

Farzin Asadi

Electric Circuits Laboratory Manual

Synthesis Lectures on Electrical Engineering

This series of short books covers a broad spectrum of titles of interest in electrical engineering that may not specifically fit within another series. Books will focus on fundamentals, methods, and advances of interest to electrical and electronic engineers.

Farzin Asadi

Electric Circuits Laboratory Manual

Farzin Asadi
Department of Electrical and Electronics
Engineering
Maltepe University
Istanbul, Turkey

ISSN 1559-811X ISSN 1559-8128 (electronic)
Synthesis Lectures on Electrical Engineering
ISBN 978-3-031-24551-0 ISBN 978-3-031-24552-7 (eBook)
<https://doi.org/10.1007/978-3-031-24552-7>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This is a book for a lab course meant to accompany, or follow, any first course in electric circuit analysis. It has been written for sophomore or junior electrical and computer engineering students who are taking their first lab, either concurrently with their first electric circuit analysis class or following that class. This book is appropriate for non-majors, such as students in other branches of engineering and in physics, for which electric circuits is a required course or elective and for whom a working knowledge of electric circuits is desirable.

This book has the following objectives:

1. To support, verify, and supplement the theory; to show the relations and differences between theory and practice.
2. To teach measurement techniques.
3. To convince students that what they are taught in their lecture classes is real and useful.
4. To help make students tinkerers and make them used to asking “what if” questions.

This book contains 33 experiments which help the reader to explore the concepts studied in the classroom. Here is a brief summary of the chapters and appendixes:

Chapter 1 introduces the commonly used measurement devices that are used during the experiments and breadboard to the reader.

Chapter 2 studies the resistors. This chapter contains 9 experiments.

Chapter 3 studies the details of measurement with Digital Multi Meters (DMM). This chapter contains 7 experiments.

Chapter 4 studies some of the important circuit theorems like Kirchhoff’s Voltage Law (KVL), Kirchhoff’s Current Law (KCL), nodal analysis, mesh analysis, and Thevenin equivalent circuit. This chapter contains 5 experiments.

Chapter 5 studies the first order (RC and RL) and second order (series and parallel RLC) circuits. This chapter contains 4 experiments.

Chapter 6 studies the DC and AC steady state behavior of electric circuits. Frequency response of filters are studied in this chapter as well. This chapter contains 5 experiments.

Chapter 7 studies magnetic coupling and transformers. This chapter contains 3 experiments.

Appendix A shows how to draw different types of graphs with MATLAB®.

Appendix B reviews the concept of Root Mean Square (RMS).

I hope that this book will be useful to the readers, and I welcome comments on the book.

Istanbul, Turkey

Farzin Asadi

farzinasadi@maltepe.edu.tr

Contents

1	Commonly Used Laboratory Equipmentes	1
1.1	Introduction	1
1.2	Digital Multi Meter (DMM)	1
1.3	Function Generator (Signal Generator)	2
1.4	Oscilloscope	4
1.5	Power Supply	5
1.6	Breadboard	5
	Reference for Further Study	14
2	Resistors	15
2.1	Introduction	15
2.2	Tolerance of Resistors	15
2.2.1	Introduction	15
2.2.2	Procedure	19
2.3	Measurement of Low Resistances	21
2.3.1	Introduction	21
2.3.2	Procedure	21
2.4	Measurement of Very Low Resistances	22
2.4.1	Introduction	22
2.4.2	Procedure	22
2.5	Series and Parallel Connection of Resistors	23
2.5.1	Introduction	23
2.5.2	Procedure	25
2.6	Ohm's Law	26
2.6.1	Introduction	26
2.6.2	Procedure	26
2.7	Potentiometer	28
2.7.1	Introduction	28
2.7.2	Procedure	31

2.8	Light Dependent Resistor (LDR)	32
2.8.1	Introduction	32
2.8.2	Procedure	33
2.9	Thermistor	34
2.9.1	Introduction	34
2.9.2	Procedure	36
2.10	Observing the Current Waveform	36
2.10.1	Introduction	36
2.10.2	Procedure	38
	Reference for Further Study	39
3	Digital Multi Meter	41
3.1	Introduction	41
3.2	Internal Resistance of DMM in Voltage Measurement Mode	41
3.2.1	Introduction	41
3.2.2	Procedure	41
3.3	Internal Resistance of DMM in Current Measurement Mode	43
3.3.1	Introduction	43
3.3.2	Procedure	43
3.4	Test Current of DMM in Resistance Measurement Mode	45
3.4.1	Introduction	45
3.4.2	Procedure	45
3.5	DC Component (Average Value) Measurement with DMM	46
3.5.1	Introduction	46
3.5.2	Procedure	47
3.6	RMS Measurement with DMM	49
3.6.1	Introduction	49
3.6.2	Procedure	50
3.7	True RMS DMM's	54
3.7.1	Introduction	54
3.7.2	Procedure	54
3.8	Frequency Response of the AC Voltmeter and AC Ammeter	55
3.8.1	Introduction	55
3.8.2	Procedure	56
	Reference for Further Study	61
4	Circuit Theorems	63
4.1	Introduction	63
4.2	Voltage Division, Current Division and KCL	63
4.2.1	Introduction	63
4.2.2	Procedure	64

