

Time Domain Measurements using Vector Network Analyzer ZNA

Application Note

Products:

- R&S®ZNA26
- R&S®ZNA43
- R&S®ZNB
- R&S®ZNBT

Vector Network Analyzers of the ZNA and ZNB family are able to measure magnitude and phase of complex S-parameters of a device under test (DUT) in the frequency domain. By means of the inverse Fourier transform the measurement results can be transformed to the time domain. Thus, the impulse or step response of the DUT is obtained, which gives an especially clear form of representation of its characteristics. For instance, faults in cables can thus be directly localized. Moreover, special time domain filters, so-called gates, are used to suppress unwanted signal components such as multireflections. The measured data "gated" in the time domain are then transformed back to the frequency domain and an S-parameter representation without the unwanted signal components is obtained as a function of frequency. As usual, other complex or scalar parameters such as impedance or attenuation can then be calculated and displayed.

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<http://www.rohde-schwarz.com/application/zna/>

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1 Abstract

Vector Network Analyzers of Rohde&Schwarz family are able to measure magnitude and phase of complex S-parameters of a device under test (DUT) in the frequency domain. By means of the inverse Fourier transform the measurement results can be transformed to the time domain. Thus, the impulse or step response of the DUT is obtained, which gives an especially clear form of representation of its characteristics. For instance, faults in cables can thus be directly localized. Moreover, special time domain filters, so-called gates, are used to suppress unwanted signal components such as multireflections. The measured data "gated" in the time domain are then transformed back to the frequency domain and an S-parameter representation without the unwanted signal components is obtained as a function of frequency. As usual, other complex or scalar parameters such as impedance or attenuation can then be calculated and displayed.

2 Typical Application

As a typical example, fig. 2 shows results of a reflection measurement in the time domain. The DUT (fig. 1) consists of a power splitter. A short-circuited 460 mm long coaxial cable is connected to one output of the power splitter, and another coaxial line with an electrical length of approx. 2700 mm is connected to the other output. The end of this cable is left open in the first case (case Open).

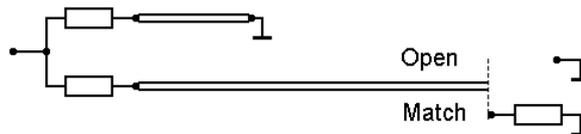


Fig. 1 DUT

Fig. 2 shows two main reflections (pulses with highest amplitudes) caused by the two total-reflecting line ends. Other smaller pulses can also be seen. They are caused by multireflections between the power splitter (12 dB mismatched at each output) and the line ends

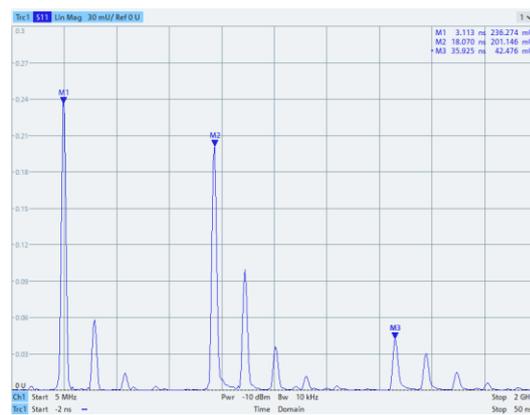


Fig. 2 Example of a reflection measurement in time domain (impulse response)

The measurement results in the frequency domain are represented by the trace shown in Fig. 3. In contrast to the time domain in which the representation is simple and clear and the different signal components can be easily distinguished, the trace in the frequency domain is obviously not easy to interpret.

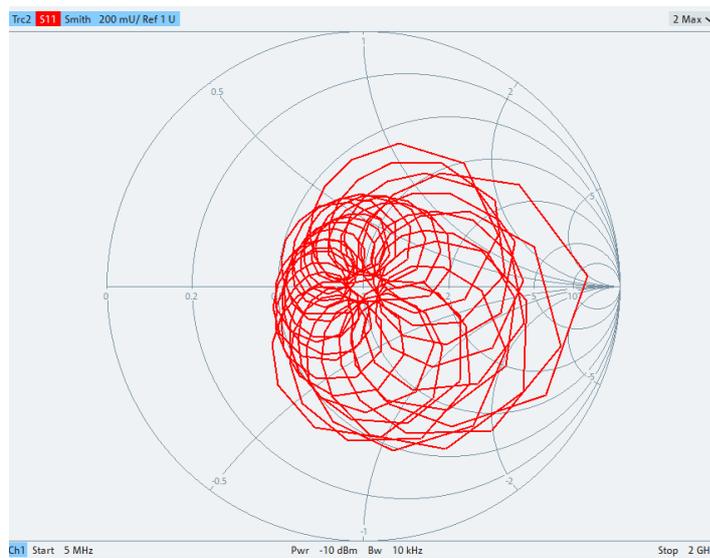


Fig. 3 Measurement results in frequency domain

Any interesting reflection can be selectively removed by means of a gate, i.e. a filter in the time domain. Such a reflection might for example be the second-highest pulse (MARKER 2 in vicinity of the center of Fig. 2) resulting from the total reflection at the open end of the longer cable. The impulse response filtered in the time domain by a suitable gate (gate center = 19 ns and gate span = 1.5 ns) is shown in Fig. 4. As can be seen, all other pulses but the interesting one are suppressed by the gate.

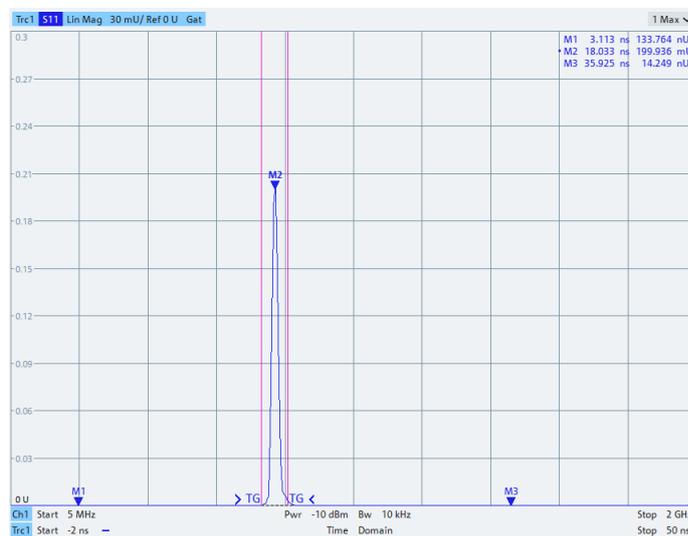


Fig. 4 Measurement results in time domain with active gate

If, in the next step, the gated impulse response is transformed back to the frequency domain, a frequency response (see Fig. 5) will be displayed, which is only representing the transfer function (in reflection) of the power splitter and the open ended cable.

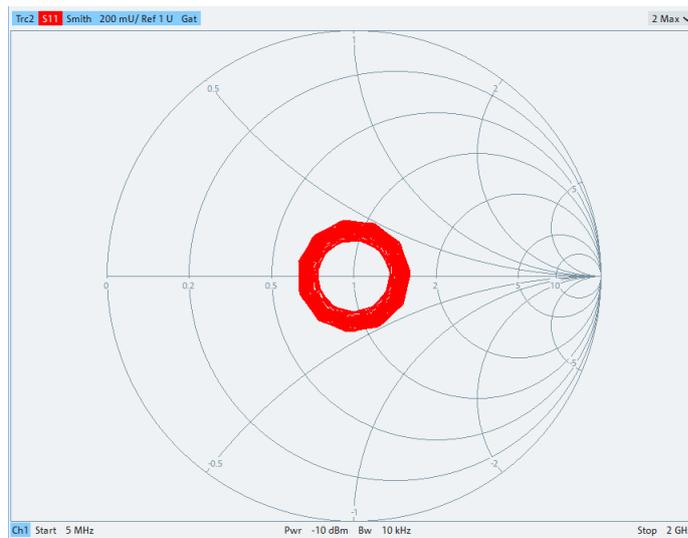


Fig. 5 Measurement results in frequency domain after time domain filtering (gating)

Now, as an experiment, the open-ended cable is terminated by a matched load (Fig. 1: case Match). The diagram in Fig. 6 shows the really impressive measurement results which are obtained despite of the numerous reflections of the test setup. Again, the gated frequency response of the DUT is displayed. Corresponding to the low reflection of the matched load used, the trace is in immediate vicinity of the center point of the Smith chart. The scaling value of the outer circle of the enlarged section around the center of the Smith chart is -20 dB. The measured values are better than -40 dB.

