LINPAR and MULTLIN for Windows: a New Generation of Powerful Tools for the Analysis of Multiconductor Transmission Lines

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Abstract

Multiconductor transmission lines are vital parts of many microwave and digital circuits. However, commonly used programs for the circuit analysis (like Touchstone, Libra, Super-Compact and SPICE) do not have adequate models for such lines. A set of two programs is described, published by the Artech House, that is a low-cost but powerful tool for the analysis of multiconductor transmission lines.

1. Introduction

The mind of a microwave engineer is adjusted to visualizing a circuit as a complex structure that supports guided waves. He or she even knows how to use properties of such structures to build matching circuits, filters, directional couplers, etc. With the development of high-speed computers, the interconnects in digital circuits (multiwire cables, printed-circuit buses, even chip interconnections) have to be considered as transmission line systems if a proper design is to be achieved. However, this idea painfully and slowly paves its way into the minds of digital-circuit designers.

From the standpoint of the electromagnetic-field theory, wave-guiding systems that consist of two or more conductors are referred to as transmission lines. To this class belong coaxial waveguides, two-wire lines, microstrips, striplines, coplanar waveguides[1], etc. Lines with exactly two conductors are referred to as simple transmission lines, and lines with more than two conductors are referred to as multiconductor transmission lines (or coupled lines). Wave-guiding systems that have only one conductor (e.g., rectangular metallic waveguides and metallo-dielectric lines) or no conductors (e.g., optical fibers) are classified as waveguides. The difference between these two classes is that the transmission lines can support TEM or quasi-TEM waves with a zero cutoff frequency (and can thus be used to carry d.c. currents), while the cutoff frequency of waveguides is rather high and practically falls into the microwave or infrared regions.

In spite of the importance of multiconductor transmission lines, the standard programs for CAD of microwave circuits (Touchstone, Libra, and Super-Compact) have very restricted capabilities in analyzing multiconductor lines. They all support only a limited number of coupled structures, consisting of two signal conductors and the ground (like coupled microstrips). To overcome this lack, in late 80's, a cooperation between the School of Electrical Engineering of University of Belgrade, the Institute for Microwave Techniques and Electronics (IMTEL, Belgrade), and the Electrical and Computer Engineering Department of Syracuse University (N.Y.) resulted in a set of techniques and computer programs for an efficient analysis of multiconductor transmission lines, published by the Artech House [1-3] as a transmission-line trilogy. All programs were designed for DOS for the 512 kB PC configuration, which was then a standard. Each program consists of a user-friendly shell (at least, according to the contemporary standards) and a kernel for the numerical analysis. The first program, LINPAR, numerically evaluates the primary matrix parameters of multiconductor transmission lines with a piecewise-homogeneous dielectric, using the method of moments [4], with a pulse approximation for the distribution of surface free and bound charges and the point-matching technique. The second program, LINRES, evaluates the time-domain response of a lossless multiconductor transmission line, driven by one or several pulse generators, and terminated into lumped elements (linear or nonlinear resistors, inductors, capacitors, short circuits, and open circuits). The third program, MATPAR, evaluates the scattering, impedance, and admittance parameters of microwave networks consisting of one or several multiconductor transmission lines and lumped elements. The work on these programs originated from a series of contracts with the Digital Equipment Corporation (in early 80's). An interesting thing happened to those contracts. After

[1] According to this classification, coplanar waveguides are transmission lines, while slotlines and finlines are waveguides!

their successful completion, the programs and reports were almost forgotten for several years, until the ever increasing speed of digital circuits demanded these tools to be put back to work.

