GENERAL-PURPOSE MICROWAVE CIRCUIT ANALYSIS INCORPORATING WAVEGUIDE DISCONTINUITY MODELS

Michael Greenspan, K. I. Thomassen, and Paul Penfield Jr.

Abstract

A project of incorporating waveguide discontinuity models into a general-purpose network-analysis program is described. The project is not yet completed. Examples are given which illustrate the need and usefulness of the project.

MARTHA is a set of cooperating computer programs, written in the language APL, to analyze electrical networks.[1] To analyze a network, a user typically defines his network, sets the frequency, and requests the output in any of several forms. With *MARTHA*, the user defines elements by means of element-definition functions, and then wires them together with several wiring functions. Standard elements in *MARTHA* include resistors, capacitors, transistors, opamps, and TEM lines, waveguides, and waveguide matched loads. Typical wiring functions simulate placing two one-port subnetworks in series or in parallel or cascading 2 two-port networks. The present work consists of expanding the collection of elements to include several waveguide discontinuity models.

Because *MARTHA* is imbedded in APL, a user (who knows how to program in APL) can extend *MARTHA*'s capabilities by writing his own specialized functions. *MARTHA* has explicit provision for user-defined elements, a provision that was taken advantage of in the work reported here.

User-Defined Elements

A user must write two types of APL functions to define his own, new type of element.[2] The first type defines elements, which are vectors of arbitrary length, independent of frequency. The first component of these vectors is the number 9, and the second, typically is a code to identify the type of new element. The remaining components are the parameters of the element.

The second type of function makes the numerical calculations associated with the model. When this function is executed, the frequency is known so frequency-dependent elements like waveguide irises can be handled. In *MARTHA*, by convention, a single user-written function named *NEWELEMENT* handles all these calculations; if (as in this case) there is more than one new type of element, the first line of *NEWELEMENT* is a branch to an appropriate portion of the function.

Goals of this Project

The present project, which is still under way, seeks to make available to a user the following waveguide discontinuity models: (1) E-plane bend; (2) H-plane bend; (3) step change in height; (4) step change in width; (5) inductive window and iris; (6) capacitive window and iris; (7) tuning post; (8) E-H tuner; (9) terminated E- and H-plane tee.

These models are intended to be valid both above and below the cutoff frequency, and to be sufficiently accurate for practical analysis of filters and impedance transformers. The set of functions generated should be used by the end user in exactly the same way as the other functions in *MARTHA*. Finally, the use of these programs should not prevent a user from simultaneously using other user-defined elements.

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Results

Many, but not all, of the models have been programmed so far; some have been more thoroughly tested than others. Two of the models are used in examples below. We used the formulas of Marcuvitz,[3] in some cases extended to frequencies below cutoff. In some cases polynomial approximations of equivalent accuracy were used.

First Example

Consider the symmetric inductive window, Figure 1. The function (written as part of this project) which defines this model is named *SYMLWINDOW* and requires an argument consisting of a vector with four components: (1) the cutoff frequency of the waveguide in Hz; (2) the infinite-frequency characteristic impedance of the waveguide in ohms; (3) the width of the guide in meters; and (4) the width of the opening.

MARTHA uses the common definition of characteristic impedance for the dominant mode of rectangular guide,

$$Z_0 = \frac{Z_\infty}{\sqrt{1 - (f_c/f)^2}} = \frac{Z_\infty \lambda_g}{\lambda}$$

but the user may specify any infinite-frequency impedance Z_∞, arbitrarily dependent on waveguide dimensions. Since the waveguide models calculate numbers relating equivalent voltages and currents, Z_∞ must be specified.

The result of the function *SYMLWINDOW* is a one-port element which may be wired with other elements to form a microwave network. Figure 2 shows two such windows separated by a length of guide which forms a crude filter (analyzed in this example). This guide is for X-band, with inside dimensions 0.4 and 0.9 in. The window opening is 0.6 in., and the two windows are separated by a quarter wave-long guide at 10 GHz.

The network model for this example (Figure 3) shows two windows cascaded with a length of guide, and terminated in a load.

In the analysis of this example (Fig. 4) *MARTHA* is loaded* and then the functions *SYMLWINDOW* and *RECT*1 are copied into the active workspace. *RECT*1 computes the cutoff frequency and infinite-frequency impedance of the guide from its dimensions. It is used to define both the window *WIND* and the waveguide section *CAVITY*. Next the input normalization impedance *ZNIN* and the load impedance *ZL* are defined to be the frequency-dependent characteristic impedance of the guide. So far no significant calculations have been made. Next, the function *NEWELEMENT* (written as a part of this project) is copied, along with the response function *VSWRIN* for the input VSWR. The frequency vector *F* is then defined, and the VSWR and the magnitude of the input reflection coefficient are calculated and plotted. The description of the network is *WIND WC CAVITY WC WIND*, where *WC* is a wiring function which cascades subnetworks. During the calculations, *NEWELEMENT* is called automatically. As expected, there is a point of low VSWR at a frequency near that at which the two windows are separated by 90°.

