UNIVERSITI PUTRA MALAYSIA

TIME DOMAIN REFLECTOMETRY COMPUTATIONAL TECHNIQUE USING AGILENT VEE

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

October 2007

To My Family, Friends and The Beloved.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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October 2007

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This thesis describes the time domain reflectometry computational technique to locate discontinuities in transmission line using Agilent VEE version 6. The reflection coefficient measurement data were transformed from frequency domain into time domain using Fast Fourier Transform (FFT) technique. Measurements were done on waveguides and coaxial cable using HP 8720B network analyzer. The vector network analyzer (VNA) has a time domain capability where transformation from frequency to time domain data is realized using chirp *z*-transform (CZT) which can be utilized to locate short circuit discontinuities. Unfortunately, the VNA is heavy, bulky and an expensive way of simulating time domain reflectometry measurement. The frequency-to-time measurement option is not a readily built in feature but needs to be purchased before it is included in the VNA in which it comes at a higher cost for end user. Additionally, frequency-to-time measurement option of the VNA has limited capability

with only selected transformation algorithm, window and gating method. This motivates the transformation using computer software instead of VNA to transform data, thus, the development of transformation software.

All the measurements and calculations were implemented using transformation software developed using Agilent VEE version 6. The analysis on resolution was done and parameters that affects the resolution; number of points and frequency range, was analyzed. The transformation software transforms frequency domain data to time domain. The peaks in the measurement data represent discontinuity in the test components/devices. Measurements were done on combinations of well define components which includes WR-90 waveguides and RG402 coaxial cable. The performance of the transformation software was tested by comparing the results with true physical measurement of the devices. The results show that the reflection coefficient obtained from the software is in good agreement with the VNA in terms of the location of discontinuity with both VNA and transformation software having ≈5% deviation with the true physical value. The transformation software results are as reliable as the VNA. This transformation software is flexible, cheap and easy to use. It is ready to be incorporated into mobile computer and can be used with any frequency domain measurement device.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

TEKNIK PENGIRAAN PANTULAN DOMAIN MASA MENGGUNAKAN AGILENT VEE

Oleh

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Tesis ini memperihalkan tentang teknik pengiraan pantulan domain masa untuk menentukan ketidakselanjaran dalam garis pancaran menggunakan Agilent VEE versi 6. Data ukuran pekali pantulan ditukar bentuk dari domain frekuensi ke domain masa dengan menggunakan teknik Jelmaan Fourier Cepat (FFT). Pengukuran dilakukan ke atas pandugelombang dan kabel sepaksi menggunakan Penganalisis Rangkaian Vektor (VNA) HP 8720B. VNA mempunyai kebolehan pengukuran dalam domain masa untuk menentukan ketidakselanjaran dimana penukaran data dari bentuk domain frekuensi ke domain masa dilakukan dengan menggunakan algoritma Jelmaan Z Chirp (CZT). Walaubagaimanapun, VNA adalah mesin yang berat, besar dan merupakan cara yang mahal untuk mensimulasikan pengukuran teknik pantulan domain masa. Pilihan pengukuran domain frekuensi ke domain masa merupakan satu pilihan yang perlu dibeli sebelum ia disertakan bersama VNA dengan harga yang lebih mahal. Di samping itu,

pilihan ukuran domain frekuensi ke domain masa VNA adalah terhad dengan hanya mempunyai transformasi terpilih dan cara tetingkap dan pepintu tertentu sahaja. Ini memberi ilham untuk menggunakan perisian komputer untuk melakukan transformasi bagi menggantikan transformasi data menggunakan VNA.

Kesemua ukuran dan kiraan telah dilakukan dengan menggunakan perisian transformasi yang diprogram menggunakan Agilent VEE 6. Analisis resolusi telah dijalankan dan parameter yang boleh mempengaruhi resolusi; bilangan titik dan julat frekuensi, telah dikaji. Perisian transformasi berjaya menukarkan data domain frekuensi ke domain masa. Puncak dalam data pengukuran mewakili ketidakselanjaran dalam komponen/alat yang diuji. Ukuran telah dijalankan ke atas kombinasi komponen yang diketahui ciri-cirinya termasuk pandugelombang siri WR-90 dan kabel sepaksi siri RG402. Prestasi perisian transformasi telah diuji melalui perbandingan keputusan dengan ukuran fizikal sebenar komponen. Keputusan menunjukan pekali pantulan yang diperolehi dari perisian transformasi dan VNA adalah dari segi penentuan ketidakselanjaran adalah memuaskan dan kedua-dua keputusan VNA dan perisian transformasi mempunyai pembezaan sebanyak ≈ 5 % dengan nilai fizikal sebenar. Keputusan perisian transformasi adalah setanding VNA. Perisian transformasi ini boleh diubah, murah dan mudah untuk digunakan. Ia juga sedia digunakan bersama komputer mudah alih atau sebarang alat ukuran domain frekuensi.

ACKNOWLEDGEMENTS

Alhamdulillah, many thanks and praises be with God Almighty for all the blessings rained upon this life.

My greatest thanks to Dr. Zulkifly Abbas whose kind enough to provide supervision until the completion of this thesis. Thank you for your supervision, guidance and words of wisdom.

To my parents, Mohamed Dan b. Jantan and Amelia Yow bt. Abdullah, whom I cannot live without; it’s never too old to learn something new. My deepest gratitude for everything.

My warm wishes and thanks to the members of Electromagnetic Lab and friends in UPM, thank you for your help and support. This journey would’ve been down the boredom road if it wasn’t for you guys.