4.3	Nodal Analysis	65
4.3.1	Introduction	65
4.3.2	Procedure	67
4.4	Mesh Analysis	67
4.4.1	Introduction	67
4.4.2	Procedure	69
4.5	Thevenin Theorem	70
4.5.1	Introduction	70
4.5.2	Procedure	73
4.6	Maximum Power Transfer	74
4.6.1	Introduction	74
4.6.2	Procedure	75
	References for Further Study	75
5	First Order and Second Order Circuits	77
5.1	Introduction	77
5.2	Output Resistance of Function Generator	77
5.2.1	Introduction	77
5.2.2	Procedure	77
5.3	Step Response of RC Circuit	79
5.3.1	Introduction	79
5.3.2	Procedure	86
5.4	Step Response of RL Circuit	87
5.4.1	Introduction	87
5.4.2	Procedure	91
5.5	Step Response of Series RLC Circuit	92
5.5.1	Introduction	92
5.5.2	Procedure	95
5.6	Step Response of Parallel RLC Circuit	98
5.6.1	Introduction	98
5.6.2	Procedure	100
	References for Further Study	102
6	Steady State DC and AC Analysis and Filters	103
6.1	Introduction	103
6.2	Steady State DC Analysis	103
6.2.1	Introduction	103
6.2.2	Procedure	104
6.3	Steady State AC (Sinusoidal) Analysis	105
6.3.1	Introduction	105
6.3.2	Procedure	106

6.4	Series and Parallel Resonance	108
6.4.1	Introduction	108
6.4.2	Procedure	117
6.5	Low-Pass Filter	119
6.5.1	Introduction	119
6.5.2	Procedure	123
6.6	High-Pass Filter	125
6.6.1	Introduction	125
6.6.2	Procedure	130
	References for Further Study	132
7	Magnetic Coupling and Transformers	133
7.1	Introduction	133
7.2	Dot Convention in Transformers	133
7.2.1	Introduction	133
7.2.2	Procedure	134
7.3	Turn Ratio of Transformer	136
7.3.1	Introduction	136
7.3.2	Procedure	136
7.4	Coupling Coefficient of Mutually Coupled Inductors	137
7.4.1	Introduction	137
7.4.2	Procedure	138
	References for Further Study	140
	Appendix A: Drawing Graphs with MATLAB®	141
	Appendix B: Root Mean Square	161



Commonly Used Laboratory Equipmentes

1

1.1 Introduction

This chapter studies the most commonly used devices in the laboratory. Measurement devices that are used in different laboratories are made by different companies. Working with each device has its own details. Therefore, you are encouraged to read the user manual of devices that you will use during the experiments. Another good reference is your laboratory instructor. Studying the reference [1] is highly recommended as well.

1.2 Digital Multi Meter (DMM)

Digital multimeters are measuring instruments that can measure quantities such as voltage, current, and resistance. Measured values are shown on a digital display, allowing them to be read easily and directly, even by first-time users.

Study the user manual of the DMM that you will use in the experiments. Ensure that you are able to do the followings:

- (a) Measurement of resistance.
- (b) Measurement of AC/DC voltages.
- (c) Measurement of AC/DC currents in the range of Amps.
- (d) Measurement of AC/DC currents in the range of milli/micro Amps.

Ask your laboratory instructor to make an explanation to you if you are not able to do one or more of the above tasks.

1.3 Function Generator (Signal Generator)

A function generator (sometime is called signal generator) is used to generate different types of electrical waveforms over a wide range of frequencies. Some of the most common waveforms produced by the function generator are the sine wave, square wave, triangular wave and saw tooth shapes.

The FG's are divided into two groups: Analog FG's and Direct Digital Synthesis (DDS) FG's. As the name suggests, the analog FG's, uses the analog circuits in order to produce the output waveform. DDS FG's use digital circuits (i.e. a microprocessor) in order to produce the output waveforms. Accuracy of DDS signal generators is better than analog signal generators.

