COMPUTER CIRCUIT ANALYSIS

THEORY AND APPLICATIONS

FRANK A. ILARDI

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Technical Career Institutes

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To my sons FRANK B., MICHAEL, and STEVEN

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COMPUTER

CIRCUIT ANALYSIS

PREFACE

This book was written after extensive discussions with representatives of the electronic industry. These people, who do the hiring for their firms, said they look for technical school graduates with good knowledge of electronics fundamentals. They feel that they can then teach them their particular system. It was noted that when these representatives interviewed prospective graduates, they tested them on their understanding of circuit theory similar to that included in this text.

This book evolved from classroom lecture notes used in courses in pulse and digital circuits at Technical Career Institutes (formerly RCA Institutes). These courses were highly successful in training students for employment with nearly every company in the electronics industry.

The first three chapters are included in this book because in some schools much of this material is not taught until the courses in pulse and digital circuits are given. To learn these subjects, a thorough understanding of network theory, semiconductor switching devices, and computer math and logic is essential. These chapters can be used by students studying the abovementioned topics for the first time or as an excellent review by those who have had courses covering this material.

The various circuits used in computers are discussed in Chapters 4 through 11. Chapter 12 is included to answer questions that have so often been asked by students of the author: How are these circuits used? How are they packaged? What determines the number of circuits that can be included in an integrated-circuit package?

The material presented in this book should also be of great value to anyone already working in the electronics field. Because of the information covered in the first three chapters, a good background in electronics fundamentals is the only prerequisite to the use of this book. The most modern pulse and digital circuits are discussed, both a qualitative and a quantitative analysis is presented.

The author wishes to thank Sprague Electric Company, Fairchild Semiconductor, Signetics Corp., and Texas Instruments, Inc. for their cooperation. The information provided by these companies allowed the most up-to-date material to be included in this text.

Special thanks is given to Mr. William Brecher (Instructor, Computer Department, Technical Career Institutes) from whom the author learned a great deal about computers, and to Jacqueline Ilardi who typed the manuscript and helped with other details.

FRANK A. ILARDI

CONTENTS

1

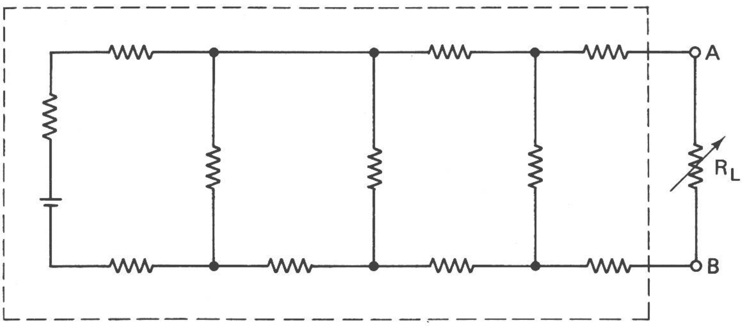
NETWORK ANALYSIS

To analyze pulse and digital circuits, it is often necessary to replace the circuit with a network of components equivalent to the actual circuit. The equivalent circuit is obtained by applying one or more network theorems. It is then analyzed by using either standard techniques or other network theorems. In this chapter only Thévenin's, Norton's, and Millman's theorems, which are used extensively throughout the text, are covered. RC time constant theory is also discussed because an understanding of these principles is essential in pulse and digital circuit analysis.

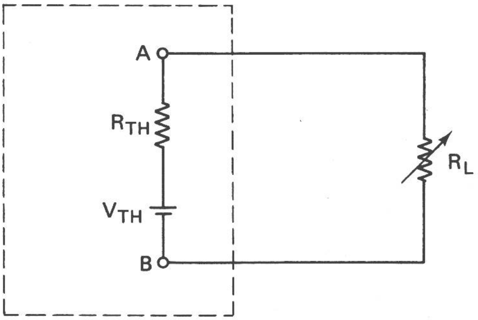
1-1 Thévenin's Theorem

Thévenin's theorem states that any two-terminal *linear* network, no matter how complex, may be replaced by a single voltage source in series with a single impedance. The value of this *Thévenin equivalent voltage* V_{TH} is the same as the voltage that appears across the load terminals if the load is replaced by an open circuit. The value of the *Thévenin impedance* Z_{TH} is the same as the impedance seen by the load when all sources are replaced by their internal impedance.

