ELECTRIC CIRCUITS

A TEXT AND SOFTWARE PROBLEMS MANUAL

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A TEXT AND SOFTWARE PROBLEMS MANUAL

Mitchel E. Schultz

Western Wisconsin Technical College

GLENCOE

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PREFACE

Electric Circuits: A Text and Software Problems Manual is designed for use in introductory courses offered by two-year colleges and technical institutes. The manual is intended to be used as a supplement to any basic dc/ac textbook, and is written for the beginning electronics student with no prior experience in the field of electricity and electronics.

The text includes 21 chapters ranging from a review of powers of 10 through coverage of both dc and ac circuits. The emphasis throughout the text is on basic concepts. Each chapter begins with a short introduction that gives a general description of the topic presented in the chapter. Within each chapter the topic presented is covered thoroughly. The topics are divided into as many parts as necessary to help students gain the best understanding of the material. Also, within each chapter, several examples apply the concepts and formulas introduced in the text. The symbols, units, notations, and abbreviations used throughout the text reflect the most current standards in the field of electronics.

Computer Software

Electric Circuits: A Text and Software Problems Manual includes abundant practice problems for all 21 chapters. All problems are contained in the computer software package, rather than in the text itself. The computer software features problems that reinforce learning of the basic concepts. Chapters 2, 4, 5, 6, 10, 14, and 17 include a special section in the computer software where students can create their own circuit problems. This allows the students to have an almost endless variety of practice problems to solve.

The computer software is designed to provide students with immediate feedback. This means that if a student solves a problem incorrectly, the computer prompts him or her to try again. After three incorrect tries, the computer displays the correct answers for the problem at hand. Another popular feature of the computer software is a pop-down calculator for students to use while solving the problems. The calculator provides all the necessary functions for solving problems provided in the software. As you will see, the computer software is both fun and easy to use.

To the Student

As Henry Ford once said, "Thinking is very hard work. That's why so few people do it." You'll need to think hard, review concepts, and apply them in order to get a true understanding of the concepts being introduced. Your study of electronics will be hard work, but the rewards will be tenfold. Also, if you are truly committed to the study of electronics you must never stop learning. Keep up-to-date with the new devices available, their applications, and the changes they make in our everyday world. Good luck, and have fun!

Acknowledgments

I would like to thank Cathy Welch for her tireless efforts in typing the manuscript. Her efforts are greatly appreciated.

Also, I would like to thank those people who have influenced me positively throughout my career as an electronics technician, instructor, and author. They include Bruce T. Hering, Lowell Freeland, Bill Beck, Don Welch, Vince Lynch, Al Bush, and John E. Hoeft. All these men have contributed to my successful electronics career. Thank you all very much.

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CHAPTER 1
POWERS OF 10

In the field of electronics, the magnitude of the various units can be extremely small or extremely large. To simplify the many mathematical operations encountered in the field of electronics, powers of 10 are used. An *exponent* is a number written above and to the right of a given number, called the *base*. The exponent, or power, indicates how many times the base is to be multiplied by itself. The base 10 is commonly used in electronics because multiples of 10 are used in the metric system of units. In general, powers of 10 allow us to keep track of the decimal point when working with very small and very large numbers.

Positive powers of 10 are used to represent numbers greater than 1, and negative powers of 10 are used to represent numbers less than 1. Table 1–1 shows the powers of 10 ranging from 10^{-12} to 10^{9}. As you will discover in your study of electronics, seldom will you use powers of 10 that fall outside this range. From Table 1–1, observe that $10^0 = 1$ and $10^1 = 10$. In the case of $10^0 = 1$, it is important to note that any number raised to the 0 power equals 1. In the case of $10^1 = 10$, it is important to realize that any number written without a power is assumed to have a power of 1.

