S-Parameter Measurements in the Time Domain

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Abstract. *The paper provides a basic overview of the theory of time-domain measurements. Results of the use time-domain techniques to obtain S-parameter are here presented. Advantages and disadvantages of this technique compared to frequency-domain measurements are mentioned.*

Keywords

Time domain, measurements, S-parameter, time-domain techniques.

1. Introduction

In recent years we can register an increasing demand for using wide band RF and microwave systems, for example UMTS and other broadband communication systems. Since those systems are digital and use burst transmission and reception it is also important to know their impulse response all over the frequency range of their operation together with standard microwave parameters, like S-parameter, antenna input impedance, etc. By using time-domain measurement techniques it is possible to reach the impulse response of microwave networks at the same time with S-parameter and other conventional frequency-domain parameters. Moreover, a conventional frequency-domain measurement can be excessively long for electrically large and or sophisticated antennas, phased arrays antennas and multi-beam antennas in radars. A dramatic reduction in the duration of a measurement for such antennas can be achieved by using time-domain measurement techniques [1]. Time-domain gating filtering the multiple reflections and other disturbing waveforms brings a substantial improvement in measurement accuracy. For time-domain measurements completely different measuring equipment is used than for conventional frequency-domain measurements.

2. Time-Domain Measurement Equipment

Since subnanosecond rise time pulses are used for a time-domain measurement it is necessary to use equipment that is able to generate, capture and process these short-time pulses. For time-domain measurements the following two instruments are prerequisite:

- **A pulse generator,** which should be able to generate very short time pulses with defined amplitude, pulse width and with very sharp rising and falling edges.
- **A sampling oscilloscope**, for capturing and sampling of an incoming waveform. Its sampling frequency should be as high as possible to restore the captured waveform with high accuracy. It should have at least two channels for simultaneous processing of transmitted and received waveforms. GPIB is very useful for the automation of measurements.

Beside those two basic instruments, a computer is usually unnecessary for time-domain measurements. However recent sampling oscilloscopes are already equipped with a computer and commonly used system Windows, a computer is still needed for the automation of measurement and for later processing of measured data.

3. General Principles of Time-Domain Measurements

As we have mentioned, the time-domain measurement configuration consists of three basic instruments: a pulse generator, a broadband sampling oscilloscope, and a computer. The basic configurations used for time-domain microwave measurements are shown in Fig. 1. In Fig. 1(a) free-space scattering measurements are made using two antennas, the returned transient response from scatterer being sampled and digitized. Reflection measurement may be also made as shown in Fig. 1(b), this technique is primarily used in closed transmission-line measurements. Free-space measurements, as in Fig. 1(b), are usually impracticable, since in order to obtain reasonable amplitude of the returned signal from the scatterer, the generated pulse must be several hundred volts in amplitude, and the sampling system is damaged by voltages in excess of a few volts. Devices such as directional couplers and circulators have limited capabilities for a work in the time domain.

An arrangement for transmission measurements in free space or closed lines is shown in Fig. 2(a). While for some reciprocal transmission line networks the arrangement in Fig. 2(b) may be used, especially if the network has a short-lived reflection transient response, then a measurement over a subsequent later time window will also give the response of the transmitted wave, which has traversed the network twice. In fact, the system in Fig. 2(b) can thus yield both reflection and transmission data, and it has been applied to microwave materials measurements and to networks with relatively low one-way insertion loss [2].

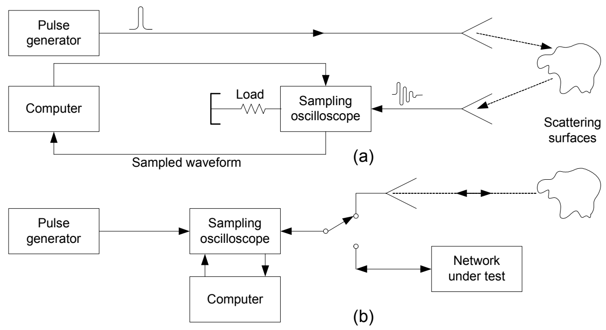

Fig. 1. Basic measurement configurations for reflection measurements.

