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Improvement of the TDR/TDT measurement using deconvolution technique in LabView

Streszczenie. *Metoda TDR/TDT (time domain reflektometry/time domain transmission) jest jedną z najczęściej używanych metod do pomiarów parametrów linii transmisyjnych, złączy w.cz. itd. Artykuł jest przewidziany dla osób które chcą stworzyć lub udoskonalić własny system do pomiarów reflektometrycznych oparty o generator impulsowy i oscyloskop cyfrowy. W artykule opisano praktyczne zastosowanie metody dekonwolucji używanej w pomiarach TDR/TDT. Metoda ta jest używana do poprawy rozdzielczości i dokładności wyników pomiaru. Pierwsza część artykułu zawiera wprowadzenie do teorii dekonwolucji. W drugiej części przedstawiono praktyczną implementację procedury dekonwolucji z wykorzystaniem popularnego programu LabView. W końcu artykułu przedstawiono praktyczne zastosowanie opisanej procedury w rzeczywistym stanowisku do pomiarów nowego rodzaju tekstylnych linii transmisyjnych mających zastosowanie w Tekstronice. (**Poprawa parametrów metody TDR/TDT z wykorzystaniem dekonwolucji w programie LabView**)*

Abstract. *TDR/TDT (time domain reflektometry/time domain transmission) technique is one of the most common method for evaluating a transmission lines, connectors etc. The paper is intended for users who want to create or improve a TDR/TDT system based on the user-owned digital oscilloscope, pulse generator and popular LabView program. The paper presents a practical application of deconvolution technique used in TDR/TDT measurements. This technique is used to improve the overall resolution and accuracy of TDR/TDT measurement results. The first part of the paper presents a theoretical introduction to a deconvolution technique. The second part describes practical implementation of the deconvolution procedure using the popular measurement program LabView. Finally, the application of the described deconvolution procedure, in the real system for the measurement of a new type of textile transmission lines applicable in Textronics, is presented.*

Słowa kluczowe: reflektometria, linie transmisyjne, dekonwolucja
Keywords: reflektometry, transmission lines, deconvolution

Introduction

Impedance controlled interconnection device (for example: transmission line) are often characterized using Time Domain Reflectrometry (TDR). This technique and its applications are widely described in the literature, for example in [1]-[4]. The ability of TDR equipment to resolve of closely spaced impedance discontinuities in the device tested depends on the response time of the overall combination of step generator, oscilloscope sampling head and all cables, connectors etc. Minimal spatial resolution is defined by:

(1) $$l = \frac{t_r c}{2\sqrt{\varepsilon_{EF}}}$$

where: l – minimal distance between points with different characteristic impedance, t_r – rise time, c – the speed of light in vacuum, ε_{EF} – effective permittivity. To assure maximum spatial resolution overall rise time of the TDR/TDT system must be as short as possible. One of the best-known methods to improve overall rise time of the TDR/TDT system is deconvolution technique. The paper describes practical implementation of this technique using the popular measurement program LabView.

Deconvolution technique

A typical TDT measurement is shown in Fig.1. Step like excitation named U_{in} is applied to a Device Under Test (DUT) and then output response, named U_{out}, occurs. Voltage U_{out}, measured by sampling oscilloscope, depends not only on DUT properties but also on all system transmission lines, connectors between step generator and DUT or DUT and oscilloscope. To estimate TDR/TDT system performance, we need to temporarily remove the DUT and measure U_{out} without it. Then we obtain a classic deconvolution measurement situation shown in Fig.2. Similar situation can be obtained also for TDR measurement. Transmission parameter of $h(t)$ box depends on parameters of all connectors and transmission lines between generator and oscilloscope.