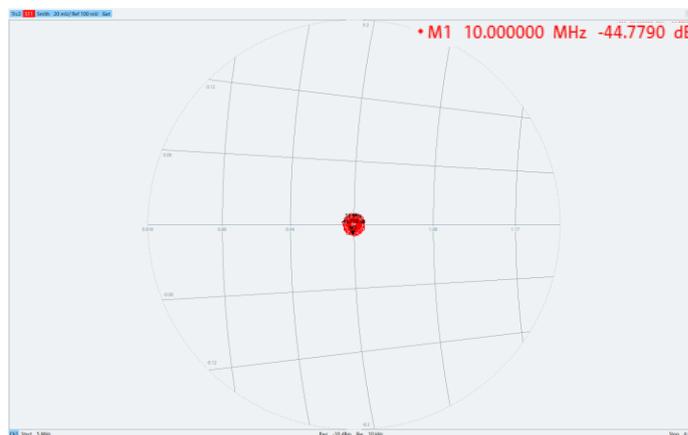


Fig.6 Measurement results in the frequency domain with active time gate. DUT of Fig. 1 with matched load at the end of the long cable

3 Theory

Each linear and time invariant network can alternatively be represented in the time domain by its impulse response $h(t)$ or in the frequency domain by its transfer function $H(f)$. The relation between the two forms of representation is given by the Fourier Transform as follows:

$$h(f) := \int_{-\infty}^{\infty} h(t) \cdot e^{-j \cdot 2\pi \cdot f \cdot t} df \quad (1)$$

Via Fourier transform, the impulse response is transformed to the spectral representation of the network in the frequency domain. The other way round, the data measured in the frequency domain by the network analyzer can be transformed to the time domain using Inverse Fourier Transform.

$$h(t) := \int_{-\infty}^{\infty} H(f) \cdot e^{j \cdot 2\pi \cdot f \cdot t} df \quad (2)$$

The step response can be obtained by integration of the impulse response $h(t)$. Fig. 7 shows the step response for the DUT in Fig. 1.



Fig. 7 Step response

This form of representation clearly shows the variation of the impedance along the DUT. The zero line in the middle of the diagram indicates zero reflection, thus representing the reference impedance Z_0 . Positive values stand for higher impedances than the reference impedance ($Z > Z_0$) and negative values for lower impedances ($Z < Z_0$). In general, the relationship between the measured reflection coefficient S_{11} and the impedance Z is as follows:

$$S_{11} := \frac{Z - Z_0}{Z + Z_0} \quad (3)$$

The operation sequence for the desired representation in the time domain is

TRACE CONFIG: TIME DOMAIN

In the menu one can select between the types Band Pass Impulse, Low Pass Impulse and Low Pass Step response.

3.1 IMPULSE AND STEP RESPONSES

As already mentioned in the previous section, the impulse response and step response offer different advantages for the representation measurement results in the time domain. Mathematically, these two forms of representation are equivalent. They can be converted into each other by differentiation or integration. Historically, the step response offers technical advantages since it is easier to generate a single steep edge, i.e. a voltage step than two voltage steps one after the other within a very short time interval, i.e. a voltage impulse. This advantage, however, is superseded by the possibility to measure the transfer function of the DUT first in the frequency domain and to transform it then to the time domain in quasi- real-time. The effort required for the numerical calculation of the two forms of representation is about the same.

It is recommended to use the step response if the impedance characteristics of the DUT are of interest. The impulse response, however, should be made use of in the most of other cases, especially for the determination of discontinuities. A further advantage of the impulse response is that in contrast to the step response its magnitude can always be sense fully interpreted even if bandpass mode is used. This will be further dealt with in section 3.4 Bandpass and Lowpass Mode.

The following diagrams (Figs 8 to 11) are examples of the impulse and step responses of typical DUTs (starting with an open, via different resistive loads till a short circuit). In each diagram, the impulse response is displayed in the upper part and the step response in the lower part with the same scaling.

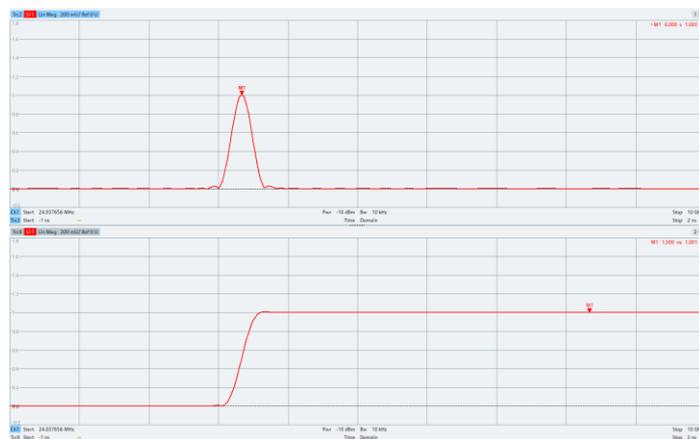


Fig. 8 Impulse and step response of an open (LOWPASS DC S-PARAM = 1)

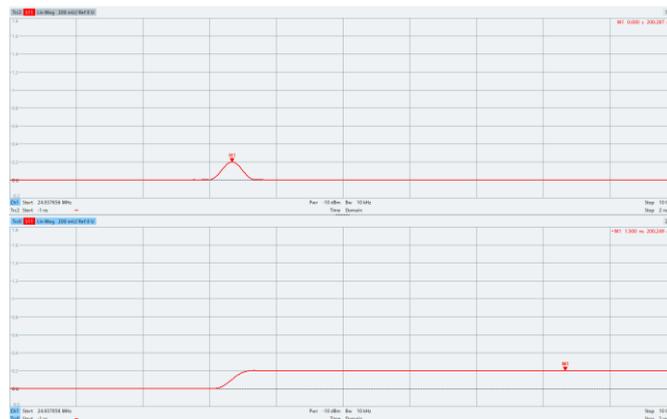
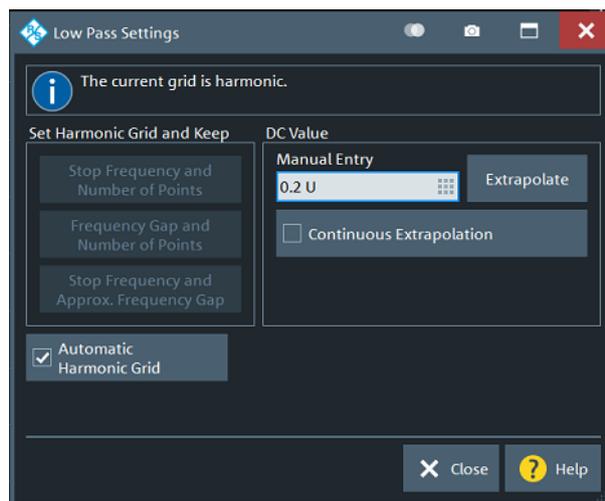


Fig. 9 Impulse and step response of a 75 Ω resistor
(LOWPASS DC S-PARAM = 0.2)

The lowpass mode (see section 3.4) was used in all figures. For a correct representation of the step response in the lowpass mode the DC- value of the displayed S-parameter is of importance. This value can be entered using the following sequence:

TRACE CONFIG: TIME DOMAIN: LOW PASS SETTINGS: DC VALUE "0,2 U"



For further details refer to section 3.4 "Bandpass and Low Pass mode".

