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Project Title: Specialized Research Equipment: Time Domain Measurement Facility

Project No: E-21-611

Project Director: Dr. Glenn S. Smith

Sponsor: National Science Foundation

Agreement Period: From 9/1/77 Until 2/28/79
(12-month budget period plus 6-month flexibility period)

Type Agreement: Grant No. ENG77-17200

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Reports Required: Final Technical Report; Summary of Completed Project

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Defense Priority Rating: N/A

Assigned to: Electrical Engineering (School/Laboratory)

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CA-3 (3/76)
GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT TERMINATION

Date: May 23, 1979

Project Title: Specialized Research Equipment: Time Domain Measurement Facility

Project No: E-21-611

Project Director: Dr. Glenn Smith

Sponsor: National Science Foundation

Effective Termination Date: 2/28/79 (Grant Expiration)

Clearance of Accounting Charges: 2/28/79

Grant/Contract Closeout Actions Remaining:

- Final Invoice and Closing Documents
- Final Fiscal X Accounting (FCTR)
- Final Report of Inventions
- Govt. Property Inventory & Related Certificate
- Classified Material Certificate
- Other

Assigned to: Electrical Engineering (School/Laboratory)

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Other

CA-4 (3/76)
SPECIALIZED RESEARCH EQUIPMENT:
TIME DOMAIN MEASUREMENT
FACILITY

by

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Final Technical Report
National Science Foundation Grant
ENG77-17200

May 1979
ABSTRACT

This grant provided the instrumentation for making electromagnetic measurements in the time domain. The system assembled includes a sampling oscilloscope, signal processor/controller and peripheral display devices for acquiring, storing, and analyzing repetitive electromagnetic signals with a fast rise time.

The waveforms acquired by the system can be analyzed directly in the time domain to provide information about the characteristics of the device under test or the electromagnetic phenomenon being observed. In addition, a Fourier transform can be performed on the waveforms, with the aid of the processor, to provide information in the frequency domain. Since the signals with a fast rise time have significant spectral content over several octaves of frequency, they can be used in a single measurement to characterize a device over a large bandwidth.

The equipment is currently being used to perform measurements in support of on-going research. These include, the measurement of the input admittance of scale model antennas over a broad band of frequencies and the measurement of the constitutive parameters of materials using monopole probes.
I. INTRODUCTION

The Research Equipment Grant from the National Science Foundation with additional funds from the Georgia Institute of Technology provided the School of Electrical Engineering with instrumentation for making electromagnetic measurements in the time domain.

Electromagnetic measurements in the time domain utilize transient signals with fast transition times, such as approximations to ideal impulses or steps, to determine the characteristics of a system. With reference to Figure 1, a stimulus \( v_i(t) \) is incident on the system to be studied and a response \( v_t(t) \) is measured. The transient signals \( v_i(t) \) and \( v_t(t) \) may be analyzed directly in the time domain to characterize the system, or, for linear systems, the Fourier transform of the signals \( (v_i(t) \leftrightarrow V_i(\omega)) \), etc.) may be used to obtain the characteristics of the system over a broad frequency range. For example, a system function \( H(\omega) = V_t(\omega)/V_i(\omega) \) may be obtained from the transformed waveforms.

The transient signals used for this type of measurement have rise times as small as 20-30 ps \((20 \times 30 \times 10^{-12} \text{ s})\). The rise time of a single waveform is too fast to be measured in real time with conventional instrumentation (oscilloscopes). To construct a facsimile of the waveform, a repetitive signal composed of several individual waveforms is used. Samples taken from each waveform in the repetitive signal are then used to construct the facsimile of the waveform (sampling oscilloscope). The sampled waveforms are processed on a computer and the desired characteristics of the system being tested are extracted by using appropriate algorithms. In a broad sense, the time-domain measurement system can be divided into two
components: an electromagnetic experiment comprised of the system under
test and the transient signals, and the instrumentation for processing
the sampled signals.
1. Perform a direct analysis of the acquired signals in the time domain to characterize the system.

2. Fourier transform the signals to obtain the characteristics of the system over a broad frequency range.

   \[
   \text{Ex: } V_i(t) \leftrightarrow V_i(w), \quad V_t(t) \leftrightarrow V_t(w)
   \]

   \[
   H(w) = \frac{V_t(w)}{V_i(w)}
   \]

Figure 1. Basic Approach to the Measurement
II. Description of Equipment Purchased

The elements of the time-domain measurement system are shown in a typical experimental arrangement in Figure 2. The pulse generator, transmission lines, system under test and sampler form the electromagnetic portion of the experiment. The fast rise-time pulses are confined to these elements.

After a waveform is acquired by the sampler, it is displayed on the oscilloscope and digitized and stored in the oscilloscope mainframe (digital processing oscilloscope). The digitized waveform is then passed to a controller/minicomputer where the signal processing is performed. A floppy disc is used for permanent storage of the processed waveforms or computer algorithms. Permanent records of the waveforms are made with a hard-copy unit.