For the system shown in fig.2 we can obtain in time domain [6]:

(2) $$V_{out}(t) = \int_0^t V_{in}(t)h(t-\tau)d\tau \ .$$

In frequency domain we can write:

(3) $$V_{out}(\omega) = V_{in}(\omega) \cdot H(\omega) \ .$$

and from equation (3):

(4) $$H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)}$$

Fig.1 Typical TDT measurement system

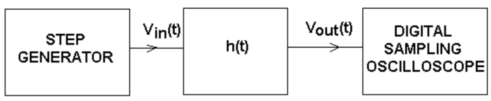

Fig.2 Typical deconvolution mesurement situation

Because, both the time domain and the frequency domain are related, Fourier transforms provide the conversions between these two domains. Especially Fast Fourier Transform (FFT) is useful to compute Discrete Fourier Transformation (DFT) for discrete data sets from digital oscilloscope. Resolving equation (4) we can estimate transmission parameter $H(\omega)$ characterizing system imperfection and next minimize the influence of measurement system imperfection using equation:

(5) $$U_{out}(\omega) = \frac{U_{mes}(\omega)}{H(\omega)} \ ,$$

where $U_{out}(\omega)$ - improved measured voltage from the DUT, $U_{mes}(\omega)$ – output voltage measured by oscilloscope.

Using inverse FFT we can obtain:

(6) $$U_{out}(t) = invFFT(U_{out}(\omega)) .$$

Conceptually the method looks to be extremely simple to implement. In practice, the big problem lies in the division operation in equation (4) and (5). When the denominator becomes very noise or very small, then the division operation result goes to infinity. In this situation, the end result is an extremely noisy or incorrect waveform. Therefore, deconvolution procedure requires the introduction of an additional filter for filtering $H(\omega)$ and $U_{out}(t)$. The following procedure doesn't contain a filter to provide the possibility to choose the most suitable type by user.

The whole minimization procedure based on the deconvolution method consists of nine steps:

- Create an ideal voltage step $V_{in}(t)$ with known rise time,
- Measure system response $V_{out}(t)$ without the DUT,
- Compute FFT of $V_{in}(t)$ and $V_{out}(t)$,
- From equation (4) compute $H(\omega)$,
- Optionally filter $H(\omega)$,
- Insert the DUT and measure $U_{mes}(t)$ voltage,
- Compute FFT of $U_{mes}(t)$ voltage,
- Compute improved voltage from equation (5).
- Filter computed voltage

The procedure described above was created in Labview. The procedure diagram is shown in fig. 3

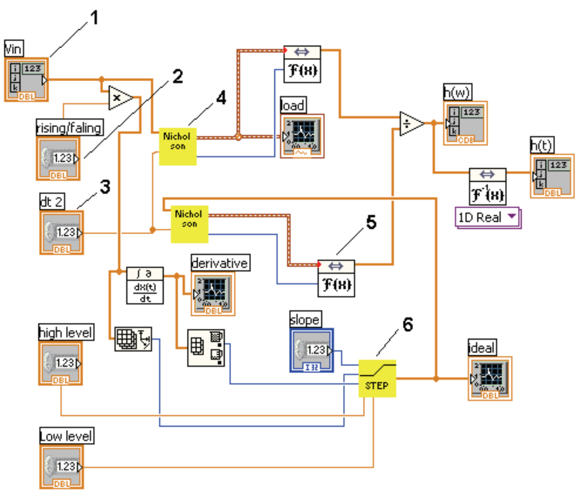

Fig.3 Deconvolution diagram written in Labview

The processed signal (The Unit Step signal) is connected to Vin control (1). The "rising/falling control" (2) enables to use two kinds of steps: rising and falling. The sample spacing dt is controlled by $dt2$ (3) control.

The Unit Step function is probably the worst case of a signal to deal with a DFT. When this data is processed by the DFT or FFT, it is converted into periodic signal. This introduces a very large truncation error at the end of the data set. This error is huge especially at high frequencies making them unusable. One of the most popular techniques to remove the step function discontinuity at the end of data set is the 'Nicolson Ramp Subtraction' [5], [8]. This involves subtracting from the step-like waveform a linear ramp whose beginning and end points match the step waveform. The final effect of operation forces the beginning and the end points down to zero. The 'Nicolson Procedure' (4) follows each FFT (5) in deconvolution procedure. The more detailed diagram of Nicolson Procedure is shown in fig.4. The "step" block (6) creates an ideal signal step with known, controlled slope, based on a high and low level of processed signal Vin. These low and high level values are usually equal to the zero and the amplitude of the generated voltage step, respectively. The more detailed diagram of "step" procedure is shown in fig.5. In this procedure to create a voltage step, Savitzky – Golay filter was used.