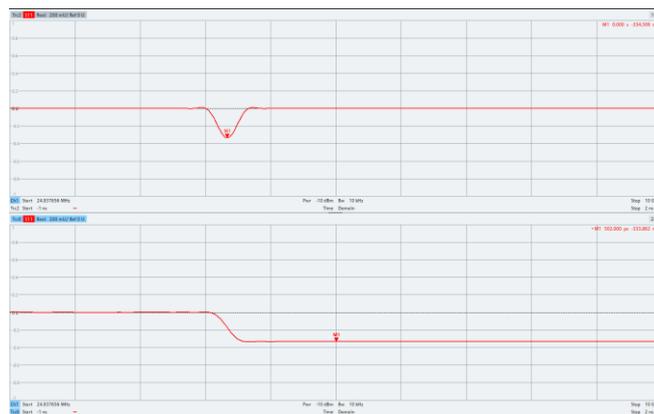


Fig. 10 Impulse and step response of a 25 Ω resistor
(LOWPASS DC S-PARAM = -1/3)

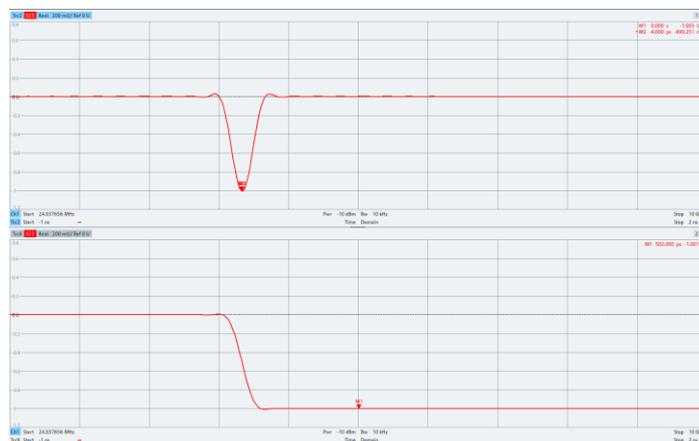


Fig. 11 Impulse and step response of a short
(LOWPASS DC S-PARAM = -1)

The impulse and step response characteristics of complex impedances are highly interesting. The measurement results shown in the following diagrams (Figs 12 to 17) were obtained with single inductors and capacitors grounded at one end (Figs 12 and 13), and with the series (Figs 14 and 15) or parallel connection (Figs 16 and 17) of an inductor or a capacitor respectively with a 50 Ω resistor.

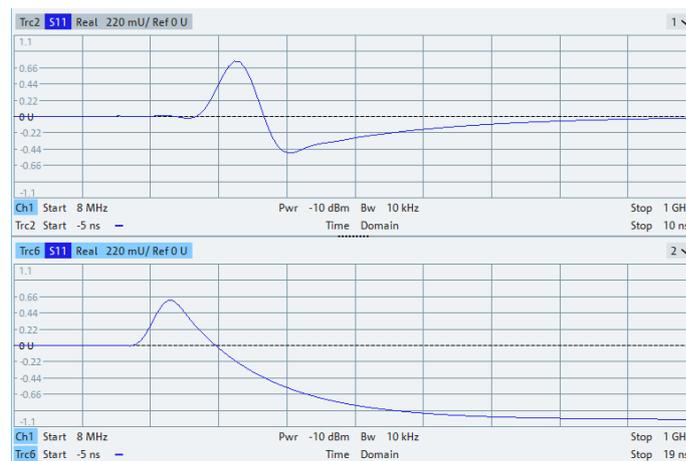


Fig. 12 Impulse and step response of a 150 nH inductor
(LOWPASS DC S-PARAM = -0.97)

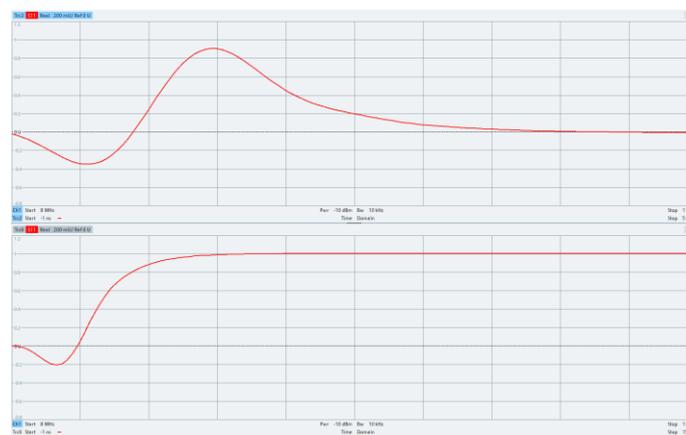


Fig. 13 Impulse and step response of a 15 pF capacitor
(LOWPASS DC S-PARAM = 1)

For a qualitative interpretation of the measured responses it is useful to first illustrate the step response: at the very beginning of a step only the high-frequency behavior of the DUT affects the step response due to the steepness of the step. Thus at the first moments of a step stimulus a capacitor reacts similar as a through connection, whereas an inductor first appears as an interruption.

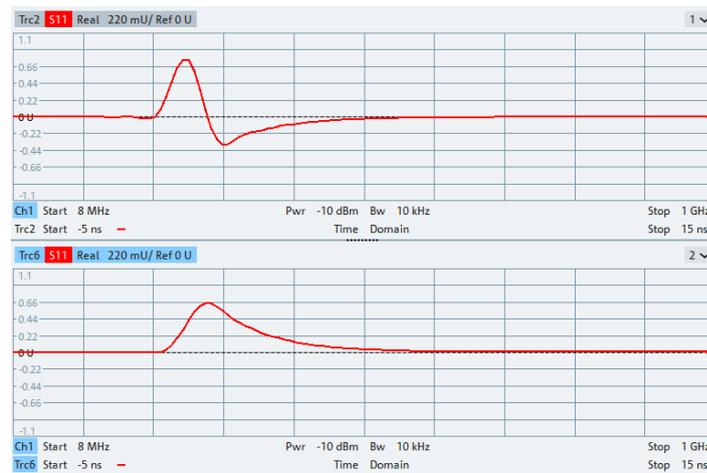


Fig. 14 Series L: Impulse and step response of series connection of a 150 nH inductor and a 50 Ω resistor (LOWPASS DC S-PARAM = 0)

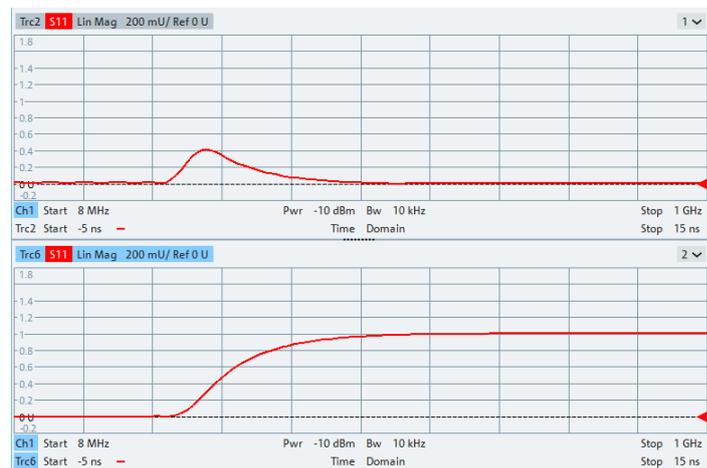


Fig. 15 Series C: Impulse and step response of series connection of a 15 pF capacitor and a 50 Ω resistor (LOWPASS DC S-PARAM = 1)

The signal components of the step response occurring later in time correspond to lower and lower frequency components down to DC. Thus only the low-frequency behavior of the DUT has an effect on the later part of the step response. A capacitor now reacts like an interruption whereas an inductor for low frequencies is similar to a direct a through connection.