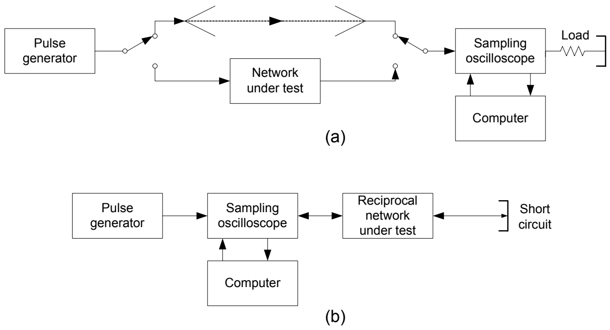

Fig. 2. Basic measurement configurations for transmission measurements.

The waveform $f_0(nT)$ captured by a sampling oscilloscope comprises N equispaced samples of the response, where N may lie usually between 64 and 1024. If the equivalent time interval between samples is T, this permits performing the discrete Fourier transform of the response

$$F_0(k\omega_0) = T\sum_{n=0}^{N-1} f_0(nT)\cdot e^{-j\frac{2\pi nk}{N}} \tag{1}$$

where $\omega_0 = 2\pi/NT$. A similar transform of the waveform of the generated pulse $f_i(nT)$ yields, by taking the ratio of corresponding frequency-domain ordinates, the value of the reflection or transmission coefficients at intervals of ω_0.

The sampling interval T must be chosen sufficiently small to sample adequately the highest frequency present in the response, and the time window NT must be sufficiently large to encompass all significant portions of the response. This produces potential errors by aliasing and truncation. It is difficult to predict these errors without full a priori knowledge of the waveform being measured and in practice it proves adequate merely to ensure visually that the most rapidly changing segments of a waveform are sampled at several points and that the window is wide enough.

4. Applications of the Time-Domain Measurement Technique

The time-domain (TD) measurement technique has been applied to measure S-parameter of a band pass filter and an automotive FM antenna to obtain parameters conventionally measured by network analyzers. The method is particularly suited to broadband networks whose impulse response is comparatively short-lived to narrowband components with long transient responses.

Although we are dealing here with microwave time-domain measurements, we have been obliged to demonstrate time-domain S-parameter measurement only in a frequency band from 0 MHz to 300 MHz because at that time we had not a suitable pulse generator to our disposal. Our pulse generator has been able to generate pulses with a minimum duration of 3.4 ns and with rising and falling edges of 2.5 ns and 3.1 ns respectively (Fig. 3-top). Its spectrum has been well uniform up to c. 300 MHz (Fig. 3-bottom). Nevertheless, for demonstration of time-domain S-parameter measurement technique it is sufficient.

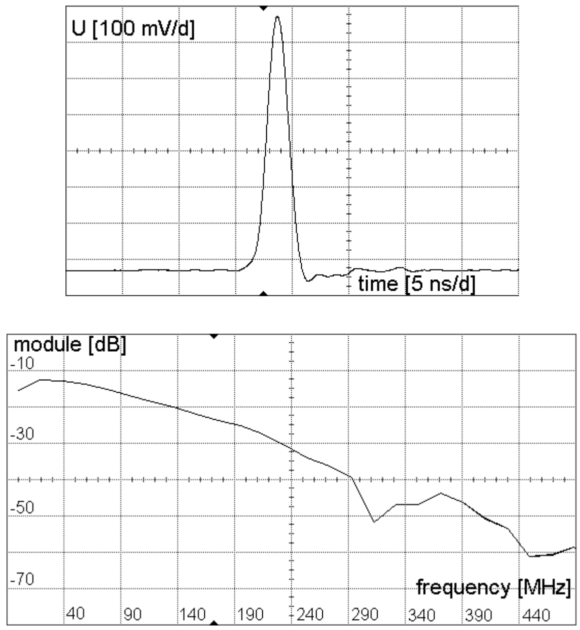

Fig. 3. The generated pulse (top) and its spectrum (bottom).