1–1 SCIENTIFIC NOTATION

The procedure required for using powers of 10 is to write the original number as two separate factors. A number is said to be written in *scientific notation* if it is written as the product of a number greater than or equal to 1 and less than 10 and a power of 10. The power-of-10 factor is used to place the decimal point correctly. As will be shown, the power of 10 indicates the number of places the decimal point has been moved to the left or right. If the decimal point is moved to the left in the original number, the power of 10 will be positive. On the other hand, if the decimal point is moved to the right in the original number, the power of 10 will be negative.

Example 1 Express 18,000 in scientific notation.

Answer 1.8×10^4

Notice that the decimal point in Example 1 has been shifted four places to the left. Notice also that the power of 10 is positive and equals 4, the same number of places the decimal point has been moved to the *left* in the original number.

Example 2 Express 0.000056 in scientific notation.

Answer 5.6×10^{-5}

Notice that the decimal point in Example 2 has been shifted five places to the right. Notice also that the power of 10 is negative and equals −5, the same number of places the decimal point has been moved to the *right* in the original number.

In both Examples 1 and 2 the original number was converted to a number greater than or equal to 1 and less than 10. The resulting number was then multiplied by the appropriate power of 10. Both results are in scientific notation. When expressing numbers in scientific notation, remember the following rules.

Table 1–1
Powers of 10

1,000,000,000	=	10^{9}
100,000,000	=	10^{8}
10,000,000	=	10^{7}
1,000,000	=	10^{6}
100,000	=	10^{5}
10,000	=	10^{4}
1,000	=	10^{3}
100	=	10^{2}
10	=	10^{1}
1	=	10^{0}
0.1	=	10^{-1}
0.01	=	10^{-2}
0.001	=	10^{-3}
0.0001	=	10^{-4}
0.00001	=	10^{-5}
0.000001	=	10^{-6}
0.0000001	=	10^{-7}
0.00000001	=	10^{-8}
0.000000001	=	10^{-9}
0.0000000001	=	10^{-10}
0.00000000001	=	10^{-11}
0.000000000001	=	10^{-12}

Rule 1 When expressing numbers in scientific notation, moving the decimal point in the original number to the left makes the power of 10 positive and moving the decimal point to the right makes the power of 10 negative.

Rule 2 For numbers expressed in scientific notation, the power of 10 always equals the number of places the decimal point has been moved to the left or right.

To test your understanding of the material presented in this section, select "Chapter 1, Section 1–1" from the menu screen.

1–2 ENGINEERING NOTATION AND METRIC PREFIXES

Engineering notation is very much like scientific notation. The difference is that in engineering notation, the powers of 10 are always multiples of 3. Engineering notation is preferred in electronics because most values are usually specified in terms of the metric prefixes such as milli (10^{-3}), micro (10^{-6}), and mega (10^{6}). Because of these frequently used prefixes, it is common practice to write a number so that the power of 10 is a multiple of 3 rather than writing it in scientific notation.

Table 1–2 lists the most common metric prefixes and their respective powers of 10. You should memorize this table. Notice that uppercase letters are used for the abbreviations for the prefixes involving positive powers of 10, whereas lowercase letters are used for negative powers of 10. There is one exception to this rule; the lowercase letter *k* is used for kilo, corresponding to 10^3.

Table 1–3 lists many of the electrical quantities that you will encounter in your study of electronics. For each electrical quantity listed in Table 1–3, take special note of the units and symbols shown. In the examples and problems that follow, we will use numerical values with the various units from this table.

