A VIRTUAL FIELD-BASED LABORATORY FOR MICROWAVE EDUCATION

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ABSTRACT

The design of complex microwave and millimeter-wave circuits requires field modeling expertise and computer tools that include electromagnetic field simulators. The need for field modeling and simulation tools is growing steadily. Present and future users of such tools must understand the underlying physical phenomena and acquire modeling expertise. Educational packages have thus been developed at the Universities of Victoria and Darmstadt that convey experience in electromagnetic field modeling, simulate a realistic electromagnetics laboratory environment, and invite students to experiment and test new ideas with a minimum of time and material investment.

1. INTRODUCTION

The "Virtual Electromagnetics Laboratory Experiments", described in this paper have been conceived for college, university and industry level training in the following areas: propagation and scattering of electromagnetic waves, waveguides and transmission lines, antennas, high speed digital circuits, microwave and millimeter-wave circuits, electromagnetic compatibility and interference, opto-electronics, and other applications of electromagnetic fields.

Typical microwave laboratory experiments are set up on a computer using the graphic user interfaces of time domain electromagnetic simulation tools developed at the Universities of Victoria and Darmstadt. The geometry of the structures under test is specified, as well as their electromagnetic excitation and the desired output features.

A step-by-step description of each experiment and of the associated input procedure has been prepared. Each experimental setup is stored in an input file for the simulators. The user interfaces allow full interactivity without requiring extensive study and experience in computational electromagnetics. This is achieved by a functionally structured menu system consisting of both pulldown menus and submenus with clearly defined functions. Extensive HELP facilities are included as well.

The most prominent features of the electromagnetic simulators are the following:

- The topology of an electromagnetic structure, including its boundaries, dielectric and magnetic properties, losses, nonlinear subregions, source configuration, nonlinear subregions, and output points are entered with the mouse and displayed on the screen, just as in a standard drafting program.
- The excitation function can be selected from a number of available waveforms or specified by a user-generated file.
- The time response of the structure can be observed and displayed, together with its Fourier transform (Frequency response in magnitude and phase).
- Alternatively, any field components of an electromagnetic problem can be visualized in the entire structure or in a part of it, for 3D field display and animation.
- Scattering parameters, time and frequency responses, excitation functions, and field pictures can be displayed and printed. Data can be stored in output files for further processing.
- Advanced features include modeling of dispersive boundaries, in particular non-TEM absorbing boundary conditions, dispersive materials, nonlinear active and passive devices, and other capabilities required for modeling realistic microwave components.

In summary, the simulators combine the functions of a time domain analyzer, a microwave/millimeter-wave vector network analyzer, a spectrum analyzer, a signal processor, and a video system. They are truly menu-driven "Virtual Electromagnetics Laboratories".

2. TYPICAL EXPERIMENTS

During the presentation of the full paper, a selection of six experiments will be demonstrated on the screen. They are:

a) Microstrip T-junction and hybrid coupler.
b) Waveguide Gunn oscillator.
c) Waveguide bandpass filter.

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d) Circular waveguide with diaphragm
   d.1) TM01-Mode fed into a circular waveguide 3x above cutoff frequency of waveguide.
   d.2) TM01-mode fed into a circular waveguide 1.5x above cutoff frequency of waveguide, below the cutoff of the diaphragm
e) Transition coax-circular waveguide. TEM mode fed into a coaxial waveguide. At the transition a TM01 mode is excited.
f) Radiation from horn antenna. TM01-mode fed into the circular waveguide of a horn antenna. Field is radiated into free space.

In this summary, only representative excerpts from a) and c) will be shown due to space limitations.

2.1 PROPAGATION PROPERTIES AND SCATTERING PARAMETERS OF A MICROSTRIP T-JUNCTION AND A HYBRID JUNCTION.

Objective: Observe propagation in a microstrip T-Junction and extract its Scattering Parameters (see Fig. 1). The entire structure is surrounded by absorbing walls (not shown in the figure).