A detailed list of the equipment purchased with funds from the National Science Foundation grant and additional matching funds from Georgia Institute of Technology is given in Table I.
Figure 2. Elements of a Time-Domain Measurement System
Table I

List of Equipment Purchased

Signal Processing Equipment

Tektronix WP 1200 System

Including:

7704A Oscilloscope Mainframe
P7001 Processor
CP4165 Controller
CP112 Dual Floppy Disc File
SPS Basic Software

Display Equipment

Tektronix 4010-1D Display Terminal
Tektronix 4631 Hard-Copy Unit

Sampling Oscilloscope Components

Tektronix Components
7S12 Sampler
S-4 Sampling Head
S-6 Sampling Head
S-52 Pulse Generator
S-53 Trigger Recognizer
7M11 Delay Line
012-0124-00 Sampling Head Extenders (2)
Pulse Generators

IKOR Model R-100 IMP Generator
Avtech Model AVH-S Pulse Generator

Miscellaneous Electronic Equipment

Tektronix TM 500 Units (to trigger, power and monitor pulse generators)
PG501 Pulse Generator
PS503A Power Supply
TM504 Power Module
040-0303-01 Plug-in Kit
DM501 Multimeter

Coaxial Components

Hewlett Packard, Precision APC-7 Connectors and Components
Weinschel Engineering, Precision APC-7 Components
Sealectro Corp., SMA Connectors and Components
Omi Spectra, SMA Connectors and Components

Miscellaneous

Beacon Electronic Cabinet
III. Use of Equipment

The equipment assembled for the time domain measurement facility is currently being used in the following research projects.

1. **Dielectric Spectroscopy Using Probes**
   Investigators: G. S. Smith and J. D. Nordgard

   The electrical properties of linear materials can be determined over a broad range of frequencies by analyzing the Fourier transform of a transient signal that interacts with the material. A conventional approach to this measurement is to fit a sample of the material to be measured into a coaxial transmission line and monitor the transient signals made incident on and reflected from the sample.

   A drawback of this method is that it requires the shape of the sample to conform to that of the coaxial sample holder. This requires the sample to be machined or cut to precise dimensions and prevents an in situ measurement. This may be a severe restriction for some materials, like biological tissue, where the cutting may destroy the sample.

   A different approach to the time-domain measurement of the constitutive parameters of a linear non-magnetic material is being investigated in this research. An open structure, the short monopole, is being used to make an in situ measurement on a material with only minor modification of the sample. The signals incident on and reflected from the terminals of the probe are being analyzed to determine the scattering coefficient $S_{11}$, or, equivalently, the input admittance $Y$ of the probe as a function of the frequency. The problem is then one of using an algorithm to extract
the effective conductivity $\sigma_e$ and permittivity $\varepsilon_e$ of the material from
the measured admittance. Symbolically,

$$\sigma_e(\omega) = S(Y(\omega))$$

$$\varepsilon_e(\omega) = E(Y(\omega)),$$

and the problem is to determine a unique expression for $S$ and $E$.
Theoretical analyses are now being performed to develop numerically
efficient algorithms for performing this procedure.

2. **Antennas in Material Media**

Investigators: L. N. An (Ph.D. Student) and G. S. Smith

The electromagnetic properties of antennas in material media are
being studied both theoretically and experimentally in this research
program. Particular attention is being given to structures that combine
a wire antenna with a dielectric insulation (insulated antennas). The
terminal admittance of these antennas is being measured over a broad range
of frequencies using the time domain instrumentation.

The terminal admittance of the antenna at the frequency $\omega$ is

$$Y(\omega) = Y_o \frac{1 - \rho(\omega)}{1 + \rho(\omega)},$$

where $\rho(\omega)$ is the reflection coefficient at the terminals and $Y_o$ the
characteristic admittance of the transmission line feeding the antenna.
To determine $\rho(\omega)$, a transient signal in the form of a step with a fast
rise time $v_i(t)$ is made incident on the terminals of the antenna and
the reflected signal $v_r(t)$ measured. The Fourier transforms of these
signals are taken using the Fast Fourier Transform Algorithm (FFT),
\( v_i(t) \leftrightarrow V_i(\omega) \), etc. The reflection coefficient

\[ \rho(\omega) = \frac{V_r(\omega)}{V_i(\omega)} \]

and terminal admittance of the antenna are then computed.

One antenna being investigated is the circular-loop antenna with an eccentric spherical dielectric insulation. Figures 3 and 4 show measured results for this antenna taken with the time-domain measurement facility. In Figure 3a, the incident step, after reflection from a short circuit is shown with the amplitude of its frequency spectrum. Note that the signal shown in Figure 3a is just the negative of the incident signal \( v_i(t) \) since the reflection coefficient for the short circuit is \( \rho(\omega) = -1 \). The step after reflection from the terminals of the loop antenna is displayed with the amplitude of its spectrum in Figure 3b. Both signals (3a and 3b) are seen to have significant content at frequencies as high as several gigahertz.

The measured terminal admittance \( Y = G + jB \) is compared with preliminary theoretical results in Figure 4. The theoretical results and those measured with the time-domain measurement facility are seen to be in good agreement. Note that the results shown are for a decade in the frequency domain and that they were measured in a matter of minutes using a single step waveform in the time domain.

A paper describing the theory for the eccentrically insulated loop antenna and these measurements is in preparation.
FIG. 3 a. STEP REFLECTED FROM SHORT CIRCUIT, b. STEP REFLECTED FROM LOOP ANTENNA
FIG. 4 COMPARISON OF THEORETICAL AND MEASURED ADMITTANCES FOR INSULATED LOOP ANTENNA.