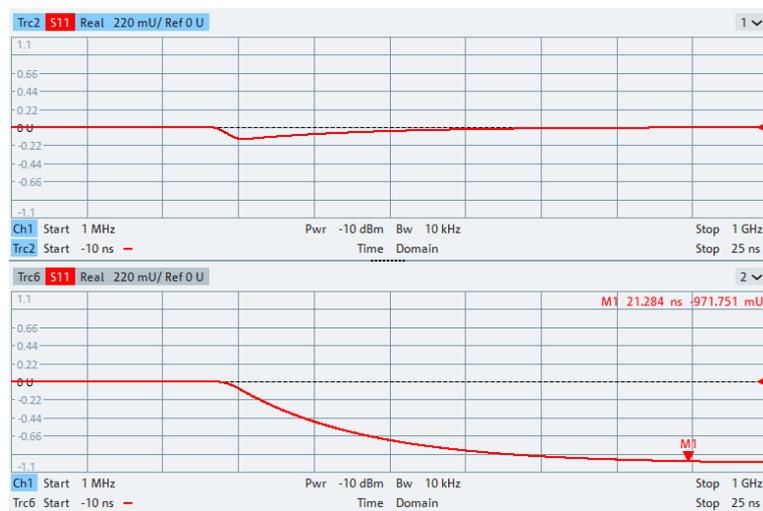


Fig. 16 Parallel L: Impulse and step response of parallel conn. of a 150 nH inductor and a 50 Ω resistor (LOWPASS DC S-PARAM = -1)

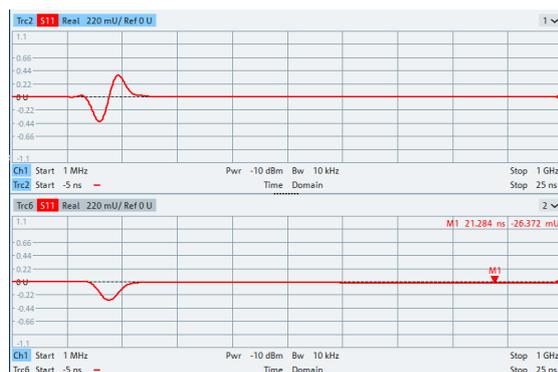


Fig. 17 Parallel C: Impulse and step response of parallel conn. of a 15 pF capacitor and a 50 Ω resistor (LOWPASS DC S-PARAM = 0)

A typical example is the previous measurement (Fig. 17 Parallel C: lower diagram). The characteristic of the measured step response can be explained as follows: first the capacitor acts as a short and is responsible for the negative edge of the step response. (Negative signal components of the step response signify low impedances.) With time, the capacitor charges up and more and more acts as an open. The parallel connection consisting of capacitor and resistor is then equivalent to a single resistor. Since the value of the resistor in the example is equal to the reference impedance ($R = Z_0$), no reflection will occur due to the matching. Thus the step response again attains zero.

The characteristic of the impulse response (Fig. 17: upper diagram) can be imagined by a differentiation of the step response. To correctly interpret the measurement results displayed in the time domain by the network analyzer note that due to

- finite span and
- frequency-discrete measurement

of the network analyzer neither ideal (Dirac) impulses nor ideal (rectangular) steps can be represented.

3.2 FINITE PULSE WIDTH

The limited span of the network analyzer widens the pulses in the time domain. Mathematically, this behavior can be explained as follows: first, an infinitely wide frequency range is assumed. Now in fact, via Fourier transform, infinitely narrow Dirac pulses can be obtained. Because of the actual finite frequency span, the frequency domain data are multiplied by a rectangular weighting function which takes the value 1 for the frequency range (e.g. 100 kHz to 4 GHz) of the network analyzer and which is otherwise zero. This multiplication in the frequency domain corresponds to a convolution of ideal Dirac pulses with a si function in the time domain.

$$si(x) := \frac{\sin(x)}{x} \quad (4)$$

The width ΔT of the si impulses is inversely proportional to the span ΔF of the frequency range:

$$\Delta T := \frac{2}{\Delta F} \quad (5)$$

For a span of, say, 4 GHz the pulse is widened to approx. 500 ps as can be observed in the following diagram (Fig. 18).

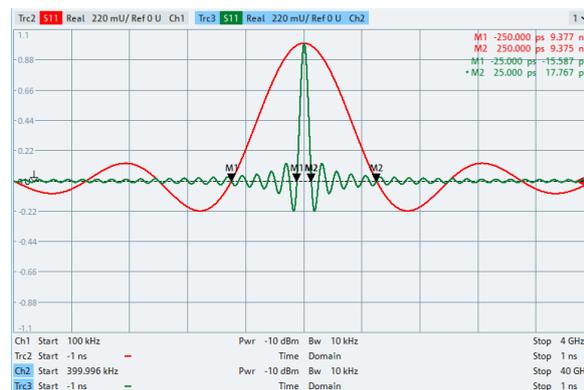


Fig. 18 Widened si impulse due to a span of $\Delta F = 4$ GHz and $\Delta F = 40$ GHz. The pulse width ΔT is approx. 500 ps and 50 ps

Besides a widened pulse, Fig. 18 shows another characteristic of si pulses which are perceived as interference in practice: i.e. the occurrence of ringing (side lobes) to the left and right of the (main) pulse. According to the si function the highest (negative) side amplitudes to the left and right of the main pulse are as follows:

$$\frac{\sin\left(3 \cdot \frac{\pi}{2}\right)}{3 \cdot \frac{\pi}{2}} = -0.212 \quad (6)$$

This corresponds to a side lobe suppression of only 13.46 dB. The side lobes can be reduced by suitable weighting methods in the frequency domain that are also called profiling or windowing. For more details see section 4.

3.3 ALIASING

The data in frequency domain are not measured continuously versus frequency but only at a finite number of discrete frequency points. This causes the time domain data after transformation to be repetitively replicated. This phenomenon is called aliasing and can be explained as follows:

The frequency discrete measurements can be assumed to be derived from an ideally continuous spectrum, which is multiplied by a comb spectrum in the frequency domain. In the time domain this corresponds to a convolution of the time response with a periodic Dirac impulse sequence. This results in the aliasing effect of a frequently repetition of the original time response. The representation in the time domain will thus become ambiguous. The time interval t between the repetitions in the time domain is called the ambiguity range. It can be calculated from the frequency step width Δf in the frequency domain as $\Delta t = 1/\Delta f$. This relationship is illustrated in the following diagram (Fig. 19).

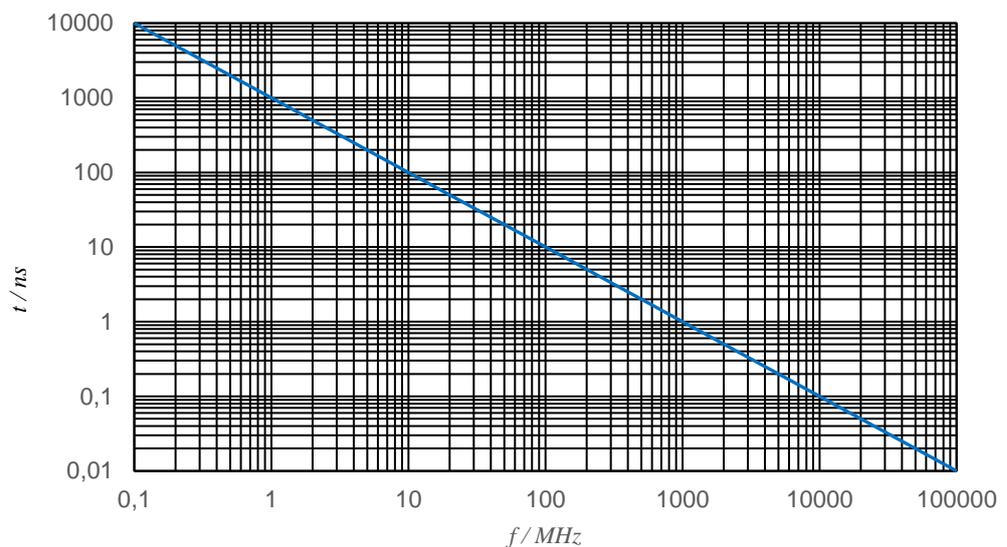


Fig. 19 Relationship between frequency step width Δf and ambiguity range Δt , or between span ΔF and width ΔT of pulses

For example, with a frequency range of 4 GHz and 400 measurement points used, the frequency step width is approximately 10 MHz. An aliasing signal such as illustrated in Fig. 20 is thus obtained every $\Delta t = 100$ ns. By the way, the previous diagram of Fig. 19 can also be used to convert for the relationship between ΔF (SPAN) described above (Eq. 5) and the resulting widening ΔT of the pulses in the time domain.

