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 'concept-maps and concept-modules' approach discussed in another article [1] in this issue. 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: Network Characterization, Scattering Parameters, ABCD Parameters, Immittance Parameters, and Concept Map Based Tutorial.  

1. Introduction  
This article 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 2-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 concept-maps/concept-module approach discussed in a companion article [1] in this issue. The electronic version of this article consists of 45 screens (all of them with audio narrations) including six computational modules (using Java applets). 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 article and its electronic version may be used as an example of a tutorial based on concept-mapping approach.  

2. 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.

2.1 S-Parameters 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: definition of S-parameters, wave variables and port voltages and currents, advantages of S-parameters, characteristics of [S] for lossless networks, derivations of the two relations for lossless networks, evaluation of S-parameters for 2-port networks, examples of symmetrical 2-port networks, S-parameters for uniform line section, a general method for non-symmetrical networks, S-parameters for a junction between two lines, S-parameters for shunt-Y in a line, and S-parameters for cascaded two-port networks. In addition to these 19 concept-map screens, the S-parameters module also includes three computational modules (java applets): (i) Interconversion among S-, A-, Z-, and Y-parameters, that forms a part of all the four modules, (ii) Network parameters of a transmission line section, that has a link from Screen 16, and (iii) Network parameters of cascaded two-port networks, which has a link from Screen 22.

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 in 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 Ohms.

The computational module for network parameters of a transmission line section, that has a link from Screen 16, finds S-, A-, Z-, or Y-parameters of a line of characteristic impedance $Z_0$, attenuation constant $\alpha$, phase constant $\beta$, length $l$, and terminating impedances $Z_{01}$ and $Z_{02}$ at the two ports. The phase constant $\beta$ can be specified by the user or calculated from the effective dielectric constant $\varepsilon_r$ and the operating
frequency (in GHz or MHz). 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.

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 2-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-hand side (input) or on the right-hand side (output) of the network AB, to obtain the results for three or more two-port networks connected in cascade.

2.2 ABCD Parameters 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 4 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 ABCD matrix and Z-matrix is included. Two computational modules linked to this concept module are: interconversion between ABCD and other parameters, and a module for finding parameters of cascaded networks. Both of these computational modules have been described in Section 2.1.
2.3 Impedance- or Z-Parameters 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: definition and properties of Z-parameters, relationship between Z and ABCD- matrices, Z-matrix of a transmission line section, and derivation of an equivalent lumped T-network representation from Z-matrix. Similar to the case of ABCD-parameters module, 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 $Z_1$ and $Z_2$ 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.

2.4 Admittance- or Y-parameters Module

The overall layout of this concept module is shown in Fig. 5. Similar to the structure for the module for Z-parameters, Y-parameters 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: definition and properties of Y-parameters, relationship between Y- and ABCD- matrices, Y-matrix of a transmission line section, and derivation of an equivalent lumped pi-network representation from Y-matrix. As for the other modules, 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 pi-network. A computational module (java applet) is included for this purpose.

3. Concluding Remarks

A study of concept modules presented in the electronic version of this article 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 article and then to move forward or backward depending on one’s background, expertise, and current interest. Thus the learning process becomes more student-centered than being the 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 article allow the users to: (i) convert any of the S-, A-, Z-, and Y-parameters into any other kind of parameters; (ii) find network parameters for a junction of two lines; (iii) find network parameters for a section of uniform transmission line with arbitrary normalizing impedances at two ports; (iv) find network parameters for a cascade of two or more two-port networks; (v) 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 (vi) find an equivalent lumped pi-network when its parameters are known, and inversely find network parameters for a pi-network when its admittances are known.

Authors hope that the case study presented here serves as an example of the potentialities of the concept-maps and concept-modules approach for web-based and CDROM-based tutorials. We look forward to more frequent applications of this approach to RF and microwave education.

References:


Click here to go to Reference [1]