LINPAR was quite a success, as about 500 copies of it were sold. The technique implemented in this program turned out to be accurate and efficient to beat any other method for the analysis of general transmission-line structures. In particular, it is far superior to various finite-difference and finite-element techniques employed even today in some high-priced software. Although LINPAR performs a quasi-static analysis, its results turn out to be sufficient for a majority of application, in particular for the time-domain response of digital-circuit interconnects, but also in most practical cases of microwave circuits. LINRES and MATPAR were less successful (about 250, and 180 copies sold, respectively). There are several reasons for that. First, they were targeted at different audience: LINRES to digital-circuit designers, and MATPAR to microwave engineers (while both of them require LINPAR as a prerequisite). Second, both programs have a restricted menu of lumped elements that can be connected to the transmission lines. Third, no direct means was provided for interfacing these programs to SPICE, Touchstone, Libra, Super-Compact, or other widely used programs.

Finally, linguists did their killing share in advertising MATPAR. Following an unbelievable path, the key sentence from the prepublication announcement, "The program is based on the nodal analysis of multiconductor transmission lines with discrete elements," was transformed and printed as "The program is based on a meticulous analysis of multiconductor transmission lines with subtle elements." My guess is that the editor was not familiar with nodal equations, and "meticulous" sounded more appealing than "nodal". For "discrete" I have another explanation. In English, there are two similar words, "discrete" and "discreet", with a somewhat different meaning. The editor changed spelling "discrete" to "discreet". Then, disliking the expression, he substituted it by "subtle". Could you guess what was inside MATPAR!? This reminds me of an old joke. A Yugoslav, frustrated by the need to cross (on foot, of course) to the other side of a busy road in an American town, with no zebra-crossing in sight, asks a policeman by a literal translation: "Please translate me to the second page of the way!"

With the vast expansion of computer hardware and software, a new generation of these programs was demanded, aimed at increasing the capabilities and improving the user-friendliness, according to Windows' standards. Based on an improved numerical algorithm [5], a new edition of LINPAR was published in 1995 [6]. It is followed by a new program, MULTLIN [7], aimed at replacing LINRES and MATPAR. A new concept is implemented in it. MULTLIN is designed as an interface between LINPAR (or any similar program), on one hand, and SPICE, Touchstone, Libra, and Super-Compact, on the other hand, so that the user can fully exploit the benefits of all his tools. Both programs are delivered in an executable form for any IBM or compatible computer running Windows (Version 3.0 or later, including Windows 95 and NT), including 386, 486, and Pentium computers.

2. LINPAR for Windows

LINPAR (Matrix Parameters for Multiconductor Transmission Lines) for Windows is a computer program for numerical evaluation of quasi-TEM matrices for multiconductor transmission lines embedded in piecewise-homogeneous dielectrics. The technique used in the program is based on an electrostatic analysis in which the dielectrics are replaced by bound charges in a vacuum and the conducting bodies are replaced by free charges. A set of integral equations for the charge distribution is derived from the boundary conditions for the electrostatic potential and the normal component of the electric field. The method of moments is applied to these equations, with a piecewise-constant (pulse) approximation for the total charge density and the Galerkin technique. The analysis method includes skin-effect conductor losses and dielectric losses.

LINPAR for Windows can analyze arbitrary planar transmission lines in multilayered dielectrics, including coupled microstrip lines, suspended striplines, striplines, coplanar waveguides, etc., which are structures built into the program. The program can also analyze any other structure defined by the user, including flat cables, multiwire shielded cables, etc. The input to the program is data defining the geometry of the transmission-line cross section and dielectric parameters. The output of the program is the primary matrix parameters [L], [C], [R], and [G], of the line, and the characteristics of modes that can propagate along the transmission line (including the modal propagation coefficients, modal voltage and current matrices, and the characteristic impedance matrix).

LINPAR has a set of windows and dialog boxes that allow the easy inputting, editing, and checking of data that define the transmission-line structure. It provides an automatic choice of functions approximating the unknown charge distribution.

3. MULTLIN for Windows

MULTLIN for Windows is a computer program for generating models for the analysis of circuits containing multiconductor transmission lines. The input to the program is the primary matrix parameters of multiconductor transmission lines (i.e., the matrices [L], [C], [R], and [G]) that are evaluated by another program (e.g., by LINPAR for Windows). MULTLIN can also accept as input the secondary parameters of a line, e.g., evaluated by a full-wave analysis program. There are two possible outputs of MULTLIN. The first one is a subcircuit modeling the line, which can be incorporated into SPICE or another similar program for the time-domain or frequency-domain circuit analysis. The second output of MULTLIN is a file with tabulated scattering parameters of the line (considered as a multiport network), which can be used by Touchstone, Libra, Super-Compact, or a compatible program for the analysis and design of microwave circuits.