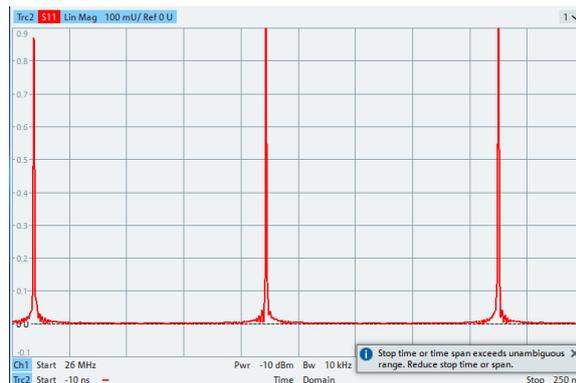


Fig. 20 Example of aliasing. The ambiguity range is $\Delta t = 100$ ns

In Fig. 20, time domain signals can only be clearly assigned within the ambiguity range of $\Delta t = 100$ ns.

If a wider ambiguity range Δt is required, the frequency points have to be arranged in a more dense frequency grid Δf . For that, either the SPAN ΔF can be reduced by which however the time domain resolution is affected, or the NUMBER OF POINTS can be increased which might reduce the measurement speed.

3.4 BANDPASS AND LOWPASS MODE

Besides the default setting bandpass mode (BANDPASS), the network analyzer also offers the lowpass mode (LOWPASS). The bandpass mode is generally used for scalar applications. It allows an arbitrary number of points and an arbitrary frequency range and it is suitable to display the magnitude of the impulse response. It does, however, not provide any information about the measured values at zero frequency, i.e. DC value, and the spectrum is limited to positive frequencies only. As a consequence, the impulse and step responses are therefore complex and their phases thus depend upon the distance between the DUT and the reference plane. This has to be considered when the real or imaginary part is displayed in the time domain. It is therefore generally not recommended to use the bandpass mode when the sign of the measured reflection coefficient is of interest. The lowpass mode is required for this purpose.

In the lowpass mode (LOWPASS), the frequency grid is arranged such that an exact extrapolation to zero frequency is possible. This is based on the condition that the step width f between the frequency points in the frequency domain is equal to the START frequency f_{START} , in other words:

$$f_{\text{START}} = \Delta f \quad (7)$$

A frequency grid meeting this requirement (7) is called a harmonic grid since the frequency value at each frequency point is an integer multiple of the START frequency. (Often, the following more general definition is used: START frequency f_{START} should be an integer multiple n of the step width f , i.e. $f_{\text{START}} = n \cdot f$. For the network analyzers of the ZNA family the more stringent definition with $n=1$ is valid. The network analyzer is able to create a harmonic grid automatically offering several options. It is important to recalibrate if the harmonic grid exceeds the calibration grid.

by using the function Automatic Harmonic Grid. For further information about this topic please refer to the HELP Menu of ZNA.

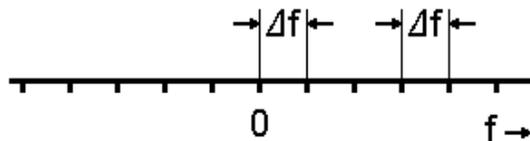
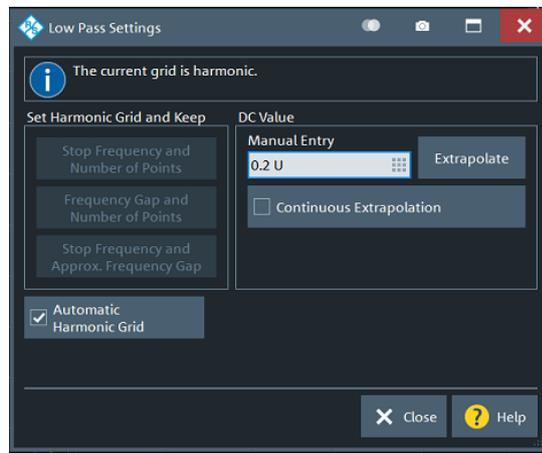


Fig. 21 Generation of the Lowpass grid

After generation of the required harmonic grid, the network analyzer is able

1. to add an additional frequency point at zero frequency (DC value) to the frequency grid and
2. to mirror the data measured at positive frequencies around zero frequency to the negative frequencies in a conjugate complex way.

In the lowpass mode the width of the frequency domain is thus doubled (see Fig. 21) and in contrast to the bandpass mode the resolution in the time domain is improved by the factor of two for the step response as well as for the impulse response. Furthermore a real time response (imaginary part = 0) is obtained. Compared to Fig. 18 the pulse in Fig. 22 is clearly narrower. The two diagrams have an identical scaling. The figure shows the width of the si pulse reduced by the factor of two which is now only 250 ps instead of 500 ps.



Fig. 22 Width of si pulse ($\Delta F = 4$ GHz) halved in lowpass mode in comparison with Fig. 18. The pulse width ΔT is now approx. 250 ps.

Besides the reduction of the pulse width the pulse in Fig. 22 has a negative amplitude in contrast to Fig. 18. Since the DUT was in both cases a shorted line ($S_{11} = -1$), the measured negative amplitude of Fig. 22 fully complies with the expectations whereas Fig. 18 needs to be afterwards explained: The reason for the apparently incorrect amplitude of Fig. 18 has already been given above. It is due to the relationship between the bandpass mode and its complex time response. In bandpass mode the phase of the time response becomes delay dependent, which corresponds to alternating amplitudes of the real and imaginary parts. The lowpass mode on the other hand provides a real time response (imaginary part = 0) and thus always the correct sign and amplitude of the reflection coefficient of the shorted line end.

4 WINDOWS

As already described in section 3.2 the pulses in the time domain are widened as a result of the limited frequency range and ringing occurs (side lobes). Especially the latter is disadvantageous for time domain measurements since fraudulent echoes may appear and the resolution as well as measurement accuracy are impaired. Suitably windowing (also called: profiling) the measured frequency domain data is a remedy. Windowing is essentially an attenuation of spectral components in the vicinity of the START and STOP frequencies. For that, the analyzer offers different windows [3] that are listed in the following table (TABLE 1).

Frequency domain Window	Time domain Gate	Filter function
NO PROFILING	STEEPEST EDGES	Rectangle
LOW FIRST SIDELOBE	STEEP EDGES	Hamming
NORMAL PROFILE	NORMAL GATE	Hann
STEEP FALLOFF	MAXIMUM FLATNESS	Bohman
ARBITRARY SIDELOBES	ARBITRARY GATE SHAPE	Dolph-Chebichev

TABLE 1 Filter functions for available windows and gates

Depending on the selected window (profile) the shape of the time domain impulses (and time domain steps) are influenced differently. This is illustrated in the following figures. In the display below, Fig. 23 shows the measured reflection of an OPEN standard directly connected to PORT 1 of the network analyzer. NO PROFILING was used in Trace1 (red). In Trace 2 (green) a profile (window) with a LOW FIRST SIDELOBE was selected. The NORMAL PROFILE recommended for general applications was used in Trace 3 (purple), and the STEEP FALLOFF (of side lobes) window in Trace 4 (black).

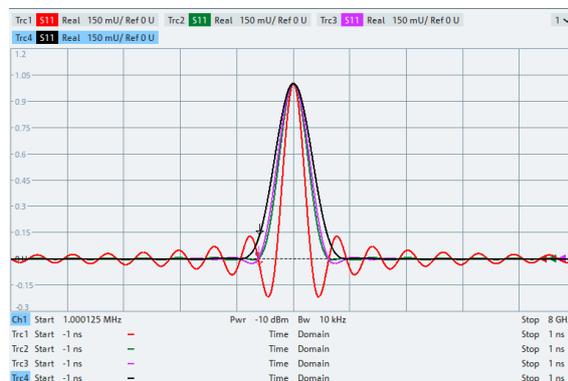


Fig. 23 Display of impulses with different windows

1. NO PROFILING (see Fig. 23 - red trace) indicates that no profiling (windowing) was used. The rectangular frequency range limitation is maintained. The impulses remain

si-shaped and have a relatively narrow main lobe but substantial side lobes. The highest side lobe is approx. 13 dB below the main lobe.