*What is actually loaded is a version of *MARTHA* currently under test at M.I.T., and scheduled for general use during the summer of 1972. In this version, *ZNIN* and *ZL* may be frequency-dependent; in this example they are set to the frequency-dependent guide characteristic impedance. This is the only time in this project where information beyond reference 1 was used.

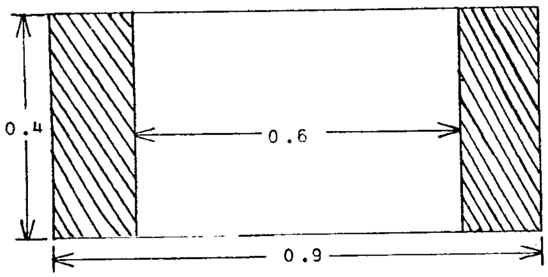

FIGURE 1

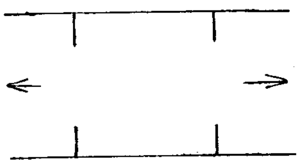

FIGURE 2

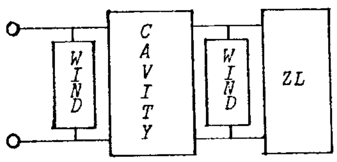

FIGURE 3

Second Example

The quarter-wave step discontinuity transformer, Fig. 5, is a design given by Young.[4]

```
      )LOAD 100 MARTHA
SAVED  37.10.05 02/25/72
      )COPY 65031 MWC SYMLWINDOW
SAVED   8.10.12 03/01/72
      )COPY 100 MARTHAX RECT1
SAVED  31.12.10 02/01/72

      WIND  ←SYMLWINDOW RECT1 .0254× .9, .4, .9, .6
      CAVITY←WG RECT1 (.0254× .4, .9), 90 DEGREESAT 10E9

      ZL←WG RECT1 .0254× .4, .9
      ZNIN←ZL

      )COPY 65031 MWC NEWELEMENT

SAVED   8.10.12 03/01/72
      )COPY 100 MARTHAR VSWRIN
SAVED  26.12.24 02/02/72

      F←1E9 × 9 + 0, .2×⍳25

      PLOT 25 HIGH VSWRIN, MAG SIN OF WIND   WC CAVITY WC WIND

CIRCUIT ANALYSIS BY MARTHA.   71•B   3/1/72    8:22
MARTHA COPYRIGHT (C) 1971 MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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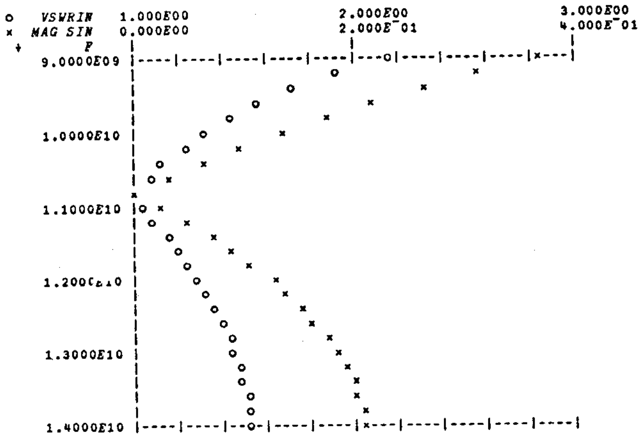

FIGURE 4

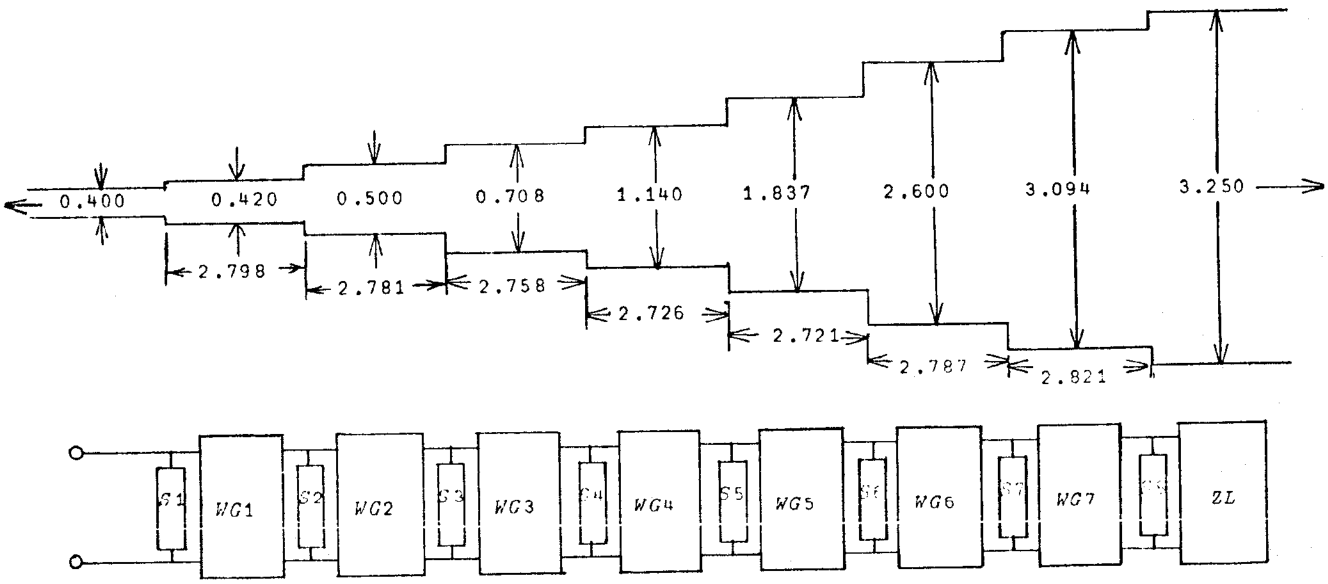

FIGURE 5

The nominal design has seven waveguide sections, each a quarter-wave long. These sections are defined in Fig. 6 as *WG*1 through *WG*7, and a network neglecting the discontinuities, called *APPROXIMATE*, is defined. Another network including the models, called *EXACT*, is defined, as are the models themselves, *S*1 through *S*8. The frequency vector is defined, and since many frequencies are desired, the automatic frequency sweeper[5] is used. The VSWR's of the two filters are plotted together, o for *EXACT* and × for *APPROXIMATE*. The difference between the two responses demonstrates the need for the waveguide models.

Young[4] also gave formulas for changing the lengths of the sections to counteract the step discontinuities, and in Fig. 7 sections *WG*1 through *WG*7 are redefined to the lengths he calculated. The new VSWR (o for *EXACT*) shows the expected improvement, while the approximate analysis × shows poorer response.