Fig. 2 shows the z-directed electric field of a Gaussian pulse in a plane beneath the strip at two instants, before (a) and after (b) scattering at the T-junction. In the actual simulation the pulse moves smoothly along the microstrip line, allowing the user to observe propagation and scattering in a generated solution mode. From the response of the microstrip structure to the Gaussian excitation the scattering parameters can be extracted over a wide frequency range via Fourier transform. Fig. 3and 4 show the magnitude and phase of S11 and S12 of the T-junction, where port 1 is the source plane, and port 2 is situated in one of the sidearms.

A snapshot of the electric field in a hybrid coupler is shown in Fig. 5. The S-parameters of the junction can be extracted in the same manner as in the case of the T-Junction. By noting the frequency at which minimum transfer of power between isolated ports occurs, and by exciting the junction with a sinusoidal wave at that frequency, one can observe the field propagation in the component and intuitively understand its operation. In particular, the 3 dB power split and the 90 degree phase shift between the transmitted signals can be directly observed.

2.2 PROPAGATION PROPERTIES AND SCATTERING PARAMETERS OF A WAVEGUIDE BANDPASS FILTER.

As in the previous experiments, the dynamic visualization of the field inside a bandpass filter (Fig. 6) provides a fascinating insight into the complex interaction between the coupled resonators of the filter. The progressive growth of the field inside the resonators, the phase relationship between the resonances, and the effect of high Q-factors on the relative amplitudes in the resonators and the ports immediately convey the physical reasons for the circuit properties of such a component. During the presentation of the paper, the entire transient response of the filter to an incident sinusoidal signal will be dynamically displayed.

3. INDUSTRIAL SIGNIFICANCE AND BENEFITS

The present and future generations of students expect computers to be an integral part of their educational process and are often motivated by sophisticated computer tools that complement the traditional theory and laboratory material. This is particularly true for abstract and theoretically demanding areas such as microwave engineering. It is thus increasingly attractive for educators to use “virtual experiments” on computers for education and professional training. At the same time, the design and packaging of high-frequency analog/high speed digital systems requires field modeling expertise and computer tools based on electromagnetic field simulation. As in most other areas of engineering realistic modeling capability dramatically reduces time and cost of development of new products. A realistic and reliable computer model allows the user to quickly test new ideas without costly prototyping and experimentation. Benefits include: stimulation of interest due to the fast availability of results, familiarization with electromagnetic CAD tools, reduced product development cost, possibility to test new ideas quickly, deeper physical insight due to visualization and animation of electromagnetic fields, ability to identify dominant and parasitic effects, and ability to “see” and understand the connection between field behavior and electrical characteristics of components or systems.

4. CONCLUSIONS

Educational packages have been developed that convey experience in electromagnetic field modeling, simulate a realistic electromagnetics laboratory environment, and invite students to experiment and test new ideas with a minimum of time and material investment. This is achieved by a suite of typical electromagnetic laboratory experiments implemented on time domain electromagnetic simulators. Their user interface provides a realistic environment that evokes the typical instruments usually found in a microwave laboratory, such as network analyzer, spectrum analyzer and oscilloscope. In addition, it allows dynamic visualization of fields, thus revealing the physical mechanisms behind the electrical characteristics of structures and circuits.

REFERENCES

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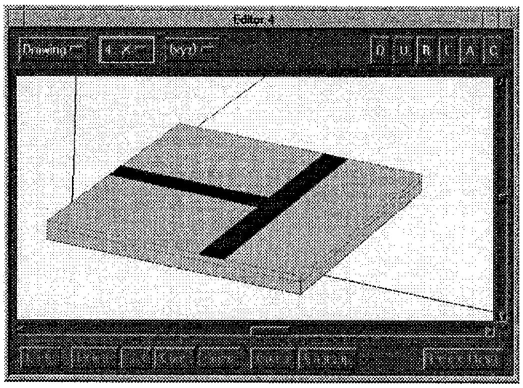

Fig. 1 Three-dimensional view of the microstrip T-junction in the editor window

a) b)