2. **LOW FIRST SIDELobe** (see fig. 23 green trace) uses the filter function according to R. W. Hamming for windowing in the frequency domain. This window yields far smaller side lobes (approx. 43 dB) than those of the rectangular window but the side lobes are hardly more attenuated even far off the main lobe. The first side lobe however is very strongly reduced. In the time domain this is indicated by a widened main lobe and clearly reduced ringing which however does not fully disappear even far from the main pulse.

3. **NORMAL PROFILE** (see fig. 23 purple trace) makes use of the filter function according to Julius von Hann. In the frequency domain it is characterized by a first side lobe of approx. 32 dB, i.e. slightly higher than the Hamming filter. The other side lobes however are attenuated more strongly. This results in a visible first side lobe in the time domain even with linear scaling, but all other side lobes further away are negligible for most applications.

4. **STEEP FALLOFF** (see fig. 23 black trace) makes use of a Bohman filter which is characterized by the steepest falloff of side lobe amplitudes of all filters used. Thus, time domain pulses with practically no side lobes are obtained. The drawback is however that the pulse width is doubled compared to the rectangular window.

5. Especially high flexibility is offered by the **ARBITRARY SIDELobES** window. A filter function according to Dolph-Chebyshev is used which is characterized by constant side lobe amplitudes both in the frequency and time domain. The user may select an arbitrary side lobe suppression between 10 dB and 120 dB. As for the other windows the same also applies here: high side lobe suppression is combined with wide main lobe and vice versa.

The effects of different windows on the shape of the time domain impulses as illustrated in Figs 23 can also be observed on the display of the network analyzer itself. To do this, for example the reflection (S11) of PORT 1 of the analyzer is measured in the time domain after connecting an OPEN standard to PORT 1. The key sequence

TRACE CONFIG: TIME DOMAIN: IMPULSE RESPPOSE

calls up the menu for defining the time domain transform. By selecting one of the five possible windows (from NO PROFILING to ARBITRARY SIDELobES) the different effects on the measured impulse or step responses can directly be observed on the display of the analyzer. Moreover, the effect of different side lobe suppressions can also be examined. The Hann filter (**NORMAL PROFILE**) is recommended for most of the general applications. It is a suitable compromise between high side lobe attenuation and relatively small main lobe widening.

5 GATES

The TIME GATE is a very powerful tool of the option Time Domain ZNA-K2. It allows to filter out components, impedance discontinuities or line faults that are spatially separated, in the time domain. Due to the different distances to the reference plane of the network analyzer the associated reflections arrive at the test port at different times and can thus be measured separately from each other in the time domain. For transmission measurements direct transmissions can be distinguished in the time domain from indirect transmissions (multipath), i.e. multi-reflected transmissions (triple transit) or signal components with different propagation speeds. These capabilities have already been mentioned in section 2 Typical Application. The real benefit of the gate function is the transformation of the impulse response of the DUT filtered in the time domain back to the frequency domain. The interesting part of the DUT can thus be displayed without unwanted discontinuities (see Figs 2 to 6).

It is important to quickly perform all required calculations so that measurement results can be displayed in virtually real time even after two Fourier transforms including time domain gating (see also section 6.2). The relationships between frequency domain and time domain described in section 4 on windowing also apply conversely between the time domain and frequency domain. During filtering in the time domain using gates it is therefore important to observe the shape of the gates besides their position and span. A rectangular gate in the time domain does not yield optimum results in the frequency domain as might have been expected. When the impulse response filtered in the time domain by a rectangular gate is transformed back, a frequency domain response is obtained which may quickly change versus frequency but whose form is falsified. This behavior is analogous to the si impulse in the time domain created by the rectangular window in the frequency domain. It has a relatively narrow main lobe with a fast cutoff rate (rapid changes can be seen) but significant side lobes (causing ripple in the frequency domain).

1. The gate with the STEEPEST EDGES is therefore recommended for use only if discontinuities that are very close to each other have to be separated. The drawback here is a falsified frequency domain response resulting from the high side lobe amplitudes (max.13 dB) of a rectangular filter spectrum which causes ripple on the trace.
2. STEEP EDGES is a filter (according to Hamming) whose side lobe amplitudes are far smaller (43 dB) but that hardly fall off further with increasing order.
3. NORMAL GATE makes use of a filter according to Hann. It is a good compromise between relatively low first side lobe (32 dB), steep falloff of further side lobes, not too wide main lobe and relatively flat passband of main lobe. It is therefore recommended for general applications.
4. MAXIMUM FLATNESS is a Bohman filter with the flattest main lobe of all filters used (nearly no passband ripple) but is also the widest main lobe. The side lobes are very low. It is suitable for use if the responses to be separated are very far from each other.
5. ARBITRARY GATE SHAPE is a Dolph-Chebyshev filter giving the same amplitude for all side lobes. The desired side lobe suppression can be chosen by the user between 10 dB and 120 dB below the main lobe. It allows individual optimization of the gate shape for especially critical measurement tasks.

6 MEASUREMENT EXAMPLE

6.1 STEPPED AIRLINE

A stepped airline comprising a section with a characteristic impedance of 25 Ω (thickened center conductor) is an especially instructive example that is often used to verify the measurement accuracy of network analyzers. Fig. 24 shows schematically a stepped airline, which is then terminated at one end with a 50 Ω matched load.

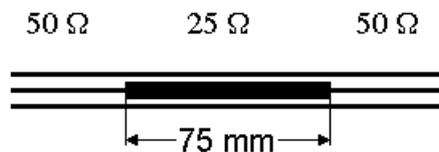


Fig. 24 Stepped airline

Impedance steps from first 50 Ω to 25 Ω and then from 25 Ω to 50 Ω cause reflections that can easily be seen in the time domain (Fig. 26). The magnitude of the reflection coefficient at the line discontinuities is 33.3% as calculated via equation (3). This corresponds to a return loss of 9.54 dB.

The impulse response is activated by

TRACE CONFIG:TIME DOMAIN: Type Low Pass Impulse

Using automatic settings for DC value and harmonic grid

TRACE CONFIG:TIME DOMAIN: Low Pass Settings...

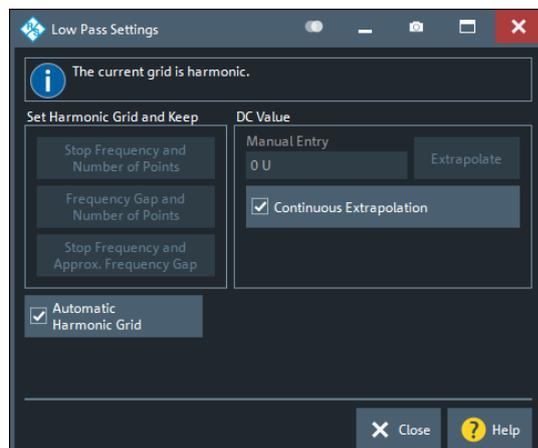


Fig. 25 Automatic selection of low pass settings

TRACE CONFIG:TIME DOMAIN: Time Domain on

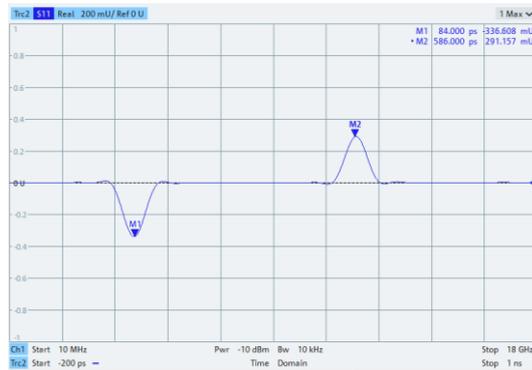


Fig. 26 Impulse response of a stepped airline

Alternatively to the impulse response, the step response can be displayed (Fig. 27). It gives a clear representation of the DUT's impedance characteristic. Selecting Impedance as parameter shows the impedance value of the line directly (Fig. 28). The measured zero of the step response can be seen in the left of the following diagram. It corresponds to the characteristic impedance of 50 Ω. The trace then falls to the value -0.33 (MARKER 3) which corresponds to the reflection coefficient expected for 25 Ω. Then, the trace slightly increases and 500 ps later (this interval corresponds to the length of the 25 Ω section of 75 mm) goes back again. A closer look at Fig. 27 reveals that the step response does not exactly return to the original value (zero) but only attains -0.04. This is partly due to the loss of energy (approx. 11%) of the transmitted step signal which is caused by the first line discontinuity. A further loss of energy is caused by the attenuation of the airline. Because of these two energy losses the amplitude of the step signal at the second impedance discontinuity (at the end of the 25 section) is smaller than at the beginning and the positive step in the amplitude is thus lower than the negative step at the beginning.