There are two subcircuits modeling the multiconductor transmission line in the analysis by SPICE. The first subcircuit consists of lossless simple transmission lines and controlled generators, which it is primarily intended for an efficient analysis of lossless multiconductor transmission lines in the time domain. The second subcircuit consists of controlled generators (some of them in the domain of the Laplace transform) and impedance networks, which is primarily intended for the analysis of lossy lines (with frequency-dependent losses). Both subcircuits can be used for the frequency-domain and the time-domain analyses. The subcircuit consists of controlled generators (some of them in the Laplace-transform domain), resistors, and simple transmission lines (that are standard SPICE elements). In the development of SPICE models, a particular care was devoted to provide a causal response in the time domain of lossy lines. The analysis by SPICE can be applied to virtually any digital or analog circuit that contains multiconductor transmission lines.

MULTLIN is an almost complete replacement of programs LINRES and MATPAR if used in conjunction with SPICE. If used with Super-Compact, Libra, and Touchstone, it partly replaces MATPAR.

4. LINPAR and MULTLIN at Work

We will illustrate the application of LINPAR and MULTLIN on two examples [7]. The first one is the analysis of the comb-line filter sketched in Figure 1 [8,3]. We want to evaluate the scattering parameters of the filter using LINPAR, MULTLIN, and PSpice, in the frequency range from 300 MHz to 600 MHz, at 301 points. Note that the multiconductor structure shown in Figure 1 cannot be directly analyzed by Touchstone, Libra, or Super-Compact!

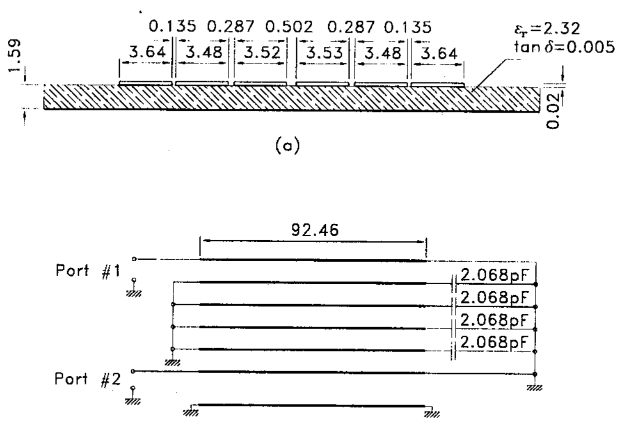
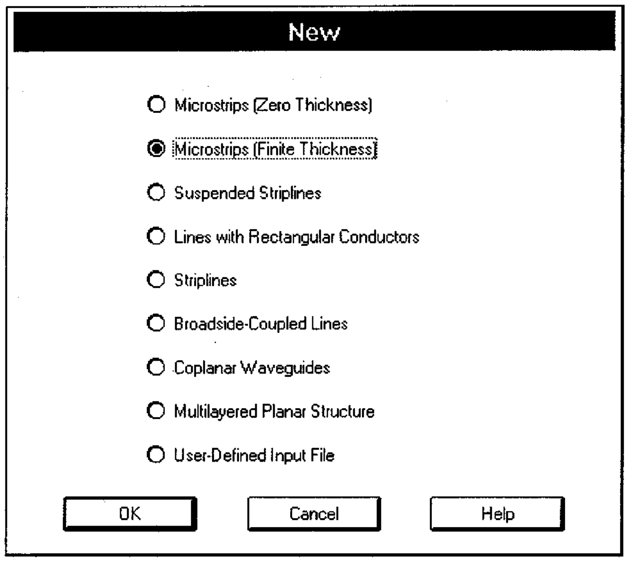
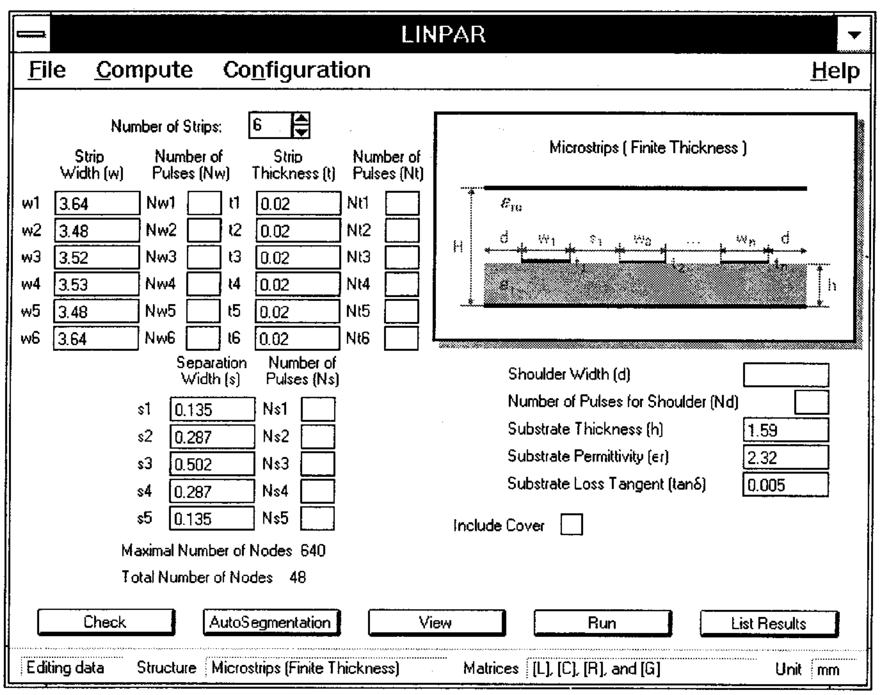


