RF and Microwave Network Characterization—A Concept-Map-Based Tutorial

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***Abstract*—Characterization of RF and microwave networks based on scattering parameters formalism is one of the most basic themes that microwave engineers need to fully comprehend. This topic is included in most of the common textbooks on microwave circuits. However, alternative tutorial presentations that help in clearer understanding of the topic are always welcome. This tutorial is such an attempt and makes use of the "concept-maps and concept-modules" approach discussed in another paper in this TRANSACTIONS. Concept maps are visual representations of relationship among various concepts relevant to topic and contribute to better understanding of concepts. In addition to S-parameters, this tutorial includes A-, Z-, and Y-parameters and their relevance to microwave network representation and design.**

***Index Terms*—$ABCD$-parameters, concept-map-based tutorial, immittance parameters, network characterization, scattering parameters.**

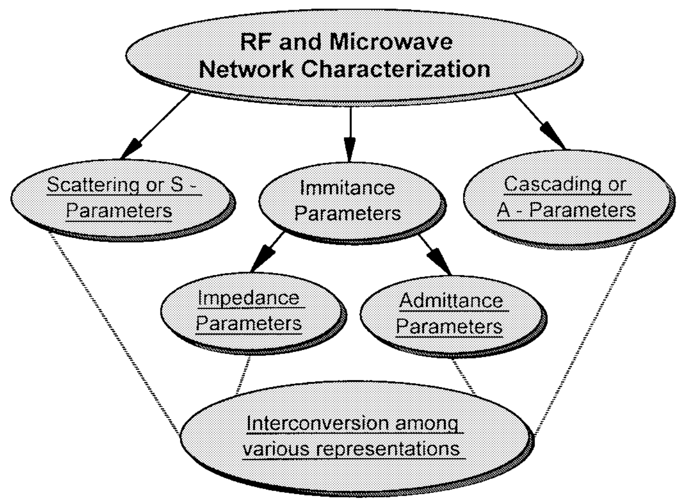

Fig. 1. Organization of the tutorial in four concept modules, one each for S-, A-, Z-, and Y-parameters.

I. INTRODUCTION

THIS paper is a tutorial presentation on the representations used for characterization of networks at RF and microwave frequencies. At these frequencies, circuits and systems can be viewed as multiport networks; the simplest case being a two-port network with an input-port (two terminals) and an output port (another two terminals). One of the terminals is usually common (reference) for these two ports. Signals at the ports may be represented in terms of the port voltages and port currents or in terms of wave variables (a and b) associated with incoming and outgoing waves at these two ports. The wave-variables representation leads to use of scattering parameters (S-parameters), which constitute the most commonly used format for (analytical and/or experimental) characterization of RF and microwave networks.

A basic understanding of S-parameters, in addition to that of conventional Y-, Z-, and $ABCD$-parameters, is essential for RF and microwave engineering. This topic is available in most of RF and microwave textbooks. However, the presentation here is in a different format as it makes use of the concept-maps/concept-module approach discussed in this TRANSACTIONS in [1]. The electronic version of this paper consists of 45 screens (all of them with audio narrations) including six computational modules (using Java applets).[1] Thirty-six of these screens include concept maps relevant to the discussion presented on that particular screen.

In addition to providing a tutorial on S-parameters (and other network representations—Z-, Y-, and $ABCD$-parameters), this paper and its electronic version may be used as an example of a tutorial based on the concept-mapping approach.

II. ORGANIZATION AND CONTENTS OF THE TUTORIAL

The tutorial consists of four interlinked concept modules, one each for S-, $ABCD$-, Z-, and Y-parameters, respectively. This organization is depicted in Fig. 1. The introductory part of the tutorial (before getting into any of the four modules) occupies four screens: title page, two screens of table of contents, and the introductory screen shown in Fig. 1. The table of contents is shown in two forms. Screen 2 shows the contents in the conventional form as we find in most of the textbooks. This is the linear form for representation of knowledge. The only difference is that each of the items in the list of contents is hyperlinked to the screen where that item is described. This is the electronic substitute to looking for the page number and flipping the pages to a particular location. The four concept modules may be accessed in any sequence.