This theorem is extremely useful when a complex circuit with a changing (variable) load is analyzed. For example, every time that load resistance R_L changes in Fig. 1-1(a) all of the voltage drops and currents change. If the load voltage V_{R_L} must be determined for many different values of R_L, the entire circuit must be analyzed each time. In Fig. 1-1(b) that part of the circuit



(a)



(b)

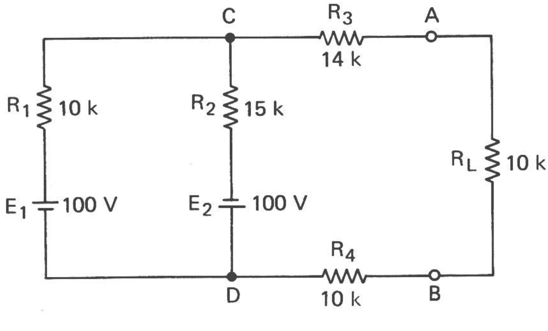
Fig. 1-1 (a) A complex series parallel circuit with a varying load. (b) The unchanging part of (a) replaced by its Thévenin equivalent.

which does *not* change is replaced by its Thévenin equivalent circuit. Now each time that R_L changes the voltage across R_L is easily calculated by

$$V_{R_L} = V_{TH}\left(\frac{R_L}{R_L + R_{TH}}\right) \tag{1-1}$$

Thévenin's theorem is also very useful when the output voltage of a circuit containing several voltage or current sources must be determined. In Fig. 1-2 a circuit containing two voltage sources is replaced by its Thévenin equivalent to produce a simple series circuit. The values of V_{TH} and R_{TH} in Fig. 1-2 are calculated by using the rules stated in the theorem, as follows:

Determine V_{TH} by removing R_L and calculating the open-circuit voltage from A to B ($V_{AB_{oc}}$). Figure 1-3(a) shows the circuit that must be analyzed to find V_{TH}.



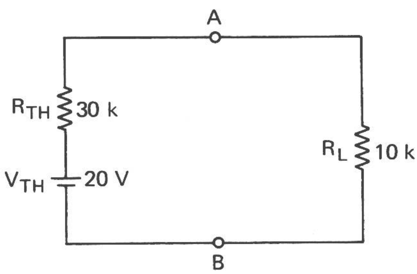


Fig. 1-2 (a) A circuit containing more than one source simplified in (b) by changing everything to the left of *A* and *B* to a Thévenin equivalent.