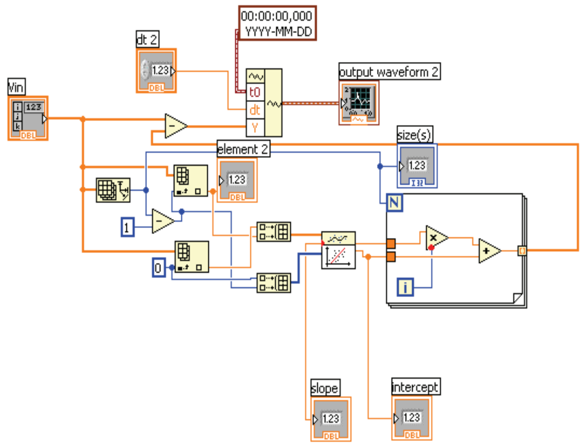

Fig.4 Diagram of Nicolson procedure

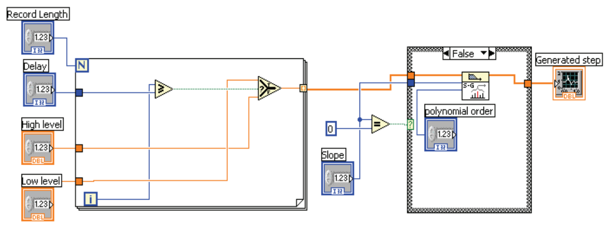

Fig.5 Diagram of ideal step procedure (6)

Example of application

The written procedure was used to improve the characteristics of our TDR/TDT system. Block diagram of the system is shown in Figure (6). It consists of a digital oscilloscope Tektronix DPO7354 and an arbitrary generator AWG7052. Signal reflected from the object under test, DUT is connected by the power divider to one of the channels of the oscilloscope. The transmission signal that passes through the DUT is measured by another oscilloscope channel. This allows both TDR and TDT measurements. It should be stressed, that the procedure described above can be used both for the TDR and TDT measurements. The author created a virtual instrument in Labview using the deconvolution procedure described above and installed it in an oscilloscope. The created, virtual instrument communicates with oscilloscope using virtual GPIB interface.

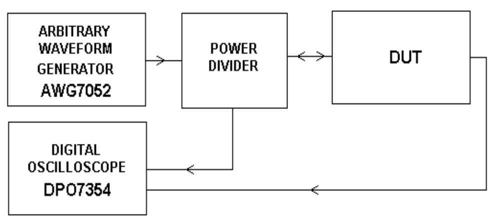

Fig. 6 Block diagram of TDR/TDT system

A simplified diagram of this virtual instrument is shown in fig.7. The processed voltage step signal passes through Nicolson and FFT procedure. On the other hand, reflected signal measured and saved earlier, (during calibration, when the DUT is replaced by ideal short) passes through the deconvolution procedure and next is optionally filtered. These two signals are connected to divider. The result of division passes through inverse FFT procedure and inverse Nicolson procedure and next is filtered.

The example results are shown in figures below. Figure (8) shows the reflected voltage waveforms when the DUT is an ideal short connected to the system by coaxial line having a length 1.2 m measured without a deconvolution procedure.

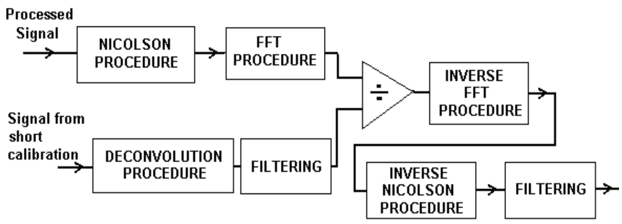

Fig. 7 Simplified LabView diagram of created virtual instrument for TDR measurement

This figure shows imperfections of the measuring system. Figure (9) shows the same step with deconvolution used but without filtering. The overall system rise time decreases significantly but signal noise increases. Figure (10) shows the processed step with deconvolution and filtering used. In example author used well known, first order Bessel filter for filtering *Uout(t)* only.

