Delay uncertainty due to SNR

The table is calculated for an aperture of 250 kHz. Decreasing the SNR by 20 dB degrades the group delay measurement by a factor of 10. Instead of increasing the signal level, the measurement time and thus averaging can be used to reach the required SNR.

4.2 Multi-tone signal and intermodulation

A very important aspect besides the influence of noise is the distortion of the multicarrier signal while it´s generation, analysis and the influence of the DUT.

In a conventional group delay measurement with a stepped single CW tone as it is performed with a network analyzer, the intermodulation distortion of the DUT is not of interest. Only a single tone is used for each test, and the receiver is tuned to the fundamental frequency of this signal.

With a multi-tone signal and a wideband analysis this is different. All non-linear components in the signal path will lead to some amount of intermodulation which has direct influence on the phase measurement and thus the group delay. The following simplified drawing will help to understand this effect.

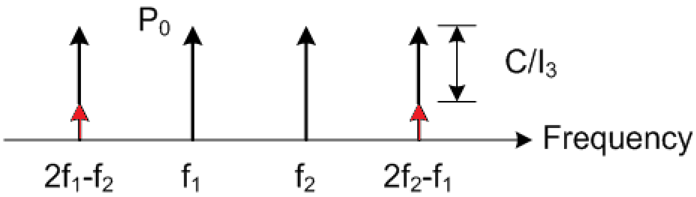


Fig. 4.2-1: Third order intermodulation of two carriers

The multicarrier signal consists of a number of tones with equal spacing. When the signals passes a nonlinear circuit, the intermodulation of two adjacent tones (f_1 and f_2) creates additional signals at both sides of these pairs (intermodulation products, $2f_1 - f_2$ and $2f_2 - f_1$) with equal distance as the spacing between the carriers. In the complete multicarrier signal, there are further carriers at exactly these frequencies.

These additional intermodulation signals will lead to a change of the phase of the adjacent carriers. For a better understanding of this effect the following graph shows this effect for a single tone:

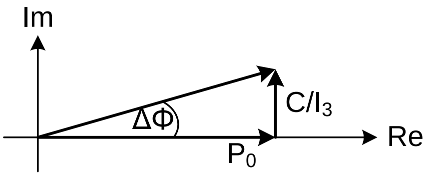


Fig. 4.3-2: Phase distortion due to intermodulation

For each tone of the multicarrier signal, there are at least two adjacent tones that create intermodulation tones on the same frequency. In order to calculate the maximum influence of this intermodulation on the group delay measurement, the effect on the phase shift of two adjacent lines in the spectrum shall be calculated. The worst case of the influence will happen if the intermodulation signal is orthogonal (90 degree) in phase to the observed spectral line. The effect on the group delay can be calculated with the following formula:

$$\tau = \frac{1}{2\pi\Delta f}\cdot 2\cdot\Delta\Phi = \frac{1}{2\pi\Delta f}\cdot 2\cdot 10^{\frac{-C/I_3\,\mathrm{dB}}{20}}$$

Equation 4.2-1: Calculation of worst case group delay error

With: Δf: frequency spacing
C/I_3: intermodulation distortion in dB

Using the example with 250 kHz carrier spacing and an assumed intermodulation distortion of 47 dB, the calculation of the maximum influence would result in 5.8 ns group delay error. One of our assumption was the worst case phase relation between the adjacent carriers, and investigating only one pair of carriers.

In a practical scenario there are hundreds of carriers that generate overlaying intermodulation products. The phases of the individual carriers can be set in a way to optimize the crest factor of the multicarrier signal. This has a positive effect on the signal to noise ratio (see chapter before) and will result in a variation of phases across the carriers, for example following the Newman phases. (Φ(k)=($\pi\cdot k$^2)/N).

The analytical solution of this scenario with hundreds of overlaying carriers and their intermodulation is difficult to imagine, but the effect can be simulated in modern software tools. The calculation of the group delay error due to intermodulation distortion, using a multicarrier signal with optimized crest factor, results in the following formula:

$$\max_k \tau(k) \approx \frac{1}{2\pi\Delta f}\cdot 0.16\cdot 10^{\frac{-C/I_3\,\mathrm{dB}}{20}}$$

Equation 4.2-2: Calculation of typical group delay error due to intermodulation

Compared to the worst case scenario it can be seen that the group delay influence is about 10 times lower for the recommended test signal with low crest factor. The following table gives an overview of the group delay error for different intermodulation distortion values:

Group Delay error due to intermodulation, for Δf = 250 kHz	
Intermodulation distortion	**Max. Group delay error**
30 dBc	3.2 ns
40 dBc	1.0 ns
47 dBc	0.46 ns
50 dBc	0.32 ns
60 dBc	0.1 ns

Table 4-2: Group Delay error due to Intermodulation

4.2.1 Identify intermodulation in group delay measurements

As explained in the previous sections, beside a definitive speed advantage the noise and distortion are the two main limitations in the multicarrier group delay measurement. While the influence of noise is very simple to recognize on the test result as unstable or flickering readings over the frequency range and time, the effect of intermodulation is more difficult to identify and the amount of distortion might not be clear.