Lastly, to the beloved; you gave me courage, you brought me happiness, you brought sorrows I never imagine I could feel but you also pour me your love and brighten the night skies with your stars. Even if we could never be together, you are always in a special place deep inside this wretched heart. A thousand thank you won’t do justice, but it’s the only thing I could offer; thank you.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NUR SHARIZAN MOHAMED DAN

Date: 6 November 2007

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LIST OF ABBREVIATIONS

α	attenuation constant in radians per unit length
β	phase constant in radians per unit length
c	velocity of light
D	length
Δf	the spacing between frequency data points
ε_r	dielectric constant.
E_{in} or E_i	incident voltage
E_r	reflected voltage
γ	complex propagation constant
I_{in}	incident current
Γ	reflection coefficient
$\lvert\Gamma\rvert$	magnitude reflection coefficient
t	two-trip time
v_f	velocity factor
v_p	velocity of propagation
ω	angular velocity in radians per second
C	capacitance
G	admittance
L	inductance
R	resistance
T	transit time from monitoring point to the mismatch and back again
Z_{in}	input impedance

Z_o	characteristic impedance
Z_L	load impedance
ADC	Analog-to-Digital Converter
Agilent VEE	Agilent Visual Engineering Environment
CZT	Chirp z-transform
DC	Direct Current
DFT	Discrete Fast Fourier Transform
FDR	Frequency Domain Reflectometry
FFT	Fast Fourier Transform
HPIB	Hewlett-Packard5 Interface Bus
IFFT	Inverse Fast Fourier Transform
MATLAB	Matrix Laboratory
RF	Radio Frequency
SNR	Signal-to-Noise Ratio
SWR	Standing Wave Ratio
TDR	Time Domain Reflectometry
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio

CHAPTER 1

INTRODUCTION

Time Domain Reflectometry (TDR) is a remote sensing electrical measurement technique that is nondestructive and has been used for many years to determine the spatial location and nature of various objects. It is utilized to determine the characteristics of transmission lines by observing reflected waveforms. It is an extension of an earlier technique in which reflections from an electrical pulse were monitored to locate faults/discontinuities and to determine the characteristics of power transmission lines.

An early form of TDR that most people are familiar with is radar and was largely developed as the result of World War II radar research. However, there is a lacked in necessary instrumentation to make full use of TDR. With the advent of commercial TDR research oscilloscopes in the early 1960's, it became feasible to test this new technology. Today, TDR technology is the "cutting edge" methodology for many diverse applications.

1.1 An Overview of the Determination of Material Discontinuities

Material discontinuity is defined as the tangible substance that goes into the makeup of a physical object lacking in connection or continuity. Translating it into a more physical term, it is the difference in impedance which causes a mismatch in connectivity or continuity of the material or object under test or of measurement. In the following subtopics the issue pertaining material discontinuities, its application and technology is discussed.

Material discontinuity can take into many forms in the world of science and technology. It is the change in electrical properties of a substance, the impedance difference or mismatch in a material or simply a disconnected electrical wire or a change of chemical property in a pure alloy.

In technological point of view, this can be applied to engineering, geographical and even agricultural industry. For example, in engineering field, this analogy applies to fault locating technique where faults in cable, cracks in pipes, walls of building and even roads need to be detected to prevent further damage. In geographical field, the study of terrain, archeological excavation and even vegetation area has a need in recognition technique. For the agriculture industry, there is a need for moisture content measurement for soil and even rubber milk. For a noninvasive and nondestructive testing technique, the microwave method can be applied.

1.1.1 Technology and Application in Determination of Material Discontinuities

The TDR is widely used for its accuracy and is one of the many nondestructive testing for locating fault. It transmits a fast rise time pulse along the conductor. If the conductor is of uniform impedance and properly terminated, the entire transmitted pulse will be absorbed in the far-end termination and no signal will be reflected back to the TDR. However, where impedance discontinuities exist, each discontinuity will create an echo that is reflected back to the reflectometer (hence the name). Increases in the impedance create an echo that reinforces the original pulse while decreases in the impedance create an echo that opposes the original pulse. The resulting reflected pulse measured at the output/input to the TDR is displayed or plotted as a function of time and, since the speed of signal propagation is relatively constant for a given transmission medium, can be read as a function of cable length. This is similar in principle to radar.

Because of this sensitivity to impedance variations, a TDR is often used to verify cable impedance characteristics, splice and connector locations and associated losses, and estimate cable lengths, as every nonhomogenity in the impedance of the cable will reflect some signal back in the form of echoes.

The TDR techniques have been utilized in many fields. It is used to determine soil moisture water content in porous media, where over the last two decades substantial advances have been made; including in soils, grains and food stuffs, and in sediments. The key to TDR's success is its ability to accurately determine the permittivity (dielectric constant) of a material from wave propagation, and the fact that there is a strong relationship between the permittivity of a material and its water content.

TDR has also been utilized to monitor slope movement in a variety of geotechnical settings including highway cuts, rail beds, and open pit mines. In stability monitoring applications using TDR, a coaxial cable is installed in a vertical borehole passing through the region of concern. The electrical impedance at any point along a coaxial cable changes with deformation of the insulator between the conductors. A brittle grout surrounds the cable to translate earth movement into an abrupt cable deformation that shows up as a detectable peak in the reflectance trace.

TDR equipment are commonly used for in-place testing of very long cable runs, where it is impractical to dig up or remove what may be a kilometers-long cable. They are indispensable for preventive maintenance of telecommunication lines, as they can reveal growing resistance levels on joints and connectors as they corrode, and increasing insulation leakage as it degrades and absorbs moisture long before either leads to catastrophic failures. Using a TDR, it is possible to pinpoint a fault to within feet or inches.

In labs and research centers, TDR technique is incorporated in measurement equipment called ‘Vector Network Analyzer’ (VNA). It makes measurement by sweeping frequencies over a device under test (DUT) and transforms it into time domain using the time domain option available in the equipment.