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[1]This paper has supplementary downloadable material available at http://ieeexplore.ieee.org, provided by the authors. This includes a tutorial that makes use of concept maps and concept modules using audio narrations. This material is 18.6 MB in size.

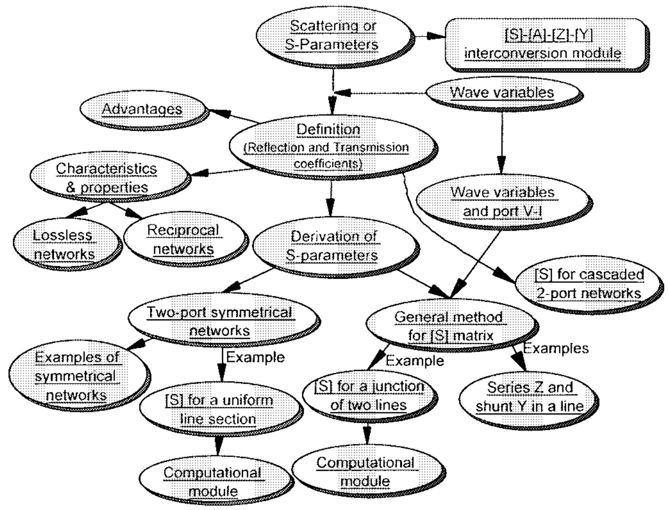

Fig. 2. Overall concept map for S-parameters concept module.

A. S-Parameter Module

The concept module on S-parameters consists of 19 screens (with concept maps, figures, text, and audio narrations) and three computational modules (java applets). An overall concept map for this module is shown in Fig. 2. Topics included in these concept maps are: 1) definition of S-parameters; 2) wave variables and port voltages and currents; 3) advantages of S-parameters; 4) characteristics of $[S]$ for lossless networks; 5) derivations of the two relations for lossless networks, evaluation of S-parameters for two-port networks; 6) examples of symmetrical two-port networks; 7) S-parameters for uniform line section; 8) a general method for nonsymmetrical networks; 9) S-parameters for a junction between two lines; 10) S-parameters for a series-Z and shunt-Y in a line; and 11) S-parameters for cascaded two-port networks. In addition to these 19 concept-map screens, the S-parameters module also includes the following three computational modules (java applets):

1) interconversion among S-, A-, Y-, and Z-parameters, which forms a part of all four modules;
2) network parameters of a transmission-line section, which has a link from Screen 16;
3) network parameters of cascaded two-port networks, which has a link from Screen 22.

The interconversion module, which can be accessed via a link from Screen 4 (or from the Table of Contents on Screens 2 and 3), allows the user to convert any of the S-, A-, Z-, and Y-parameters to any other of these parameters. The input and output information can be expressed in terms of real and imaginary parts of parameters or in terms of amplitude and angle. The angle values may be expressed either in radians or degrees. A warning message is displayed if any one kind of parameters cannot be calculated. The user can select the normalizing impedances for S-parameters. The default value is 50 Ω.

The computational module for network parameters of a transmission-line section, which has a link from Screen 16, finds S-, A-, Z-, or Y-parameters of a line of characteristic impedance Z_0, attenuation constant α, phase constant β, length l, and terminating impedances Z_{01} and Z_{02} at the two ports. The phase constant β can be specified by the user or calculated from the effective dielectric constant ε_{re} and the operating frequency (in gigahertz or megahertz). Any of the four S-, A-, Z-, or Y-parameters may be computed and expressed in terms of real and imaginary parts of parameters or in terms of amplitude and angle.

