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By Richard F. Shea

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Consulting Engineer, Schenectady, New York

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Preface

In the more than ten years since the advent of the junction transistor, many books have been published on practically every aspect of transistor theory and applications. The wisdom of publishing still *another* book on such an already well-covered subject may, therefore, logically be questioned. The answer to this question has to be that another book on the subject, to be a worthwhile contribution to the art, must either present new information, or available information in a new way or for a new purpose. This, I submit, is the object of this book. It is not a textbook—most of the theoretical derivations have been deliberately omitted for the sake of conciseness. It is not a handbook—detailed treatments of all the aspects of the subject could not possibly be included in this amount of space. It is, in essence, a concise treatment of the subject, designed specifically for the industrial engineer who wishes to understand the basic theory of transistor applications, yet has neither the time nor the inclination to become expert in the field. It will not, therefore, generally enable the reader to design immediately transistor circuits, although there is considerable design detail included. It will, I trust, enable him to analyze transistor circuits, and thus learn how they work. With this beginning, and with a reasonable amount of supplementary study, the engineer-reader will then be ready to assume the burden of design.

Although not specifically designed as a textbook, this volume can still prove valuable as a supplemental text. I have had the privilege of teaching an industrial transistor course for many years, using as a text *Transistor Circuit Engineering*. In the course of this teaching I found it valuable to develop a set of supplemental notes to help emphasize certain aspects of the subject that were particularly difficult to understand, or, in some cases, to up-date the material or add new angles to the presentation. These notes formed the basis of the material in this book. Thus, this book can provide considerable practical "meat" to the skeleton formed by the usual theoretical textbook.

Additionally, the book has many qualities which can be of considerable value to the engineer who is already conversant with the basic transistor theory. For example, most textbooks, and many handbooks as well, are deficient from the standpoint of ease of utilization. Transistor specifications today almost universally employ a standard symbology and give their values in specific forms, yet all too often the designer working from available texts must convert these published values to some other form which happened to be more attractive to the author. As one aim, therefore, I determined, as far as practicable, to evolve all equations in such form that the reader could insert available specifications directly, without the necessity of conversion.

There are obvious deficiencies in an approach such as this, as well as advantages. The subject coverage is as extensive as is warranted for the avowed purpose, to give the reader understanding, not expertness. In many portions of the book, this means, however, that only typical designs can be included. As an example, the subject of transistor logic can easily be, and has been, expanded to encompass whole volumes. To compress such a subject within the relatively few pages alloted to it here therefore presents quite a challenge. I sincerely believe that I have managed to supply the necessary tools to understand the elements of this subject, and of the other phases of transistor technology included. Of course, having boiled the "fat" off the subject, as it were, the essential information left behind becomes easier to find! On this hopeful note I will end this preface.

RICHARD F. SHEA

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Schenectady, N.Y.

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Two-Port Networks

1.1 Introduction

A complicated electronic circuit may be broken up into a number of smaller circuits, or networks, connected in series, parallel, combinations of series and parallel, and cascade. These networks may contain active elements, such as transistors, passive elements, such as resistors or capacitors, or combinations of active and passive elements. Networks containing only passive elements are called passive networks, whereas those containing active elements are called active networks, though they may also contain passive elements.

A network has a number of "ports" to which external connections are made. A two-port network has an input port, to which a source is connected, and an output port, to which a load is usually connected, although occasionally the output may connect to a load containing an active element, such as a voltage source. In transistor circuits the input port is usually supplied from the signal source or a preceding stage, and the output port supplies signal to a load or to a succeeding stage.

1.2 Network Conventions

Figure 1.1 illustrates the conventions usually used in designating input and output currents and voltages. Note that the positive direction for current is flowing *into* the network. If the current actually flows *out* of the network, it is given a negative sign. This convention must be borne in mind when dealing with transistor circuits, since the

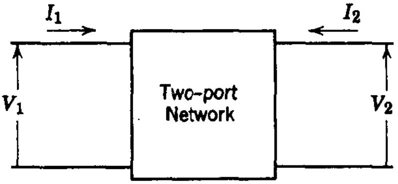

Fig. 1.1 Network voltage and current conventions.

direction of current will depend upon the type of transistor as well as on the circuit details, and we will be frequently encountering negative currents.

It will also be noted that no external connections are shown. This is one of the distinguishing features of network theory, in that it allows us to analyze the network without regard to external connections, then take these into effect subsequently by combining the termination representations with the formulations representing the network.