Figure 1. A microstrip comb-line filter: (a) cross section, (b) schematic. All dimensions are in millimeters.

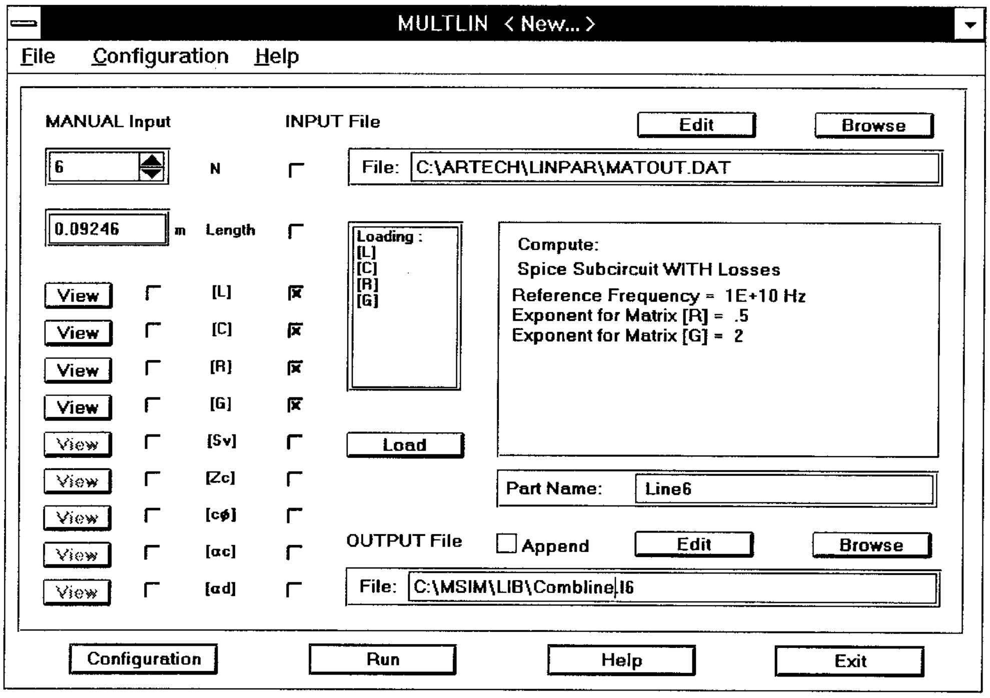
First, we run LINPAR. From its menu of built-in structures, shown below, we select finite-thickness microstrips.