Example 3 **Write 2,700,000 Ω in engineering notation, and then replace the power of 10 with its corresponding metric prefix.**

Answer **2,700,000 Ω = 2.7×10^6 Ω. Referring to Table 1–2, note that the metric prefix M corresponds to a power of 10^6. This gives us 2,700,000 Ω = 2.7×10^6 Ω = 2.7 MΩ. It is common practice to substitute the appropriate metric prefix for a power of 10 listed in Table 1–2.**

Table 1–2
Metric Prefixes

Power of 10	Prefix	Abbreviation
10^{12}	tera-	T
10^{9}	giga-	G
10^{6}	mega-	M
10^{3}	kilo-	k
10^{-3}	milli-	m
10^{-6}	micro-	μ
10^{-9}	nano-	n
10^{-12}	pico-	p

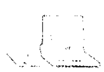
Table 1–3
Electric Quantities with Their Units and Symbols

Quantity	Unit	Symbol
Current	Ampere (A)	I
Electromotive force	Volt (V)	V
Resistance	Ohm (Ω)	R
Frequency	Hertz (Hz)	f
Capacitance	Farad (F)	C
Inductance	Henry (H)	L
Power	Watt (W)	P

Example 4 Write 0.015 A in engineering notation, and then replace the power of 10 with its corresponding metric prefix.

Answer $0.015 \text{ A} = 15 \times 10^{-3}$ A. Refer to Table 1–2 to see that the metric prefix m corresponds to a power of 10^{-3}. Finally, replace 10^{-3} with the metric prefix m. This gives $0.015 \text{ A} = 15 \times 10^{-3} \text{ A} = 15$ mA. Again, it is common practice to substitute the appropriate metric prefix for a power of 10 listed in Table 1–2.

Rule 3 When using metric prefixes to express a quantity, write the original number in engineering notation and then substitute the metric prefix for the power of 10 involved.



To test your understanding of the material presented in this section, select "Chapter 1, Section 1–2" from the menu screen.

1–3 CONVERTING BETWEEN METRIC PREFIXES

As you've already seen, metric prefixes can be substituted for certain powers of 10. It is sometimes necessary to convert from one metric prefix to another. When converting from one metric prefix to another, the numerical part of the expression must also be changed so that the value of the original number remains the same.

Example 5 Convert 15 mV to microvolts (μV).

Answer First recall that the prefix m corresponds to 10^{-3} and that the prefix μ corresponds to 10^{-6}. Since 10^{-6} is less than 10^{-3}, the numerical part of the expression will have to be increased to retain the value of the original expression. Since the prefix value decreased by a factor of 10^3, the numerical part of the expression must be increased by a factor of 10^3. Therefore, $15 \times 10^{-3} \text{ V} = 15{,}000 \times 10^{-6}$ V, or, simply, 15 mV = 15,000 μV.

Example 6 Convert 1510 kHz to megahertz (MHz).

Answer First recall that the prefix k corresponds to 10^3 and that the prefix M stands for 10^6. Since 10^6 is greater than 10^3, the numerical part of the expression has to be decreased in order to retain the value of the original expression. Since the prefix value increased by a factor of 10^3, the numerical part of the expression must be decreased by a factor of 10^3. Therefore, 1510×10^3 Hz $= 1.51 \times 10^6$ Hz, or, simply, 1510 kHz = 1.51 MHz.

It should be obvious that working with metric prefixes is the same as working with powers of 10.

When converting from one metric prefix to another, observe the following rule.

Rule 4 When converting from a larger metric prefix to a smaller one, increase the numerical part of the expression by the same factor that the metric prefix has been decreased. When converting from a smaller metric prefix to a larger one, decrease the numerical part of the expression by the same factor that the metric prefix has been increased.

To test your understanding of the material presented in this section, select "Chapter 1, Section 1–3" from the menu screen.

1–4 ADDITION AND SUBTRACTION USING POWERS OF 10

When adding numbers that are expressed using powers of 10, the powers of 10 for all terms must be the same before the terms can be added. When all terms have identical powers of 10, just add the numerical parts of each term and then multiply the sum by the power of 10 common to each term.

Example 7 Add 25×10^4 and 75×10^3.