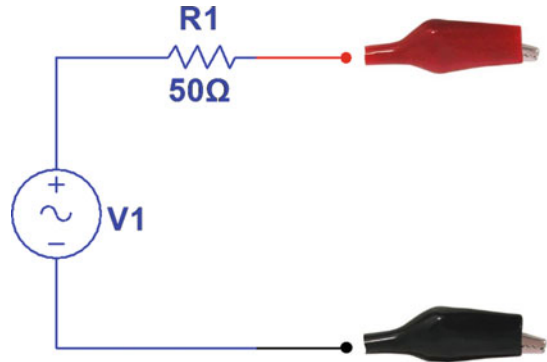
Beside the standard waveforms (i.e. sinusoidal, square, triangular and saw tooth), some DDS FG's are able to produce arbitrary waveforms. These type of FG's are called Arbitrary Waveform Generator (AWG). They have software which permits you to draw the waveform that you want. After drawing the waveform in the software environment, the hardware of AWG produces the waveform for you.

Output of function generator is connected to the circuit under test with the aid of a cable (Fig. 1.1). Black wire is connected to the ground of the signal generator as shown in Fig. 1.2. R₁ shows the output resistance of the signal generator which is generally 50 Ω .



Fig. 1.1 Signal generator cable

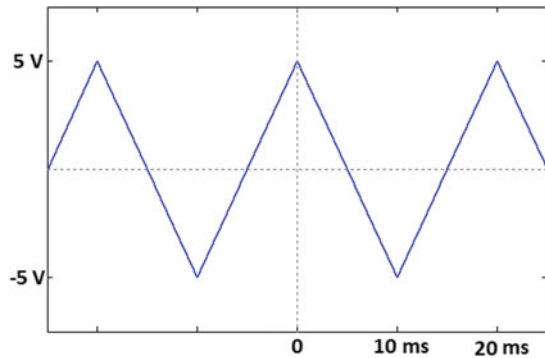
Fig. 1.2 Simple model for signal generator



Study the user manual of the function generator that you will use in the experiments. Ensure that you are able to do the followings:

- Generation of a sinusoidal signal with amplitude of 5 V and frequency of 50 Hz, i.e., $v(t) = 5 \times \sin(2\pi \times 50 \times t)V$.
- Generation of a sinusoidal signal with amplitude of 5 V, frequency of 50 Hz and average value of 3 V, i.e., $v(t) = 3 + 5 \times \sin(2\pi \times 50 \times t)V$.
- Generation of a sinusoidal signal with peak value of 50 mV, i.e., $v(t) = 0.05 \times \sin(2\pi \times 50 \times t)V$.
- Generation of a triangular wave with frequency of 50 Hz and peak value of 5 V (Fig. 1.3).

Fig. 1.3 Sample triangular wave



- Generation of a pulse with frequency of 50 Hz and duty cycle of 25% (Fig. 1.4).

Ask your laboratory instructor to make an explanation to you if you are not able to do one or more of the above tasks.

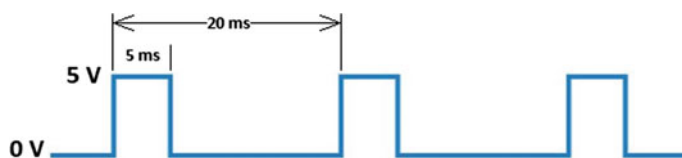


Fig. 1.4 Sample pulse

1.4 Oscilloscope

An oscilloscope is an instrument that graphically displays electrical signals and shows how those signals change over time. Scientists, engineers, physicists, repair technicians and educators use oscilloscopes to see signals change over time. These days generally digital scopes are used in laboratory.

Study the user manual of the oscilloscope that you will use in the experiments. Ensure that you are able to do the followings:

- Measurement of peak value of a signal.
- Measurement of period and frequency of a periodic signal.
- Use the cursors to read voltage or time difference between two points.
- Observing two waveforms simultaneously.
- Measurement of phase difference between two waveforms. Remember that you can measure the phase difference between two waveform easily with the aid of $\Delta\phi = \frac{\Delta t}{T} \times 360^\circ$ formula (Fig. 1.5).

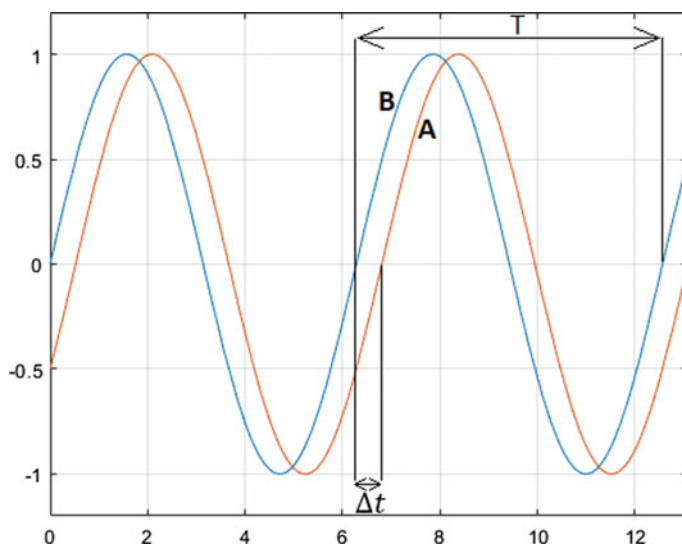


Fig. 1.5 Measurement of phase difference. B leads A by $\Delta\phi = \frac{\Delta t}{T} \times 360^\circ$