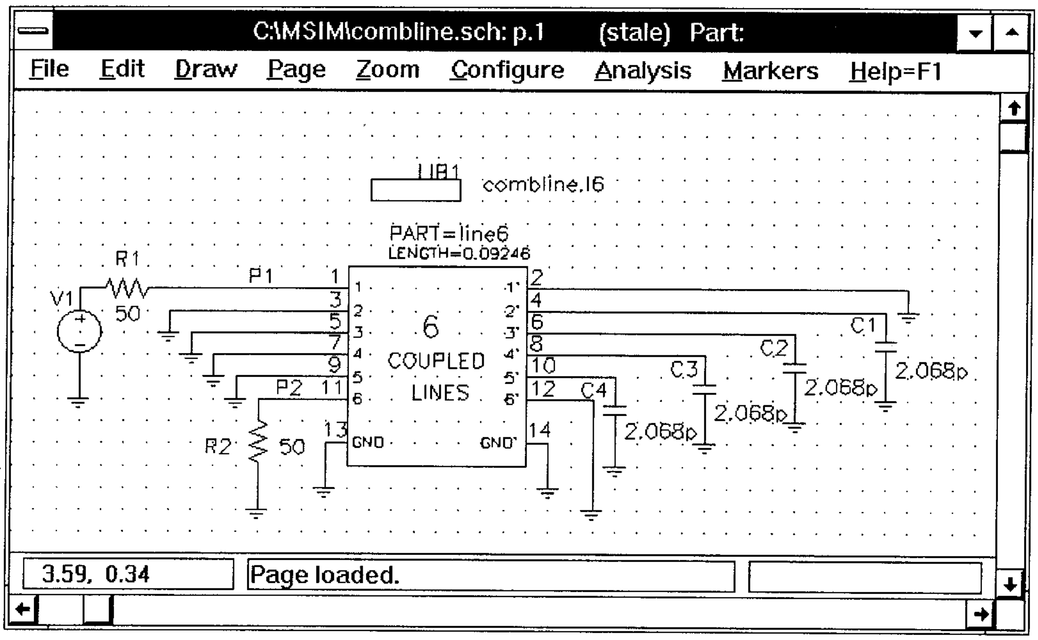
In the Structure Definition window for this line we have to enter data that define the cross section of the line, as shown below.



Thereafter, we have to click the Run button at the bottom of the window. The program will automatically evaluate the numbers of pulses and the remaining required data and perform the numerical analysis. Next, we run MULTLIN to load the primary matrix parameters evaluated by LINPAR and create a SPICE-compatible subcircuit that models the transmission line of Figure 1. The MULTLIN Main window, with all data entered, looks as shown below.



Finally, we run SPICE. In our example, we use PSpice (Version 5.1). In the PSpice Schematic Editor we draw the scheme of circuit, as shown below.



We run the a.c. analysis, and in Probe we calculate and display the magnitudes of the scattering parameters (in dB) to obtain the plot shown in Figure 2.