Answer First, we must express both terms using either 10^3 or 10^4 as the power of 10. Either one can be used. For this example we will use 10^3 as the power of 10 for each term. Rewriting 25×10^4, we have 250×10^3. (We simply divided 10^4 by 10 and then multiplied the numerical factor, 25, by 10.) The numerical value of this term remains the same even though the power of 10 used is different. Summarizing, we have $(25 \times 10^4) + (75 \times 10^3) = (250 \times 10^3) + (75 \times 10^3) = 325 \times 10^3$. Expressed in scientific notation, the answer is 3.25×10^5.

When subtracting numbers that are expressed using powers of 10, the powers of 10 for each term must be the same before the numbers can be subtracted. When all terms have identical powers of 10, just subtract the numerical parts of each term and then multiply the difference by the power of 10 common to each term.

Example 8 Subtract 400×10^3 from 2×10^6.

Answer First, we must express both terms using either 10^3 or 10^6 as the power of 10. Either one can be used. For this example we will use 10^6 as the power of 10 for each term. Rewriting 400×10^3, we have 0.4×10^6. (We simply multiplied 10^3 by 10^3 and then divided the numerical part, 400, by 10^3.) The numerical value of this term remains the same even though the power of 10 used is different. Summarizing, we have $(2 \times 10^6) - (400 \times 10^3) = (2 \times 10^6) - (0.4 \times 10^6) = 1.6 \times 10^6$.

Rule 5 When adding or subtracting numbers that are expressed using powers of 10, the powers of 10 used for the terms must be the same before the terms can be added or subtracted. When all terms have identical powers of 10, simply add or subtract the numerical parts of each term and then multiply the result by the power of 10 common to each term.

To test your understanding of the material presented in this section, select "Chapter 1, Section 1–4" from the menu screen.

1–5 MULTIPLICATION AND DIVISION USING POWERS OF 10

When multiplying or dividing numbers expressed using powers of 10, the powers of 10 do not have to be the same before they can be multiplied or divided. To multiply numbers expressed using powers of 10, observe the following rule.

Rule 6 When multiplying numbers expressed using powers of 10, multiply the numerical parts and powers of 10 separately. When multiplying powers of 10, add the exponents to obtain a new power of 10.

Example 9 Multiply 2×10^4 by 40×10^2.

Answer First, we multiply 2×40 to get 80. Next, we multiply $10^4 \times 10^2$ to get 10^{4+2}, or 10^6. Summarizing, $(2 \times 10^4) \times (40 \times 10^2) = 80 \times 10^6$, or 8.0×10^7.

To divide numbers expressed using powers of 10, observe the following rule.

Rule 7 When dividing numbers expressed using powers of 10, divide the numerical parts and powers of 10 separately. When dividing powers of 10, subtract the power of 10 in the denominator from the power of 10 in the numerator to obtain the new power of 10.

Example 10 Divide 500×10^5 by 25×10^2.

Answer First, we divide 500 by 25 to get 20. Next, we divide 10^5 by 10^2 to get 10^{5-2}, or 10^3. Finally, as an answer, we have 20×10^3. Summarizing,

$$\frac{500 \times 10^5}{25 \times 10^2} = \frac{500}{25} \times \frac{10^5}{10^2} = 20 \times 10^3, \quad \text{or} \quad 2.0 \times 10^4$$

To test your understanding of the material presented in this section, select "Chapter 1, Section 1–5" from the menu screen.

1–6 RECIPROCALS WITH POWERS OF 10

Taking the reciprocal of a power of 10 is really a special case of division using powers of 10. A numerator of 1 can be written as 10^0. As will be seen, taking the reciprocal of a power of 10 results in a sign change for the power of 10.

Example 11 Find the reciprocal of 10^6.

Answer

$$\frac{1}{10^6} = \frac{10^0}{10^6} = 10^{0-6} = 10^{-6}$$

Notice that taking the reciprocal of a power of 10 results in a sign change for the power of 10.

Rule 8 When taking the reciprocal of a power of 10, keep the power of 10 the same, but change its sign.

To test your understanding of the material presented in this section, select "Chapter 1, Section 1–6" from the menu screen.