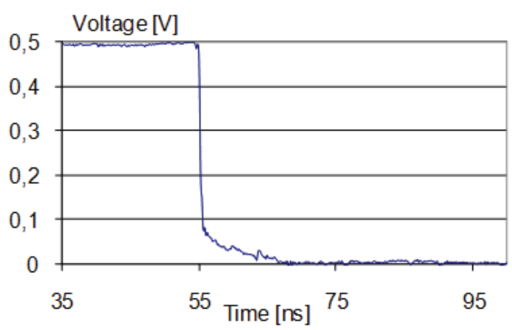

Fig. 8 Reflected voltage waveforms when the DUT is a coaxial line having a length 1.2 m shorted at the end (without deconvolution)

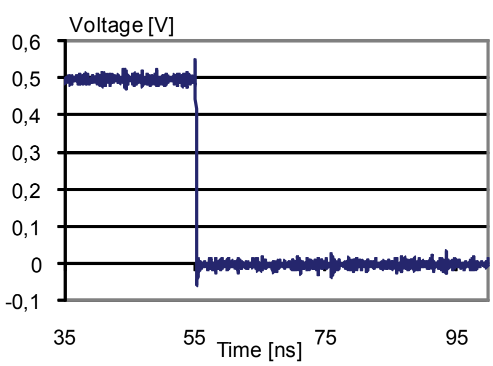

Fig.9 Reflected voltage waveforms when the DUT is a coaxial line having a length 1.2 m shorted at the end (with deconvolution)

But nevertheless, appropriate choice of filter is essential to obtain satisfactory results. In the paper [2], for filtering, the Bennia-Nahman minimum phase filter is proposed. More about proper filtering we can find also in [7]. The procedure presented can be used as a part of the virtual instrument created in LabView for TDR/TDT measurement. The TDR/TDT stand using procedure described above is presented in [9].

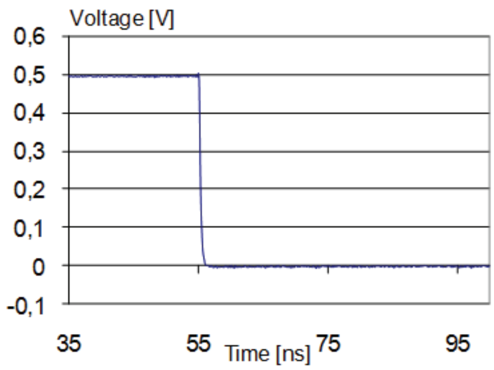

Fig.10 Reflected voltage waveforms when the DUT is a coaxial line having a length 1.2 m shorted at the end (with deconvolution and simple filtering)

Conclusion

The deconvolution procedure presented in the article significantly reduces the influence of the TDR/TDT measurement on the voltage step rise time increasing resolution of measurement. However the proper selection of the filter is crucial to obtaining satisfactory results. The procedure presented can be used as a part of the virtual instrument created in LabView for inexpensive TDR/TDT measurement.

REFERENCES

[1] Rigg P. R., Carroll J. E., Low-cost computer-based time-domain microwave network analyser, *Proc. Inst. Elec. Eng.*, 127(1980), no. 2, 107-111

[2] Nahman N. S. et all., Applications of time-domain methods to microwave measurements, *Proc. Inst. Elec. Eng.*, 127(1980), no. 2, 99-106

[3] Agilent Technologies, AN 1304-2 Time Domain Reflectometry Theory, Application Note, Literature Number 5966-4855E

[4] Agilent Technologies, AN 1304-1 Evaluating Microstrip with Time Domain Reflectometry, Application Note, Literature Number 5968-0007E

[5] Nicolson A.M., Forming the fast Fourier transform of a Step Response in Time-Domain Metrology, *Electron.Lett.*, 9(1973),317-218,

[6] Andrews J.R., Deconvolution of System Impulse Responses and Time Domain Waveforms, Picosecond Pulse Labs, Application Note AN-18, November 2004

[7] Dhaene T., Martens L., De Zutter D., Generalized Iterative Frequency Domain Deconvolution Technique, *Proc. IEEE Instrum. Meas. Techol.*, May 1993, 85–87

[8] Andrews J.R., Time Domain Spectrum Analyzer and "S" Parameter Vector Network Analyzer, Picosecond Pulse Labs, Application Note AN-16a, November 2004

[9] Leśnikowski J., Stanowisko do pomiarów wybranych parametrów elektrycznych linii transmisyjnej, *Pomiary Automatyka Kontrola*,56(2010), nr 9, 1085-1088

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