```
      )LOAD 100 MARTHA
SAVED  37.10.05 02/25/72
      )COPY 65031 MWC SYMCSTEP
SAVED   8.10.12 03/01/72
      )COPY 100 MARTHAX RECT1
SAVED  31.12.10 02/01/72

      WG1←WG RECT1 .0254× 6.5, .42, 2.808
      WG2←WG RECT1 .0254× 6.5, .5, 2.808
      WG3←WG RECT1 .0254× 6.5, .708, 2.808
      WG4←WG RECT1 .0254× 6.5, 1.14, 2.808
      WG5←WG RECT1 .0254× 6.5, 1.837, 2.808
      WG6←WG RECT1 .0254× 6.5, 2.6, 2.808
      WG7←WG RECT1 .0254× 6.5, 3.094, 2.808

      S1←SYMCSTEP RECT1 .0254× 6.5, .4, .4, .42
      S2←SYMCSTEP RECT1 .0254× 6.5, .42, .42, .5
      S3←SYMCSTEP RECT1 .0254× 6.5, .5, .5, .708
      S4←SYMCSTEP RECT1 .0254× 6.5, .708, .708, 1.14
      S5←SYMCSTEP RECT1 .0254× 6.5, 1.14, 1.14, 1.837
      S6←SYMCSTEP RECT1 .0254× 6.5, 1.837, 1.837, 2.6
      S7←SYMCSTEP RECT1 .0254× 6.5, 2.6, 2.6, 3.094
      S8←SYMCSTEP RECT1 .0254× 6.5, 3.094, 3.094, 3.25

      ZNIN←WG RECT1 .0254× 6.5, .4
      ZL←WG RECT1 .0254× 6.5, 3.25

      ∇Z←APPROXIMATE
[1]   Z←WG1 WC WG2 WC WG3 WC WG4 WC WG5 WC WG6 WC WG7
[2]   ∇

      ∇Z←EXACT
[1]   Z←S1 WC WG1 WC S2 WC WG2 WC S3 WC WG3 WC S4 WC WG4 WC S5 WC WG5
[2]   Z←Z WC S6 WC WG6 WC S7 WC WG7 WC S8
[3]   ∇