If $R_{AB} = \infty$,

$$I_{AB} = 0$$

and

$$V_{R_3} = V_{R_4} = 0$$

If $V_{R_3} = 0$,

$$V_A = V_C$$

and if $V_{R_4} = 0$,

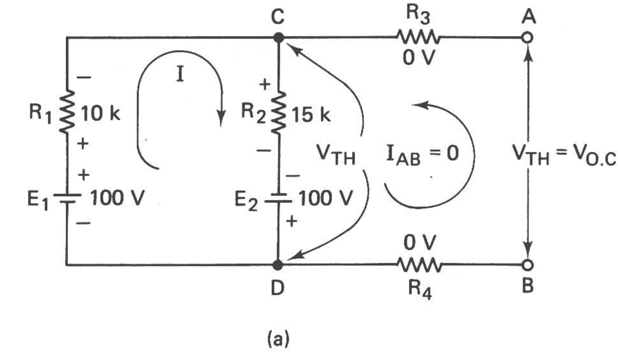
$$V_B = V_D$$

Hence

$$V_{AB} = V_{CD}$$

and

$$V_{CD} = V_{R_2} + E_2 = V_{R_1} + E_1$$



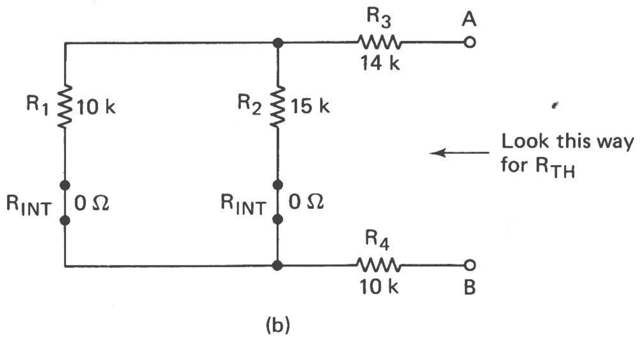


Fig. 1-3 (a) The circuit that must be analyzed to find V_{TH} in Fig. 1-2. (b) The circuit that must be analyzed to find R_{TH} in Fig. 1-2.

Therefore, to find V_{TH}, solve for either V_{R_1} or V_{R_2} and add it to the appropriate voltage source. With $R_{AB} = \infty$, the only current I flows through the series circuit shown in Fig. 1-3(a). Since E_1 and E_2 are series aiding, the total voltage in this loop is

$$E_T = E_1 + E_2$$
$$= 100 + 100$$
$$E_T = 200 \text{ V}$$

and

$$V_{R_1} = E_T \frac{R_1}{R_1 + R_2}$$
$$= 200 \frac{10}{25}$$
$$V_{R_1} = 80 \text{ V}$$

Therefore,

$$V_{CD} = V_{R_1} + E_1$$
$$= (-80) + (100)$$
$$V_{CD} = 20 \text{ V}$$

and

$$V_{TH} = 20 \text{ V}$$

The polarities for V_{R_1} and E_1 are those seen at the point C side of R_1 and E_1 when finding the voltage at C with respect to D.

Now solve for R_{TH} by replacing both sources with their internal resistance and by calculating the resistance seen by R_L. Fig. 1-3(b) shows the circuit that must be analyzed to find R_{TH}. Unless otherwise stated, assume that voltage sources have zero internal resistance and that current sources have infinite internal resistance. Then

$$R_{TH} = R_3 + R_4 + \frac{R_1 R_2}{R_1 + R_2}$$
$$= 14 + 10 + \frac{(10)(15)}{25}$$
$$R_{TH} = 30 \text{ k}\Omega$$

An alternate method of calculating V_{TH} is now shown.

$$V_{R_2} = E_T \frac{R_2}{R_1 + R_2}$$
$$= 200\frac{15}{25}$$
$$V_{R_2} = 120 \text{ V}$$

Hence,

$$V_{CD} = V_{R_2} + E_2$$
$$= (120) + (-100)$$
$$V_{CD} = 20 \text{ V}$$

In either case

$$V_{TH} = 20 \text{ V}$$

The Thévenin equivalent of more complex networks is found section by section. The circuit is broken (opened) so that a Thévenin equivalent can be determined for a circuit no more complex than the one illustrated in Fig.

1-3(a). Then the remaining circuit is replaced one section at a time. After each section is replaced, a new partial Thévenin equivalent is calculated until finally the entire circuit has been included. This is illustrated in Ex. 1-1 in which the Thévenin equivalent of Fig. 1-4(a) is calculated.

Example 1-1: Find the Thévenin equivalent of the circuit shown in Fig. 1-4(a).

Solution: If the circuit is broken at the points marked X, the circuit arrangement to the left of these points is exactly the same as Fig. 1-3(a), and since the same values are used,

$$V_{TH_{XX}} = 20 \text{ V}$$

and

$$R_{TH_{XX}} = 30 \text{ k}\Omega$$

This results in Fig. 1-4(b). By removing R_L and solving the remaining circuit [Fig. 1-4(c)] for V_{TH} and R_{TH} the overall Thévenin equivalent is found.