1–7 SQUARING NUMBERS EXPRESSED USING POWERS OF 10

In some cases it may be necessary to square numbers expressed using powers of 10. When squaring numbers expressed using powers of 10, observe the following rule.

Rule 9 To square any number expressed using a power of 10, square the numerical part of the expression and double the exponent.

Example 12 Square 4.0×10^2.

Answer We square 4 to obtain 16. Next, $(10^2)^2 = 10^4$, so $(4 \times 10^2)^2 = 16 \times 10^4$. Expressing the answer of 16×10^4 in scientific notation gives 1.6×10^5.

To test your understanding of the material presented in this section, select "Chapter 1, Section 1–7" from the menu screen.

1–8 SQUARE ROOTS OF NUMBERS EXPRESSED USING POWERS OF 10

In many cases it is necessary to find the square root of numbers expressed using powers of 10. When taking the square root of numbers expressed using powers of 10, observe the following rule.

Rule 10 To find the square root of a number expressed as a power of 10, take the square root of the numerical part of the expression and divide the exponent by 2.

Example 13 Find the square root of 9×10^4.

Answer

$$\sqrt{9 \times 10^4} = \sqrt{9} \times \sqrt{10^4}$$
$$= 3 \times 10^2$$

Here we take the square root of 9 to obtain 3. Next, we take the square root of 10^4 by dividing the exponent by 2, yielding 10^2.

In some cases a power of 10 is not divisible by 2. In such a case it is easiest to convert the number to one involving a power of 10 divisible by 2 before taking the square root.

Example 14 Find the square root of 40×10^3.

Answer Here, the problem is simplified if we increase the power of 10 and decrease the numerical part of the expression. We can increase 10^3 to 10^4 and decrease 40 to 4. Then we have the following:

$$\sqrt{40 \times 10^3} = \sqrt{4 \times 10^4} = 2 \times 10^2$$

To test your understanding of the material presented in this section, select "Chapter 1, Section 1–8" from the menu screen.

CHAPTER 2

OHM'S LAW AND POWER

For electric circuits, the relationship between voltage, current, and resistance is clearly expressed in a simple but extremely valuable law known as *Ohm's law.* This law states that the current (I) in amperes (A) is equal to the voltage (V) in volts (V) divided by the resistance (R) in ohms (Ω). Expressed as an equation, Ohm's law is

$$I = \frac{V}{R} \tag{2–1}$$

where: I = current in amperes (A)
V = voltage in volts (V)
R = resistance in ohms (Ω)

2–1 APPLYING OHM'S LAW

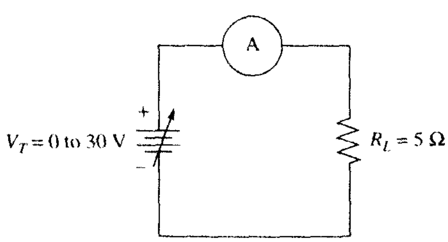
For a given circuit, the current (I) can be calculated when the voltage and resistance are known. Simply divide the voltage (V) by the resistance (R), as shown in Equation 2–1.

Example 1 A 10-Ω resistor is connected across a 50-V dc source. Calculate the current (I).

Answer Using Equation 2–1, we proceed as follows:

$$I = \frac{V}{R} = \frac{50\text{ V}}{10\ \Omega} = 5\text{ A}$$

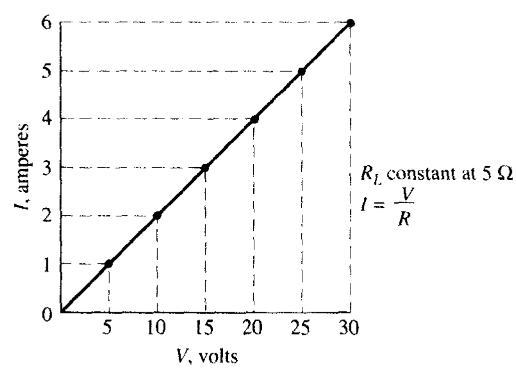
For Example 1, the current (I) can be increased by either increasing V or decreasing R. Likewise, the current (I) can be decreased by either decreasing V or increasing R.