      )COPY 65031 MWC NEWELEMENT
SAVED   8.10.12 03/01/72
      )COPY 100 MARTHAR VSWRIN
SAVED  26.12.24 02/02/72

      )COPY 100 MARTHAX FSWEEP
SAVED  31.12.10 02/01/72
      ∇ATATIME[3] STORE (VSWRIN OF EXACT), VSWRIN OF APPROXIMATE ∇

      F←1E6 × 1032+16×ι47

      PLOT SS 16 ATATIME F
```

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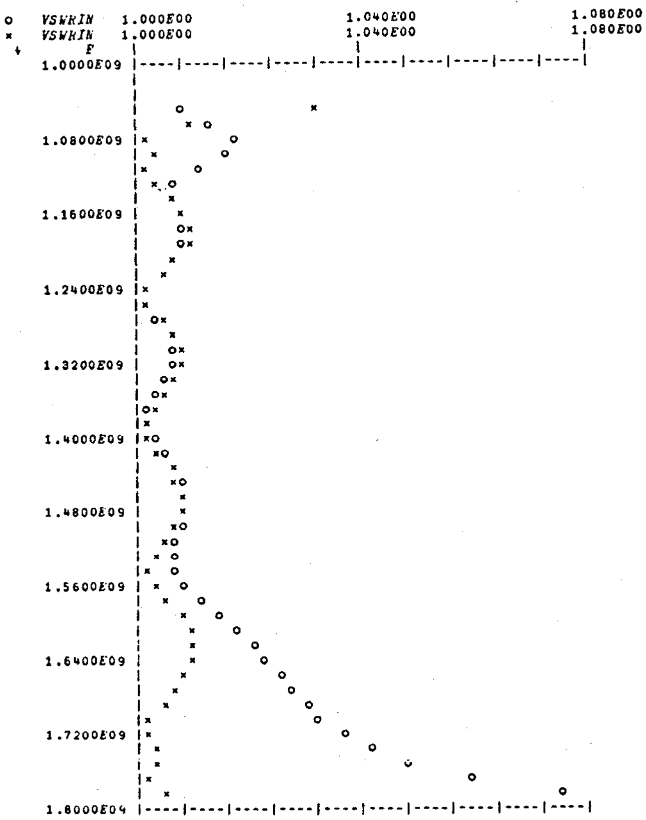

FIGURE 6

References

1. P. Penfield Jr., "*MARTHA* User's Manual," The MIT Press, Cambridge, Mass.; 1971.
2. Reference 1, pp. 63-68.
3. N. Marcuvitz, "Waveguide Handbook," McGraw-Hill Book Co., Inc., New York, N. Y.; 1951.
4. L. Young, "Practical Design of a Wide-Band Quarter-Wave Transformer in Waveguide," The Microwave Journal, vol. 6, no. 10, pp. 76-79; October, 1963.
5. Reference 1, pp. 77-78.


```
      WG1←WG RECT1 .0254× 6.5, .42, 2.798
      WG2←WG RECT1 .0254× 6.5, .5, 2.781
      WG3←WG RECT1 .0254× 6.5, .708, 2.758
      WG4←WG RECT1 .0254× 6.5, 1.14, 2.726
      WG5←WG RECT1 .0254× 6.5, 1.837, 2.721
      WG6←WG RECT1 .0254× 6.5, 2.6, 2.787
      WG7←WG RECT1 .0254× 6.5, 3.094, 2.821

      PLOT SS 16 ATATIME F
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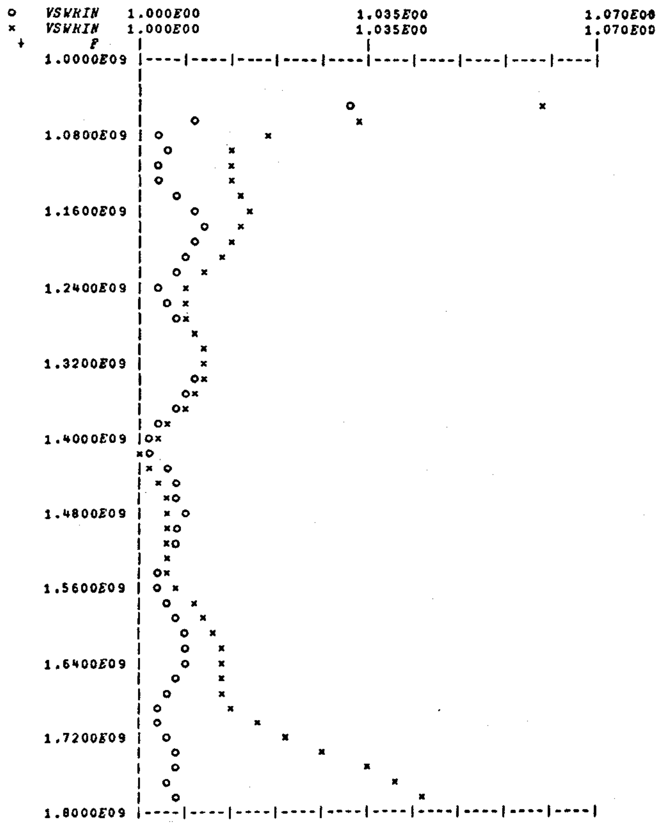

FIGURE 7