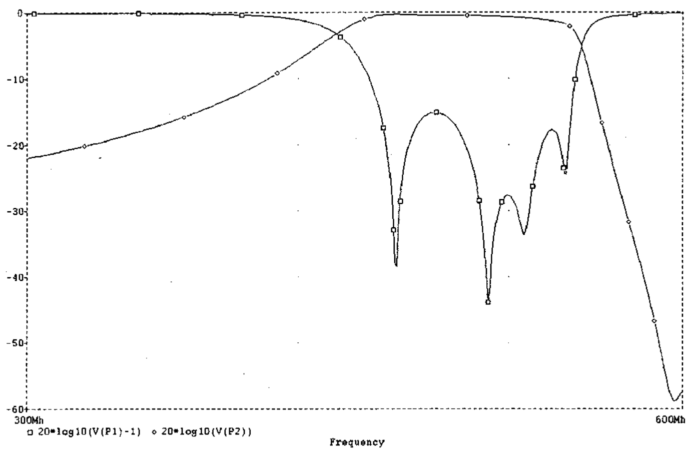


Figure 2. Scattering parameters of the structure of Figure 1, evaluated by LINPAR, MULTLIN and PSpice.

Based on the matrices evaluated by LINPAR, we can also run MATPAR to obtain the same result. With MULTLIN, we distribute a patch program that converts the output of MATPAR to the Touchstone-compatible format. Thus, the scattering parameters our filter can be loaded into Touchstone, Libra, or Super-Compact, so that the filter can become a part of a complex microwave circuit.

The second example is the time-domain response of the microstrip bus shown in Figure 3. The bus has four signal conductors and a branching at its middle, and it models a fast digital circuit interconnect. One port of such a network is excited by a pulse generator, of amplitude 5 V, delay time 1 ns, rise time 0.5 ns, duration 5 ns, fall time 0.5 ns, and internal resistance 50 Ω, while all the remaining ports are terminated in 50 Ω resistors to ground. The example is aimed at showing the large noise level on a microstrip bus primarily caused by reflections at the junction and by different modal velocities of propagation.

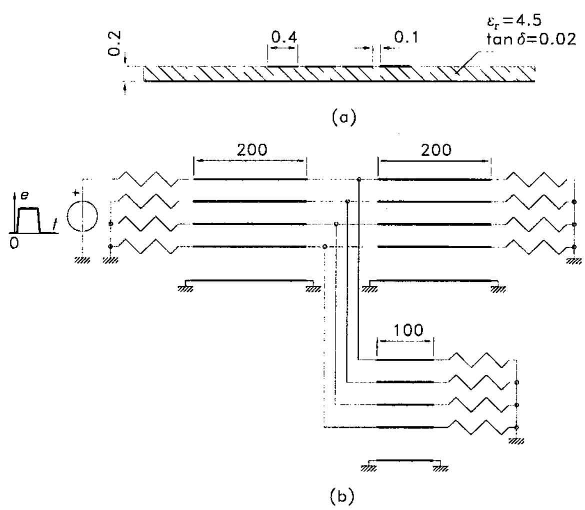
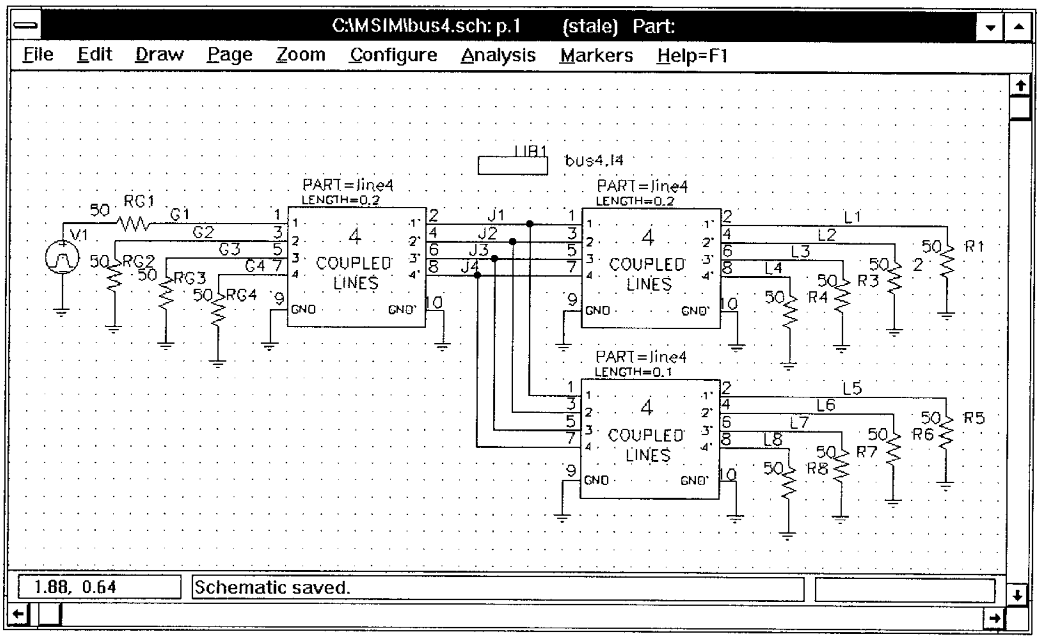