(a)

Volts, V	Ohms, Ω	Amperes, A
0 V	5 Ω	0 A
5 V	5 Ω	1 A
10 V	5 Ω	2 A
15 V	5 Ω	3 A
20 V	5 Ω	4 A
25 V	5 Ω	5 A
30 V	5 Ω	6 A

(b)



(c) *(discussed on next page)*

Figure 2–1
The current (I) is directly proportional to the voltage (V). (a) Circuit with variable V but constant R. (b) Table of increasing I for higher V values. (c) Graph of the I and V values. The graph shows a direct proportion between V and I.

The circuit, table, and graph in Figure 2–1 (p. 9) are used to illustrate that V and I are directly proportional. Figure 2–1(a) shows a voltage source, V_T, that is variable over a range of 0 to 30 V. The table in Figure 2–1(b) shows how the current (I) varies as the voltage is increased in 5-V increments. Finally, Figure 2–1(c) shows a graph of the values of I and V. For each row in the table of Figure 2–1(b), the current (I) is calculated as V/R.

First row: $I = \dfrac{0\text{ V}}{5\ \Omega} = 0\text{ A}$

Second row: $I = \dfrac{5\text{ V}}{5\ \Omega} = 1\text{ A}$

Third row: $I = \dfrac{10\text{ V}}{5\ \Omega} = 2\text{ A}$

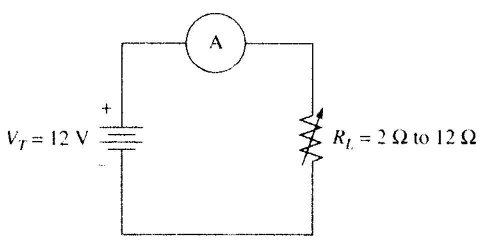
Fourth row: $I = \dfrac{15\text{ V}}{5\ \Omega} = 3\text{ A}$

Fifth row: $I = \dfrac{20\text{ V}}{5\ \Omega} = 4\text{ A}$

Sixth row: $I = \dfrac{25\text{ V}}{5\ \Omega} = 5\text{ A}$

Seventh row: $I = \dfrac{30\text{ V}}{5\ \Omega} = 6\text{ A}$

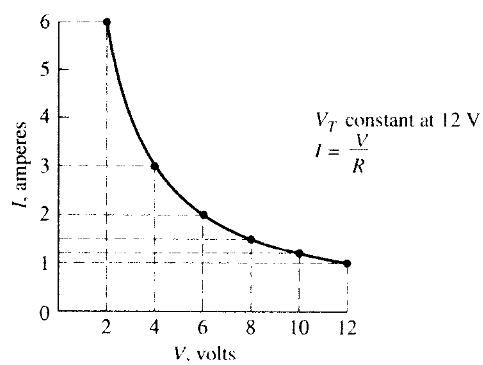
From the calculated values of current shown, we see that the current (I) increases in direct proportion to the voltage (V). What this really means is that equal increases in voltage produce equal increases in current. Doubling the voltage doubles the current, tripling the voltage triples the current, etc.



(a)

R_L (Ω)	V_T (V)	I (A)
2 Ω	12 V	6 A
4 Ω	12 V	3 A
6 Ω	12 V	2 A
8 Ω	12 V	1.5 A
10 Ω	12 V	1.2 A
12 Ω	12 V	1 A

(b)



(c)

(discussed on next page)

Figure 2–2
The current (I) is inversely proportional to the resistance (R). (a) Circuit with variable R but constant V. (b) Table of decreasing I for higher R values. (c) Graph of the I and V values. This graph shows that the relationship between I and R is not linear.