TRACE CONFIG:TIME DOMAIN: Type Low Pass Step

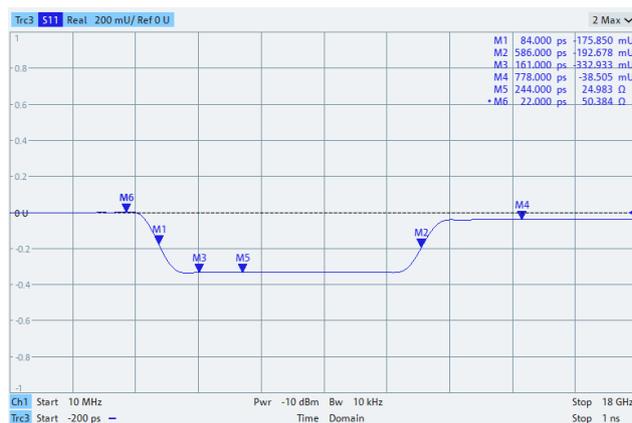


Fig. 27 Step response of stepped airline

The line attenuation can be seen within the 25 Ω section of the airline. The central section of the trace of Fig. 27 has been zoomed. This section corresponds to the 25 Ω

section of the airline and is shown in Fig. 28 with a higher resolution. The S11 parameter was converted to Z (impedance) to display the line impedance directly in Ohm (Marker 3). The Dolph-Chebichev filter (ARBITRARY SIDE-LOBES) with a side lobe suppression of 70 dB was selected as window in the time domain.

MEAS: Z<-S-Parameters: Z<-S11

TRACE CONFIG: TIME DOMAIN: Impulse Response Arbitrary Sidelobe...: Arbitrary Sidelobe: Dolph-Chebichev:

TRACE CONFIG: TIME DOMAIN: Side Lobe Level: 70 dB

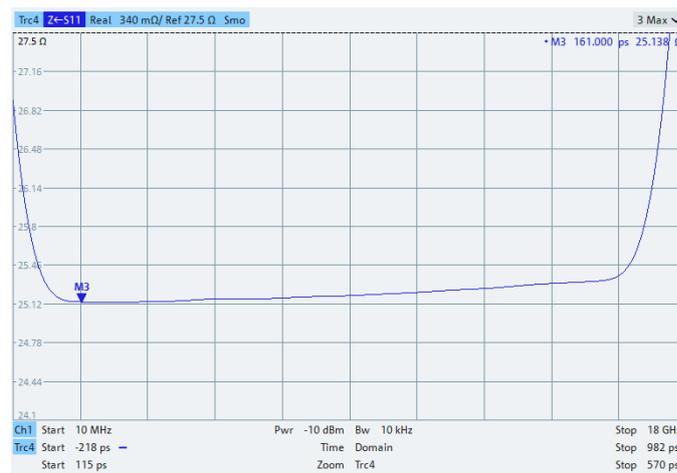


Fig. 28 Amplitude falloff of the step response due to attenuation of the airline

A smooth trace is thus obtained that corresponds to the constant attenuation of the airline. With an unsuitable window selected, an interfering ripple of the trace would be produced.

The lowpass step response is strictly recommended to display impedance versus time or distance e.g. on connectors or lines.

7 Literature

- [1] H. Marko: Methoden der Systemtheorie, Springer-Verlag, 1982.
- [2] R. Rabiner et al.: The Chirp z-transform Algorithm, IEEE Trans. on Audio and Electroacoustics, vol. AU-17, no.2, June 1969, pp. 86-92.
- [3] F. J. Harris: On the Use of Windows for Harmonic Analysis with Discrete Fourier Transform, Proc. Of the IEEE, vol. 66, no.1, Jan. 1978, pp. 51-83.

8 Ordering Information

Designation	Type	Order No.
Vector network analyzer, 2 ports, 26.5 GHz	R&S@ZNA26	1332.4500.22
Vector Network Analyzer 4 Ports 26,5 GHz	R&S@ZNA26	1332.4500.24
Vector network analyzer, 2 ports, 43.5 GHz	R&S@ZNA43	1332.4500.43
Vector Network Analyzer, 4 Ports, 43,5 GHz	R&S@ZNA43	1332.4500.44
Time domain analysis	R&S@ZNA-K2	1332.5336.02
Vector Network Analyzer, 2/4 ports 4/8/20/40 GHz	R&S@ZNB4/8/20/40	1311.6010.xx
Time Domain Analysis	R&S@ZNB-K2	1316.0156.02
Vector Network Analyzer, 4..24 Ports 8/20/26/40 GHz	R&S@ZNBT8/20/26/40	1318.xxxx.xx
Time Domain Analysis	R&S@ZNBT-K2	1318.8425.02

Appendix

Frequency domain Window	Time domain Gate	Filter function
NO PROFILING	STEEPEST EDGES	Rectangle
LOW FIRST SIDELOBE	STEEP EDGES	Hamming
NORMAL PROFILE	NORMAL GATE	Hann
STEEP FALLOFF	MAXIMUM FLATNESS	Bohman
ARBITRARY SIDELOBES	ARBITRARY GATE SHAPE	Dolph-Chebichev