As an example of the transmission measurement in the TD a band pass filter over 0 to 300 MHz has been chosen. As an example of the reflection measurement in the TD an automotive FM antenna has been chosen.

A pulse generator produced by Systron Donner Ltd. has been used for pulse generation with properties described above. A four channel Agilent Infiniium 54853A sampling oscilloscope has been used for waveform capturing and sampling. The oscilloscope has been able to sample an incoming waveform with a speed 20 GSa/s and to perform FFT in real time simultaneously in all channels. A Hanning window function has been applied to all received waveforms.

5. A Band Pass Filter Transmission Measurement in the Time Domain

The transmission coefficient of a band pass filter with bandwidth 120 MHz has been measured in the time domain and compared with frequency domain-measurement performed on the network analyzer HP 8752A. The circuit diagram of the band pass filter is shown in Fig. 4.

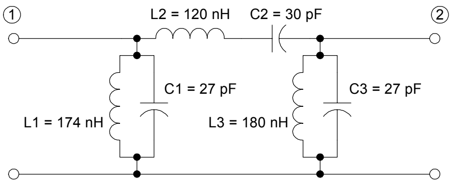

Fig. 4. The circuit diagram of the band pass filter measured in the time domain.

A pulse described above with the amplitude of 540 mV has been used as an incident pulse. Because the generated pulse has been quite unstable in amplitude an averaging over 256 measurements has been used. The measured transmission amplitude of the band pass filter in the time domain is shown in Fig. 5 together with the transmission amplitude reached in the frequency domain. Very good agreement between time and frequency domains has been reached up to c. 250 MHz. Differences between time- and frequency-domain measurements at higher frequencies are caused by decreasing signal to noise ratio and amplitude fluctuation of the generated pulse. We should also say that no calibration has been used in this time-domain transmission measurement how it is necessary in frequency domain.

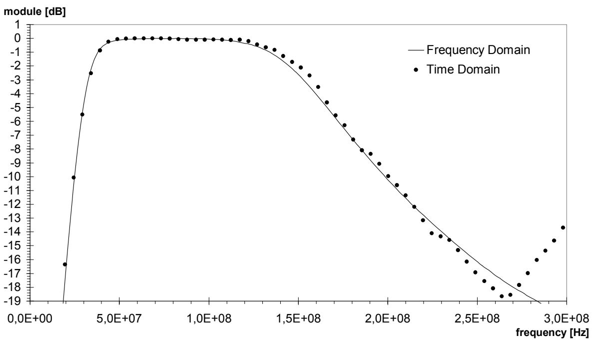

Fig. 5. The measured transmission amplitude of the band pass filter.

At the same time we got the transmission amplitude response of the band pass filter we could see the transmitted waveform (Fig. 6). This is a great advantage compared to frequency-domain measurements.

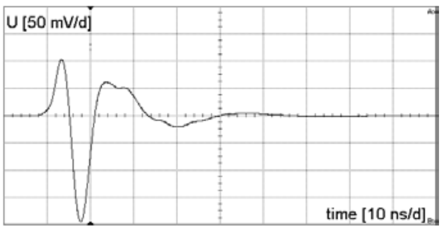

Fig. 6. The transmitted waveform.

6. FM Antenna Reflection Measurement in the Time Domain

A standard commercial FM automotive antenna for reflection measurement in the time domain has been chosen. For both measurements in the time and frequency domain (FD) the antenna has been at the same place to keep the utmost similar conditions for both measurements.

For the FM antenna reflection measurement in the time domain an arrangement shown below has been used.

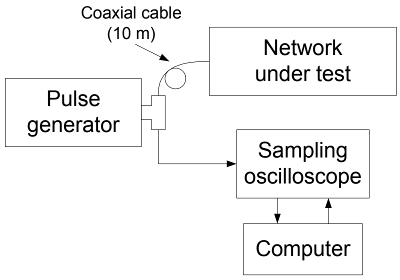

Fig. 7. The reflection measurement in the time domain arrangement.