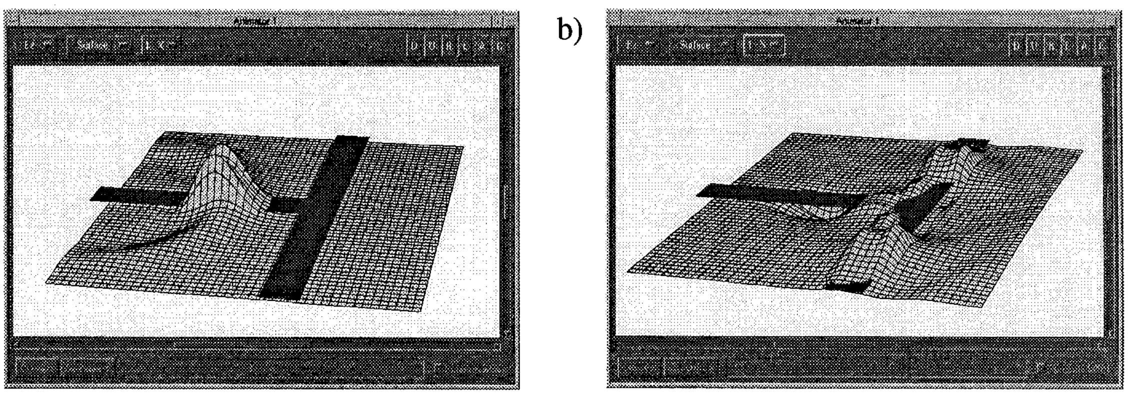

Fig. 2 a) Gaussian pulse before the scattering and b) after the scattering.

a) b)

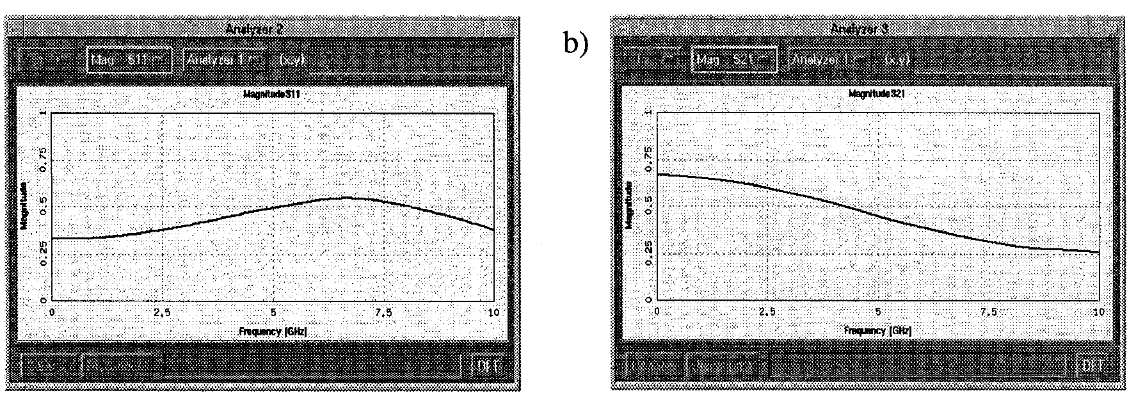

Fig 3 Scattering parameters of the microstrip T-junction; a) magnitude of S_{11}, b) magnitude of S_{21}