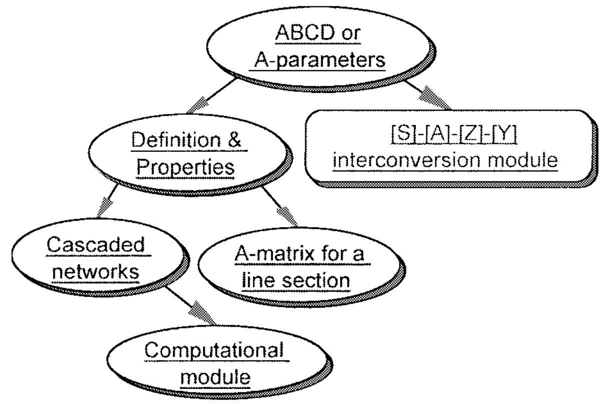

Fig. 3. Overall concept map for $ABCD$- or A-parameters concept module.

The computational module for network parameters of cascaded two-port networks has a link from Screen 22 or can be reached from the Table of Contents (Screens 2 or 3). This java applet calculates the network parameters of a cascaded two-port network AB composed of two networks A and B. Parameters of networks A and B, and the resulting parameters of cascaded network AB can be expressed in any of the four S-, A-, Z-, or Y-parameters. These parameter values can be in real/imaginary, amplitude/degree, or amplitude/radian format. Once the two networks have been cascaded, a third network can be added in cascade either on the left- (input) or right-hand side (output) of the network AB to obtain the results for three or more two-port networks connected in cascade.

B. $ABCD$-Parameter Module

$ABCD$-parameters are used extensively at RF and microwave frequencies because a number of circuits at these frequencies can be considered as being a cascade of two-port components. One of the very early microwave network analysis software was based on describing microwave networks as a cascade of two-port components and using $ABCD$-matrices for circuit analysis.

The $ABCD$-parameter concept module consists of four concept-map screens and is linked to two computational modules. The overall concept map for this module is shown in Fig. 3. Contents of this module include definition and properties of $ABCD$-parameters, $ABCD$-matrix of a transmission-line section, and $ABCD$-matrix for cascaded two-port networks. A link to the screen for relationship between the $ABCD$-matrix and Z-matrix is included. Two computational modules linked to this concept module are: 1) interconversion between $ABCD$ and other parameters and 2) a module for finding parameters of cascaded networks. Both of these computational modules have been described in Section II-A.

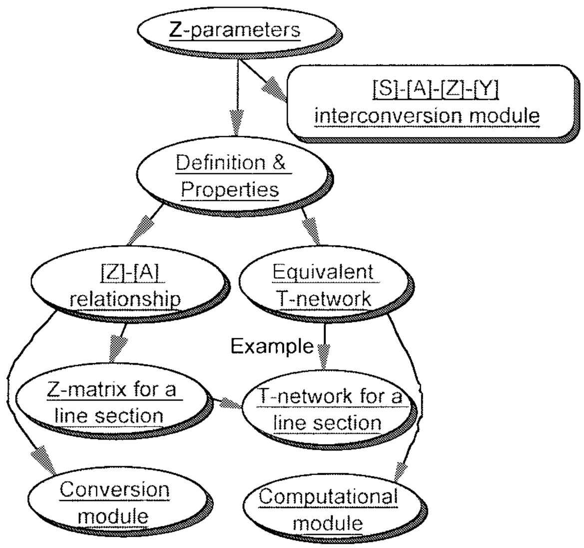

Fig. 4. Overall concept map for Z-parameters concept module.

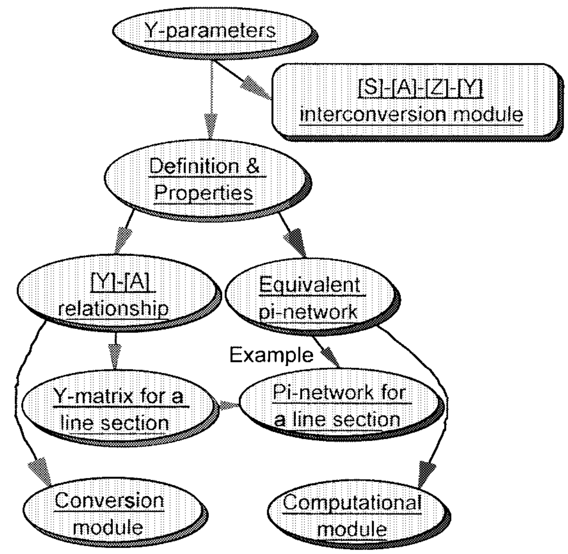

Fig. 5. Overall concept map for Y-parameter concept module.