Figure 3. A microstrip bus with branching: (a) cross section, (b) schematic. All dimensions are in millimeters and all resistances are 50 Ω.

We have to consider the structure of Figure 3b as three interconnected multiconductor transmission lines, each with four signal conductors. Since the cross sections of the three lines are identical, we have to run LINPAR only once. We then switch to MULTLIN to produce a SPICE-compatible subcircuit. The circuit scheme in the PSpice Schematic Editor window looks as shown below.



After executing a transient analysis, the voltages at the labeled points can be displayed in the Probe window, as shown in Figure 4.

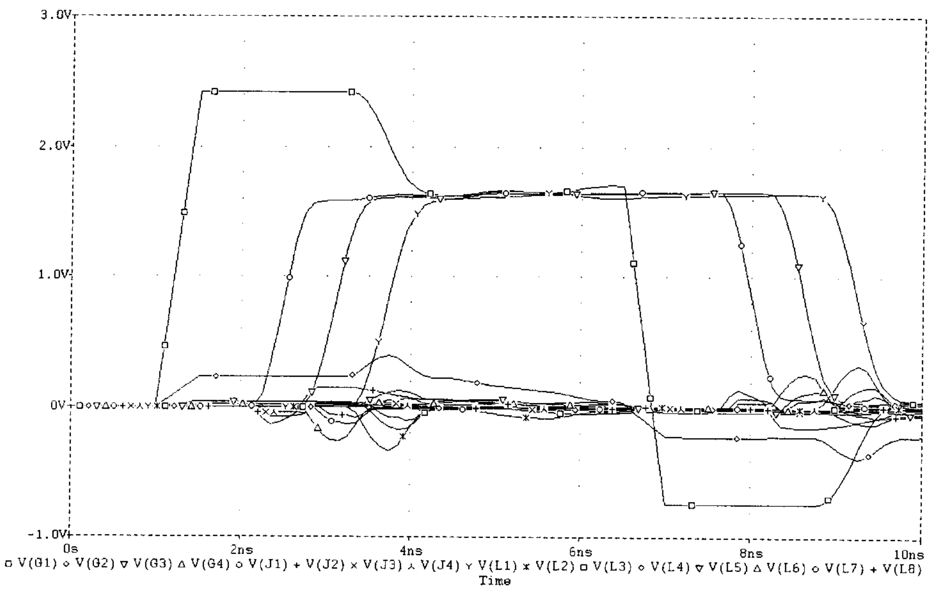


Figure 4. Voltages at the terminals of the microstrip bus of Figure 3.

Conclusion

A set of programs is described, developed at the School of Electrical Engineering (University of Belgrade), Institute for Microwave Techniques and Electronics (in Belgrade), and Department of Electrical and Computer Engineering (Syracuse University, N.Y.), and published by the Artech House. The programs are a powerful, efficient, user-friendly, and low-cost tool for the analysis of multiconductor transmission lines, which is expected to be of a significant value to microwave and digital-circuit engineers. The programs can be used with SPICE, Touchstone, Libra, Super-Compact, and similar programs, which significantly extends the capabilities of these CAD tools.

References

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