We can express the relations between the input and output currents and voltages in a number of ways. For example, we can use the impedance parameters and express the network behavior as follows:

$$V_1 = z_{11}I_1 + z_{12}I_2 \tag{1.1}$$

$$V_2 = z_{21}I_1 + z_{22}I_2 \tag{1.2}$$

The meaning of the above z parameters may be obtained by assuming that the input or output terminals are respectively open-circuited. Thus, if the output terminal is open I_2 becomes zero, and eqs. 1.1 and 1.2 reduce to $V_1 = z_{11}I_1$ and $V_2 = z_{21}I_1$ respectively. Therefore the parameter z_{11} is evidently the ratio V_1/I_1, or input impedance, with the output open-circuited. Likewise, the parameter z_{21} is V_2/I_1, or the open-circuited output voltage produced by an input current, divided by that input current. This is called the forward transfer impedance. In similar manner, by assuming that the input terminals are open, we can obtain equations defining the other two z parameters:

$$V_1 = z_{12}I_2 \qquad \text{and} \qquad V_2 = z_{22}I_2$$

Therefore, z_{12} is a backward transfer impedance with the input open-circuited and z_{22} is the output impedance with the input open. Thus we have defined the four z parameters in terms of input and output impedances and transfer impedances with either the input or the output port open.

1.3 Matrix Representation of Network Equations

A matrix equation is, in effect, a shorthand representation of the relationships given in eqs. 1.1 and 1.2. It is written in the following form:

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \tag{1.3}$$

Each of the three sections of eq. 1.3 contained in brackets is a matrix; thus this equation states that the voltage matrix is the product of an impedance matrix and a current matrix. Equation 1.3 can be further simplified to the form:

$$[V] = [Z][I] \tag{1.4}$$

where each bracketed symbol represents a voltage, impedance, or current matrix as given in eq. 1.3.

Another commonly used set of parameters consists of the admittance parameters. The relationships between inputs and outputs may be shown in the following form:

$$I_1 = y_{11}V_1 + y_{12}V_2 \tag{1.5}$$

$$I_2 = y_{21}V_1 + y_{22}V_2 \tag{1.6}$$

Following the method used for the z parameters, we can obtain meanings for the above y parameters, only now we must short-circuit the input or output terminals to eliminate the V_1 or V_2 terms, as desired. In this manner we find that:

y_{11} = input admittance with the output short-circuited;
y_{12} = backward transfer admittance with input short-circuited;
y_{21} = forward transfer admittance with output short-circuited;
y_{22} = output admittance with input short-circuited.

A third set of parameters, used most extensively in transistor circuit analysis, combines impedance, admittance, and ratios. These are the h parameters, and the current-voltage relationships are:

$$V_1 = h_{11}I_1 + h_{12}V_2 \tag{1.7}$$

$$I_2 = h_{21}I_1 + h_{22}V_2 \tag{1.8}$$

As before, we define these parameters, only now some are defined for short-circuited termination and some for open-circuited termination.

h_{11} = input impedance with output short-circuited;
h_{12} = backward voltage transfer ratio with input open-circuited;
h_{21} = forward current transfer ratio with output short-circuited;
h_{22} = output admittance with input open-circuited.

A fourth set of parameters also occasionally used in transistor circuit analysis consists of the g parameters, which are expressed as follows:

$$I_1 = g_{11}V_1 + g_{12}I_2 \tag{1.9}$$

$$V_2 = g_{21}V_1 + g_{22}I_2 \tag{1.10}$$

These parameters have the following meanings:

g_{11} = input admittance with output open-circuited;
g_{12} = backward current transfer ratio with input short-circuited;
g_{21} = forward voltage transfer ratio with output open-circuited;
g_{22} = output impedance with input short-circuited.

Finally, there are two other arrangements possible and these use the a and b parameters respectively. The matrix expressions are:

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix} \tag{1.11}$$

$$\begin{bmatrix} V_2 \\ I_2 \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ -I_1 \end{bmatrix} \tag{1.12}$$

Note the negative signs preceding the current terms in the third matrix of both equations.

Although these parameters can be defined in similar manner to the other parameters, these definitions can be anomalous, and it is more convenient to define them by relationship to the other, more easily defined, parameters. Thus:

$$a_{11} = \frac{1}{g_{21}} \qquad a_{12} = -\frac{1}{y_{21}} \qquad a_{21} = \frac{1}{z_{21}} \qquad a_{22} = -\frac{1}{h_{21}}$$

and

$$b_{11} = \frac{1}{h_{12}} \qquad b_{12} = -\frac{1}{y_{12}} \qquad b_{21} = \frac{1}{z_{12}} \qquad b_{22} = -\frac{1}{g_{12}} \tag{1.13}$$

The above definitions frequently permit calculation of these parameters by inspection. Consider, for example, the simple resistive network