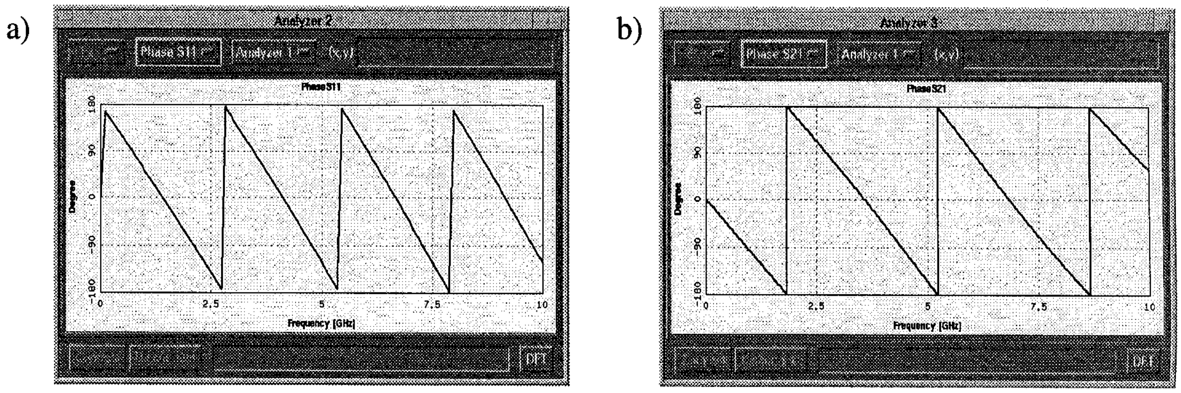

Fig 4 Scattering parameters of the microstrip T-junction; a) phase of S_{11}, b) phase of S_{21}

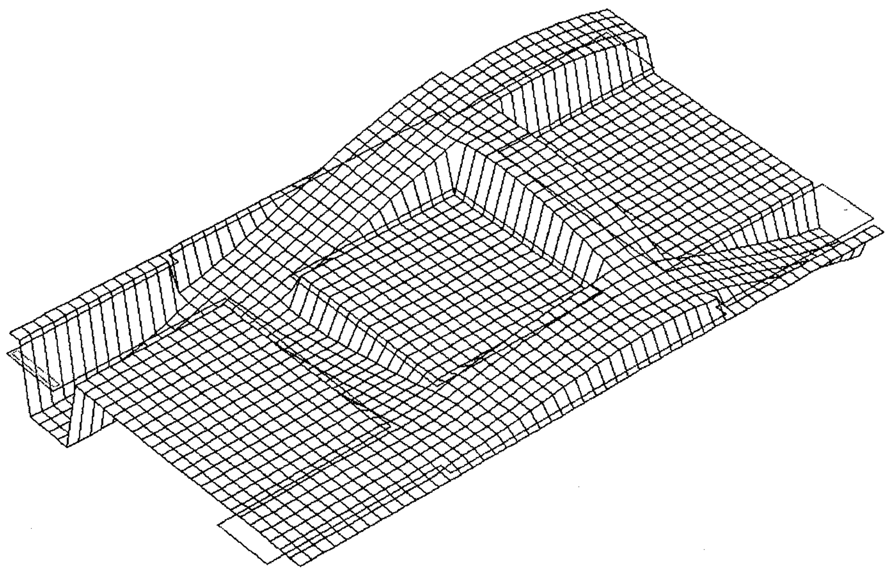

Fig. 5 Electric field distribution in a hybrid microstrip coupler

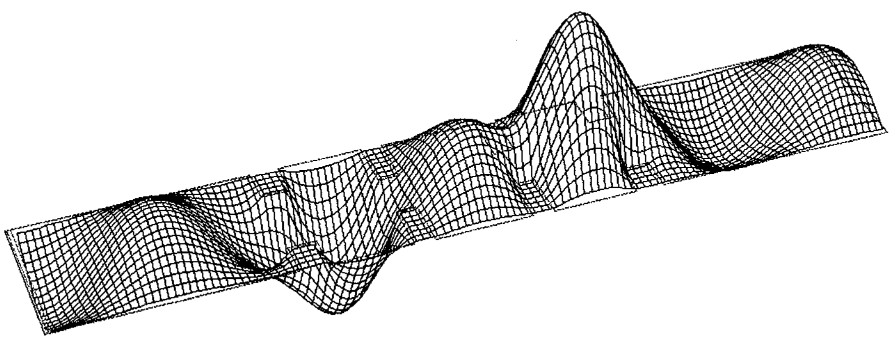

Fig. 6 Electric field in a three-resonator waveguide bandpass filter at midband frequency.