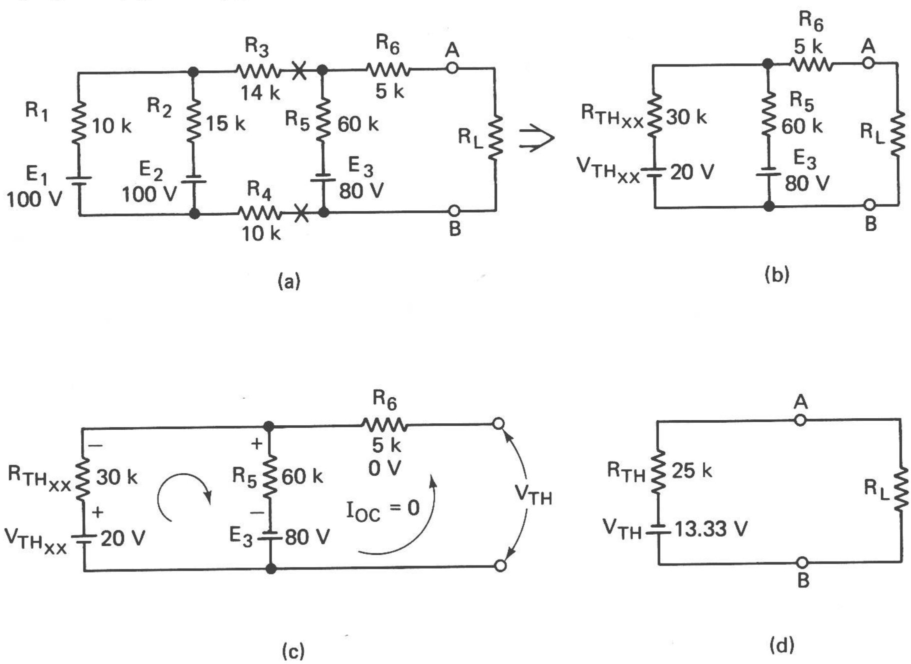


Fig. 1-4 (a) A more complex network containing three sources. (b) Fig. (a) partially simplified by finding the Thévenin equivalent of everything to the left of the points marked X. (c) Fig. (b) showing the only current with R_L removed. (d) The overall Thévenin equivalent circuit seen by R_L.

Solving for V_{TH}, it is determined that

$$V_{TH} = V_{AB_{oc}} = V_{R_5} + E_3$$

where

$$V_{R_5} = (V_{TH_{XX}} + E_3)\frac{R_5}{R_5 + R_{TH_{XX}}}$$

$$= 100\frac{60}{90}$$

$$V_{R_5} = 66.67 \text{ V}$$

Therefore,

$$V_{TH} = (+66.67) + (-80)$$

$$V_{TH} = -13.33 \text{ V}$$

Solving for R_{TH}, it is determined that

$$R_{TH} = R_6 + \frac{R_5 R_{TH_{XX}}}{R_5 + R_{TH_{XX}}}$$

$$= 5 + \frac{(60)(30)}{90}$$

$$R_{TH} = 25 \text{ k}\Omega$$

Because of the complexity of some circuits the Thévenin equivalent cannot always be found directly. In such cases other theorems are used to first simplify the circuit; then V_{TH} and R_{TH} are calculated.

1-2 Norton's Theorem

Norton's theorem states that any two-terminal linear network, no matter how complex, can be replaced by a single current source in parallel with a single impedance. The value of this *Norton equivalent current* I_N is the same as the current that flows between the load terminals if the load is replaced by a short circuit. The value of the *Norton impedance* Z_N is the same as the impedance seen by the load when all sources are replaced by their internal impedance. Note that Z_N *is the same as* Z_{TH}.

Norton's theorem is very useful when the load impedance $Z_L \ll Z_N$. For example, in Fig. 1-5, R_L varies between 10 and 100 Ω. When $R_L = 10\,\Omega$

$$I_L = I_N\frac{R_N}{R_L + R_N}$$

$$= 0.5 \text{ mA}\,\frac{10{,}000\,\Omega}{10{,}010\,\Omega}$$

$$I_L \approx 0.5 \text{ mA}$$