A ten-meter coaxial cable has been used for the time separation of the generated pulse (Fig. 8(1)), the reflected pulse (Fig. 8(2)), and multiple reflections (Fig.8 (3)).

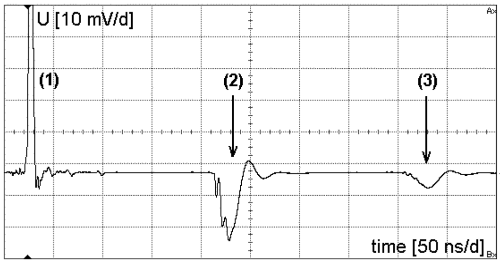

Fig. 8. Time separated waveforms (1) the generated pulse, (2) the reflected pulse, (3) multiple reflections.

The measured reflection amplitude in the time domain (dots) is shown in Fig. 9 together with the measured reflection amplitude in the frequency domain (solid line). Very good agreement between time and frequency domains has been reached up to c. 300 MHz. An antenna has two frequencies of resonance in the frequency band from 0 to 400 MHz. The first resonant frequency has been observed at 92.8 MHz in the time domain and at 92.75 MHz in the frequency domain. The second resonant frequency has been observed at 263.7 MHz in TD and 262.6 MHz in FD. It appears from this that the maximum difference between resonant frequencies measured in TD and FD is 1.1 MHz at 262.6 MHz, i. e. an error of 0.4%. This error is caused by frequency resolution in the time domain measurement and by lower signal to noise ratio at that frequency.

The measured reflection phase in the frequency band from 0 to 400 MHz is shown in Fig. 10. Up to 100 MHz the reflection phase measured in the time domain is identical with the reflected phase measured in the frequency domain. Above this frequency the difference between both measurements becomes bigger and at frequency 300 MHz this difference is already 50 degrees. Mostly the decreasing signal to noise ratio with the increasing frequency causes this error. It is the greatest disadvantage of the time-domain measurement. An improvement should be achieved by using shorter pulses with very sharp rising and falling edges and with higher amplitude.

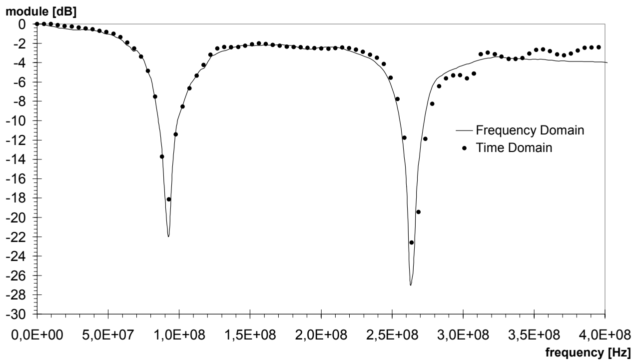

Fig. 9. The measured reflection amplitude of the automotive FM antenna.

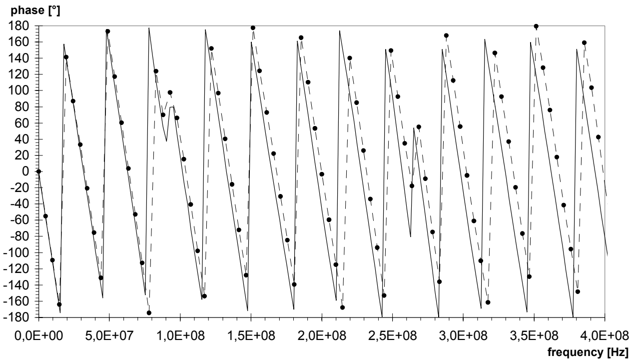

Fig. 10. The measured reflection phase of the automotive FM antenna in the time domain (dashed line with dots) and in the frequency domain (solid line).

The input impedance of the automotive FM antenna has been computed from measured values in both domains using the well-known formula [3]

$$Z_{VST} = 50\frac{1+\rho_{VST}}{1-\rho_{VST}} \quad (2)$$

where ρ_{VST} is a measured complex reflection coefficient at the input of the FM antenna.