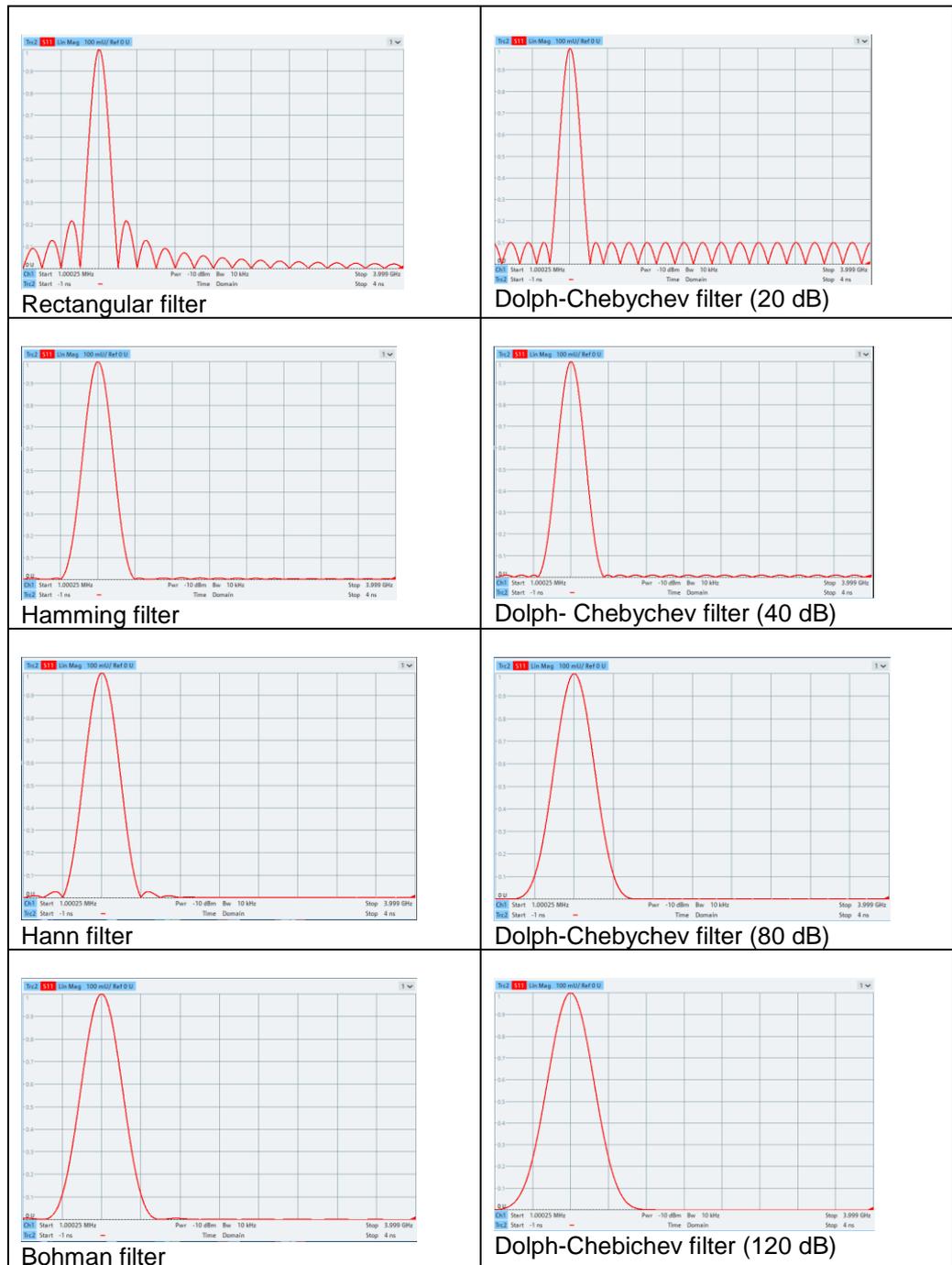
8.1 TIME DOMAIN REPRESENTATIONS

Some examples of impulse responses are given. They show the reflection of an OPEN standard directly connected to PORT 1 of the network analyzer. Different windows are used. For the filter function according to Dolph-Chebichev any side lobe suppressions between 10 dB and 120 dB can be set. Values 20 dB, 40 dB, 80 dB and 120 dB are given as an example in the Annex.

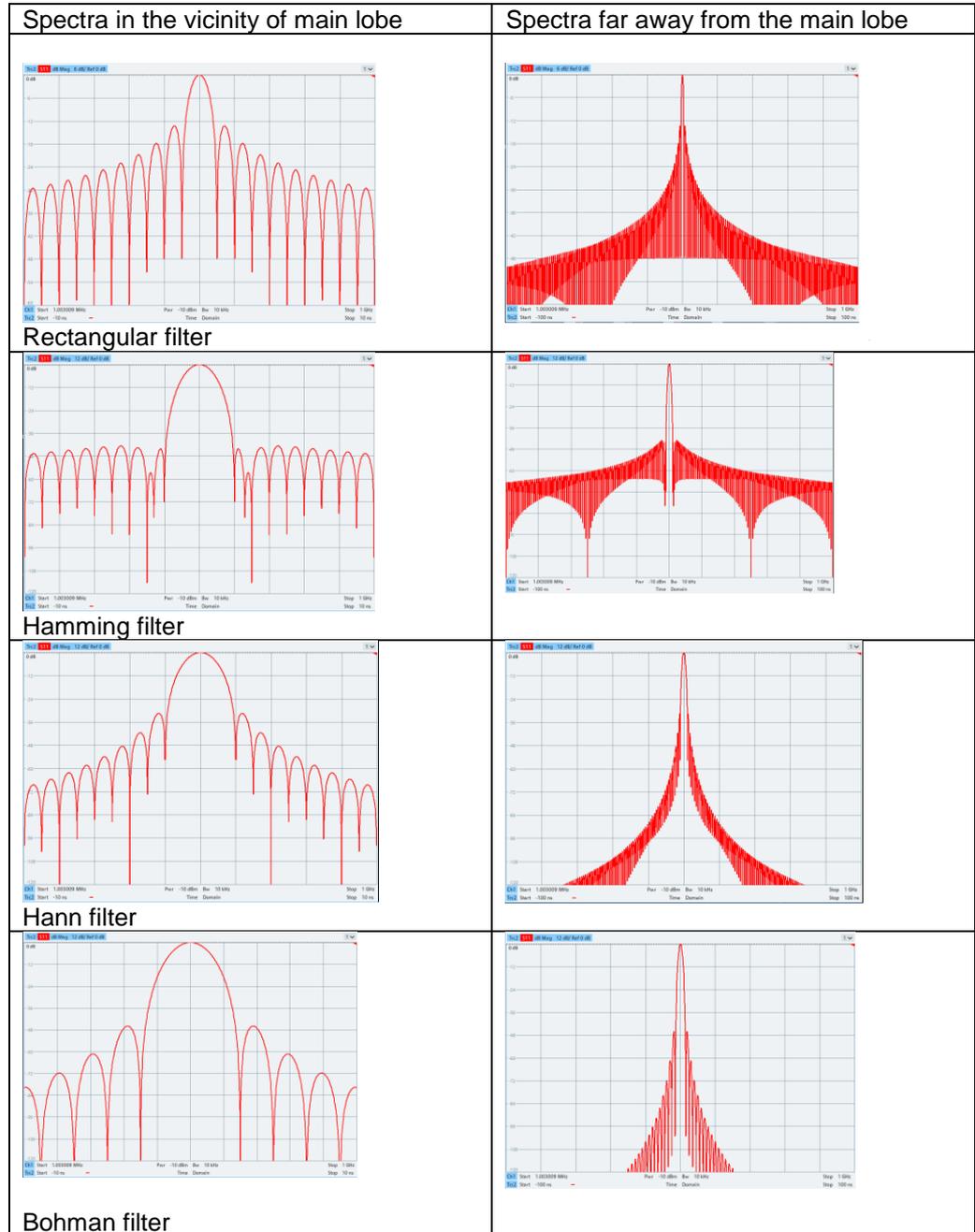
8.2 SPECTRA OF FILTER FUNCTIONS

The spectra of the available filter functions are shown. The diagrams in the left column show the spectra in the vicinity of the main lobe. The right column shows the characteristic of the spectra far from the main lobe.

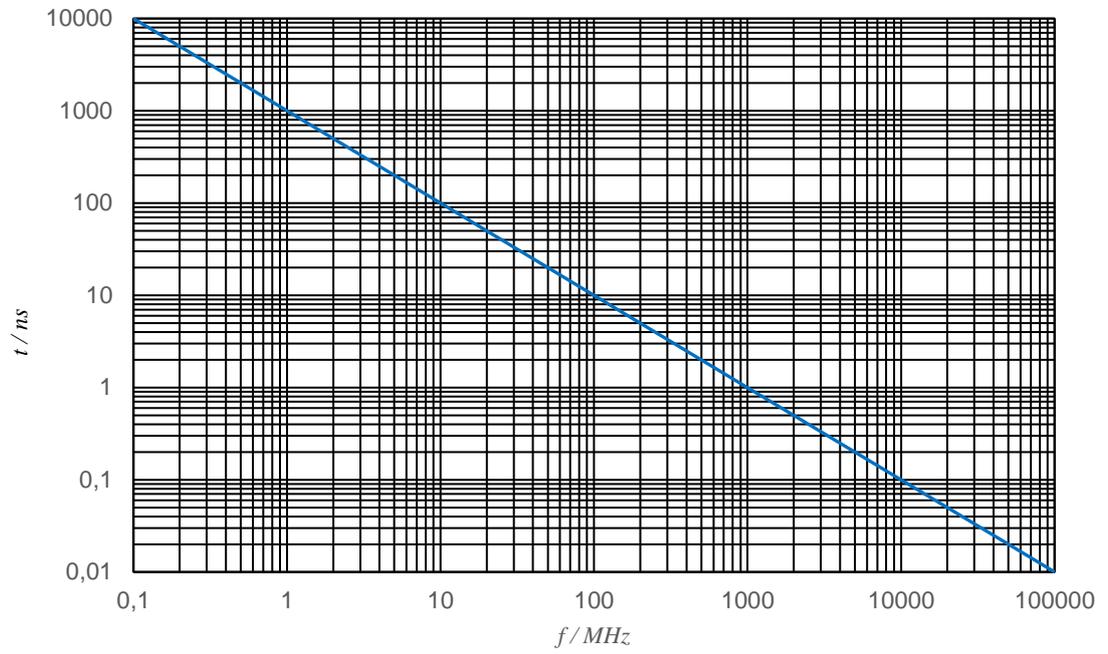
Time Domain Representations



Spectra of Filter Functions



Relation between step width and ambiguity range or between frequency span and pulse width



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