- (f) Explain the difference between AC and DC coupling.
- (g) Explain the functionality of X1/X10 switch on the probe.

Ask your laboratory instructor to make an explanation to you if you are not able to do one or more of the above tasks.

1.5 Power Supply

All the circuits require an energy source in order to work. The power supply (PS) is responsible for providing the required energy for the circuit. The power supply takes the AC electric energy from the grid and converts it into a DC voltage. Generally, they provide the voltages in the 0–30 V range. Generally, the output current could be up to 3 A. The outputs of a PS are called a “Channel”. So, when we speak about a 3 channel PS, we mean a PS with three outputs. Generally, the outputs are variable and the user could set them to the desired value he/she wants. Generally, PS’s have one regulated output with voltage of 5 V. This output is used to supply digital circuits. Remember that traditional digital circuits work with 5 V (However this voltage decreased to 3.3 V and even 1.1 V these days!). So, it is a good idea to use this fixed 5 V when you work with traditional digital circuits. You can connect a digital circuit to variable outputs of a PS. However, if you increase the voltage of that variable channel by mistake, then your circuit may be damaged. So, always use this fixed 5 V when you are working with traditional digital circuits.

Study the user manual of the power supply that you will use in the experiments. Ensure that you are able to do the followings:

- (a) Generation of 12 V with maximum output current of 0.5 A.
- (b) Generation of 12 V with maximum output current of 5 A (Use parallel mode).
- (c) Generation of 40 V with maximum output current of 1 A (Use series mode).
- (d) Generation of a symmetric voltage for instance +12 V and –12 V with maximum output current of 0.5 A.

Ask your laboratory instructor to make an explanation to you if you are not able to do one or more of the above tasks.

1.6 Breadboard

A breadboard is used to build and test circuits quickly. The breadboard has many holes into which circuit components like ICs and resistors can be inserted. A typical breadboard is shown in Fig. 1.6.

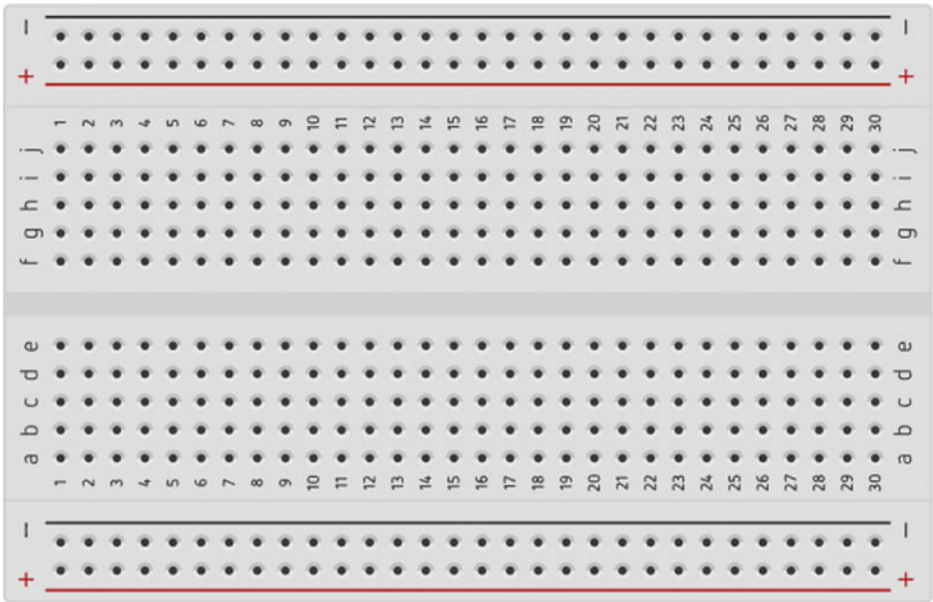


Fig. 1.6 Bread board

The breadboard has strips of metal which run underneath the board and connect the holes on the top of the board. The metal strips are laid out as shown below. Note that the top and bottom rows of holes are connected horizontally while the remaining holes are connected vertically (Figs. 1.7 and 1.8).