The input impedance behavior of the FM antenna computed from measured data in the time and frequency domains is shown in Fig. 11 (real part) and in Fig. 12 (imaginary part). Both characteristics in time and frequency domains are the same in shape but they are moving away each other with the increasing frequency. This behavior is caused by a phase error as mentioned above which is 1,5% at the frequency of 400 MHz. Differences in maximum values of the input impedance are caused by frequency resolution of time-domain measurement and by used Hanning window function. However these differences are not so substantial in the wideband structures for which the time domain measurements particularly suit than in structures with narrowband behavior.

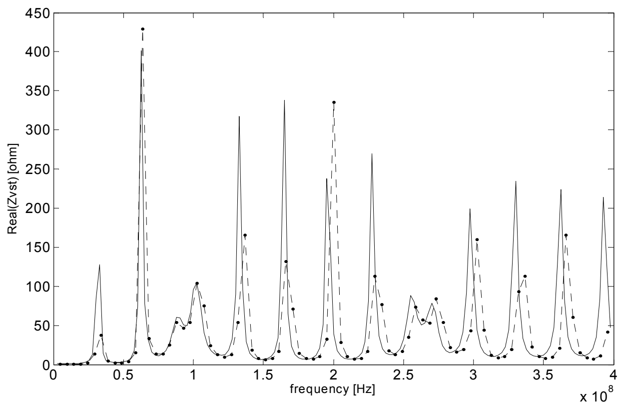

Fig. 11. The real part of the automotive FM antenna input impedance measured in the time (dashed line) and the frequency (solid line) domain.

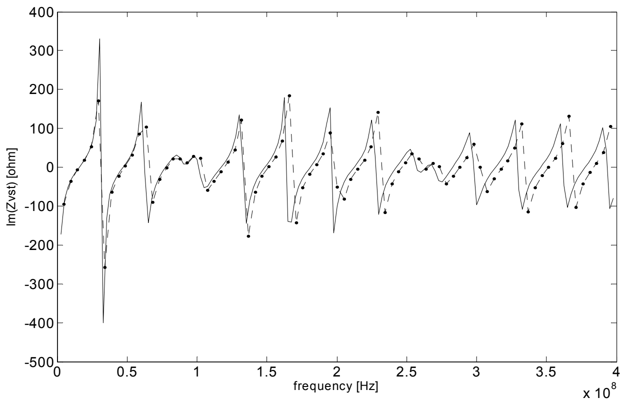

Fig. 12. The imaginary part of the automotive FM antenna input impedance measured in the time (dashed line) and the frequency (solid line) domains.

7. Conclusion

This paper illustrates an application of the time-domain techniques for common S-parameter measurements. Measurements of both reflection and transmission coefficients have been described and demonstrated. A very good agreement with frequency-domain measurement in amplitude reflection and transmission measurement has been reached. While, decreasing spectral intensity with increasing frequency caused bigger differences in phase reflection measurement, a good agreement has been reached.

The time-domain measurement technique is an alternative to frequency-domain measurements. Even nowadays when network analyzers are mostly equipped with very fast sweeping oscillators and measurements of very broadband structures take just a few seconds, the time-domain measurements technique provides several advantages that are impossible in the frequency domain. At first it is simultaneous measurement of time- and frequency-domain parameters. Then it is time-domain gating to filter multiple reflections and other disturbing waveforms. And at least it is huge time saving in the measurements of very complex antennas and near-field antenna measurements where one can observe a radiation pattern over the whole used frequency band from a single measurement.

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Roman TKADLEC was born in the Czech Republic, in 1978. In 2002 he received MS degree in Electrical Engineering from the Brno University of Technology. Since 2002 he has been a post-graduate student at the Dept. of Radio electronics, Brno University of Technology. He spent six-month stay at the Institute of Electromagnetics at Tampere University of Technology working with the time-domain measurement and dielectrics measurement. His research interests are antennas, near-field antenna measurement techniques, wireless communication, and time-domain measurement techniques.

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