C. Impedance- or Z-Parameter Module

The overall layout of the Z-parameters concept module is shown in Fig. 4. This module consists of six concept maps and is linked to three computational modules. Various concept maps in this module describe the: 1) definition and properties of Z-parameters; 2) relationship between Z- and $ABCD$-matrices; 3) Z-matrix of a transmission-line section; and 4) derivation of an equivalent lumped T-network representation from the Z-matrix. Similar to the case of the $ABCD$-parameters module, the Z-parameter module is also linked to the two computational modules for interconversion between various kinds of parameters, and for finding parameters of cascaded networks, as discussed earlier.

Another computational module, contained inside the Z-parameters concept module, allows the users to construct a lumped equivalent T-network from Z-parameters of a reciprocal network. This java applet also finds the network parameters when the three impedances in a T-network are specified. S-, Y-, Z-, and $ABCD$-parameters for the T-network can be calculated and the input/output data can be in real/imaginary, amplitude/degree, or amplitude/radian format. Of course, for finding S-parameters, we need the port impedances Z_{01} and Z_{02} at the two ports considered equal to Z_0. This module is very helpful in finding the lumped network equivalences for distributed circuits used extensively at RF and microwave frequencies.

D. Admittance- or Y-Parameter Module

The overall layout of this concept module is shown in Fig. 5. Similar to the structure for the module for Z-parameters, the Y-parameter concept module consists of five concepts maps and is linked to three computational modules. As in the previous case, various concept maps in this module describe the: 1) definition and properties of Y-parameters; 2) relationship between Y- and $ABCD$-matrices; 3) Y-matrix of a transmission-line section; and 4) derivation of an equivalent lumped π-network representation from the Y-matrix. As for the other modules, the Y-parameter module is also linked to the two computational modules for interconversion between various kinds of parameters, and for finding parameters of cascaded networks, as discussed earlier.

Just as we can derive an equivalent lumped T-network from Z-parameters, the admittance parameters may be used for deriving an equivalent lumped π-network. A computational module (java applet) is included for this purpose.

III. Concluding Remarks

A study of concept modules presented in the electronic version of this paper reveals several interesting features of this concept-mapping approach. These may be summarized as follows.

1) After a look at the Table of Contents, it is convenient to start with any item included in the tutorial and then to move forward or backward depending on one's background, expertise, and current interest. Thus, the learning process becomes more student centered as opposed to being instructor centered.
2) Visual display of concept maps, accompanying text, and audio narration are designed to reinforce each other.
3) Details of several mathematical derivations (not always required in the first reading) are made available by clicking at the links in the relevant concept maps.
4) The computational modules (java applets) associated with concept modules may be used independently by the users familiar with the subject matter.

The six computational modules included in this paper allow the users to: 1) convert any of the S-, A-, Z-, and Y-parameters into any other kind of parameters; 2) find network parameters for a junction of two lines; 3) find network parameters for a section of uniform transmission line with arbitrary normalizing impedances at two ports; 4) find network parameters for a cascade of two or more two-port networks; 5) find an equivalent lumped T-network when its network parameters (S-, A-, Z-, or Y-matrix) are known, and inversely find network parameters for a T-network when its impedances are known; and 6) find an equivalent lumped π-network when its parameters are known, and inversely find network parameters for a π-network when its admittances are known.

The authors hope that the case study that has been presented in this tutorial article serves as an example of the potentialities of the concept-maps and concept-modules approach for Web-based and CD-ROM-based tutorials. The authors look forward to more frequent applications of this approach to RF and microwave education.

REFERENCES

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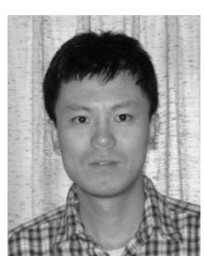

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