Using the above mentioned simulation of a multicarrier signal and adding a known amount of third order intermodulation to the signal, it is possible to draw the influence of the intermodulation on the ideal, linear signal without any group delay distortion.

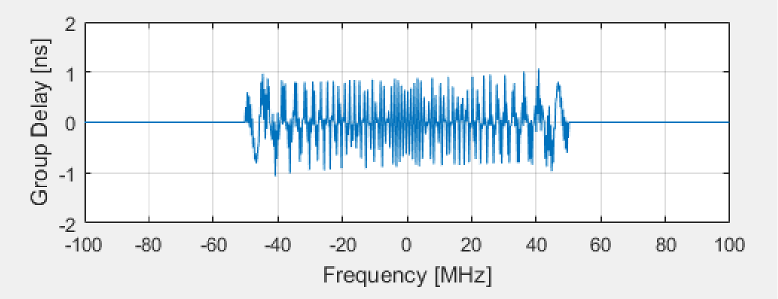


Fig. 4.4.1-1: Simulated group delay result with intermodulation distortion

The above simulation result shows a group delay calculation with 40 dBc intermodulation distortion. The group delay distortion periodically resonates between +1 and -1 ns across the full bandwidth of the signal. What can be seen is that the frequency of these resonances increases to the center of the signal. The reason for this effect is the distribution of the phases along the tones within the signal, which leads to this very prominent result.

A practical test was performed to verify the above calculations. The DUT is a broadband amplifier, tested with a power level to generate 40 dBc intermodulation distortion in case of a two-tone signal.

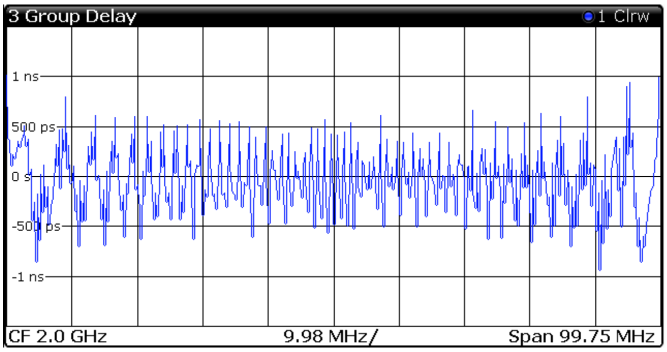


Fig. 4.5.1-2: Group delay measurement with intermodulation distortion

As described before, the periodic changes of the group delay are easy to recognize in the test result. The value of the group delay distortion approaches the predicted 1ns error at both sides of the bandwidth.

5 Conclusion

The R&S®FSW-K17 multicarrier group delay measurement option provides a comprehensive range of measurements of the distortion characteristics of transmission systems. The group delay as a measure of phase distortion can be measured both relatively and absolutely. Because of the extremely easy operation, the fast measuring procedure and the high degree of accuracy, the option can make its mark in practice. And it expands the wide-ranging measurement capabilities of the R&S®FSW high-end signal and spectrum analyzer. Together with signal generators such as the R&S®SMW and the R&S®SMBV, Rohde & Schwarz offers a complete solution to measure group delay.

The approach of multi-carrier group delay measurements may be unknown in contrast to the well-known single tone measurement with the VNA. Once we have understood the basic principles behind this technique it is as simple as the traditional way of measuring. Testing with multicarrier signals has its own limitations, but also some very important speed advantages in comparison to the conventional approach with its single sine stepped stimulus.

5.1 Multi-tone signal versus stepped CW

This short table compares the traditional method with the multicarrier signal method. While the VNA is superior in measurement accuracy and interpretation of results, the multicarrier method offers advantages in test speed.

Group Delay measurement in comparison		
Item	**Stepped CW**	**Multi-tone**
Signal characteristics	Very simple	Requires knowledge
Similarity to real signal	Not so good	good
Measurement time	increases with test points	Very short and constant over number of points
Test result interpretation	Very simple	Requires knowledge

Table 5.1: Group Delay measurement comparison

6 Ordering Information

Designation	Type	Order Nr
Signal and Spectrum Analyzer	R&S®FSW8	1312.8000.08
Multicarrier Group Delay Measurements	R&S®FSW-K17	1313.4150.02
Analysis Bandwidth	R&S®FSW-B28/40/80/160/320/512	1)

1) The R&S®FSW offers several signal analysis bandwidth extension options. A desired BW extension option should be added to the configuration. For details, please contact R&S sales.

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radiomonitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

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Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership

Certified Quality Management
ISO 9001

Certified Environmental Management
ISO 14001

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PAD-T-M: 3573.7380.02/02.05/EN/

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