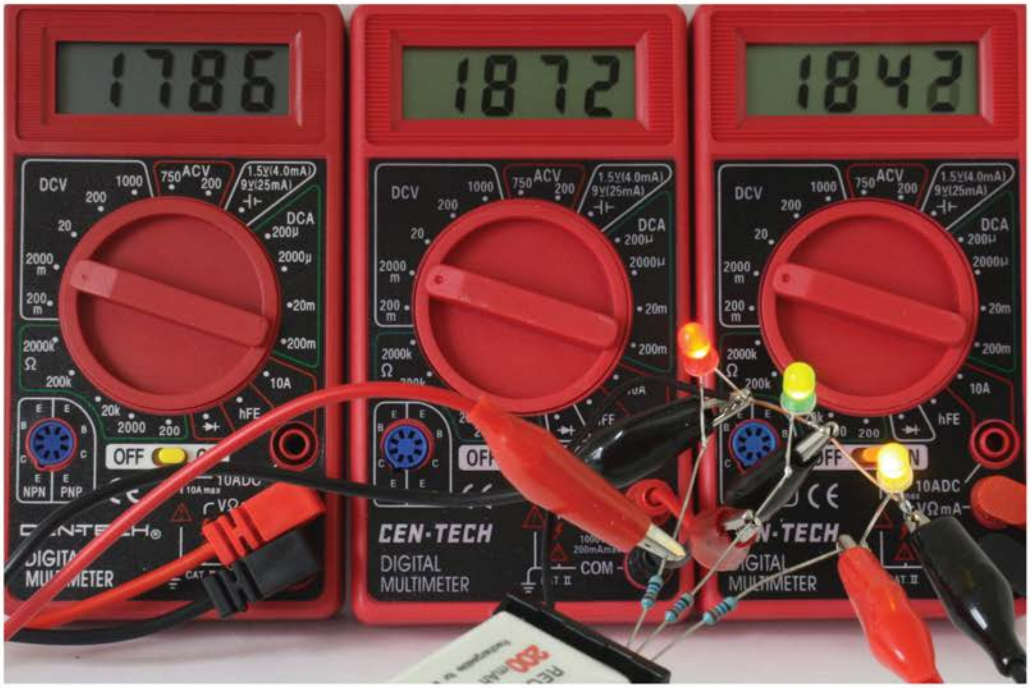
Troubleshooting ELECTRONIC CIRCUITS

A Guide to Learning Analog Electronics



McGraw Hill
TAB
Make Great Stuff!

RONALD QUAN

Troubleshooting Electronic Circuits

About the Author

Ronald Quan has a BSEE degree from the University of California at Berkeley and is a member of SMPTE, IEEE, and the AES. With a General Radiotelephone license, he has worked as a broadcast and maintenance engineer for FM and AM radio stations, and he also holds an Extra Class amateur radio license. Before becoming a design engineer, he worked in TV-Radio-HiFi repair shops.

He is the author of *Build Your Own Transistor Radios* (McGraw-Hill/TAB Electronics, 2012) and *Electronics from the Ground Up* (McGraw-Hill/TAB Electronics, 2014).

For over 30 years he has worked for companies related to video and audio equipment (Ampex, Sony, Macrovision, Monster Cable, and Portal Player). At Ampex, he designed CRT (cathode ray tube) TV monitors and low-noise preamplifiers for audio and video circuits. Other designs included wide-band FM detectors for an HDTV tape recorder at Sony Corporation, and a twice color subcarrier frequency (7.16 MHz) differential phase measurement system at Macrovision, where he was a Principal Engineer. Also at Macrovision he designed several phase lock loop circuits to provide a regenerated clock signal from the raw EFM (eight-fourteen modulation) data stream from a CD player.

At Hewlett Packard, working in the field of opto-electronics, he developed a family of low-powered bar code readers, which used a fraction of the power consumed by conventional light pen readers.

Currently, he is the holder of more than 450 worldwide patents (which includes over 90 United States patents) in the areas of analog video processing, video signal noise reduction, low-noise amplifier design, low-distortion voltage-controlled amplifiers, wide-band crystal voltage-controlled oscillators, video monitors, audio and video IQ modulation, in-band carrier audio single-sideband modulation and demodulation, audio and video scrambling, bar code reader products, and audio test equipment.

Also, he has served as an Adjunct Lecturer and Lecturer in Stanford University's Electrical Engineering Department.

Troubleshooting Electronic Circuits

Debugging and Improving Your DIY Projects and Experiments

Ronald Quan

McGraw Hill

New York Chicago San Francisco
Athens London Madrid
Mexico City Milan New Delhi
Singapore Sydney Toronto

ISBN: 978-1-26-014357-7
MHID: 1-26-014357-0

The material in this eBook also appears in the print version of this title: ISBN: 978-1-26-014356-0,
MHID: 1-26-014356-2.

eBook conversion by codeMantra
Version 1.0

Contents

This page intentionally left blank

Preface

This book on troubleshooting analog circuits is intended for the hobbyist, student, educator, or engineer. Because the subject is more into debugging or improving circuits, the book does not require the reader to have an engineering background.

Students who take electronics classes at the technician or engineering level may find this book useful. Some chapters will include basic electronics theory (with some high school algebra). However, we will not be looking for exact calculations when troubleshooting. Instead, approximations will be presented.

Hobbyists who read this book will not only learn troubleshooting techniques. They will also gain insight into why some circuits perform badly. Suggested circuit modifications will be offered to improve the performance of these types of circuits.

This page intentionally left blank

Acknowledgments

I would like to thank very much Lara Zoble of McGraw-Hill.

Also, thanks to Lauren Poplawski at McGraw-Hill, and to Michael McCabe, formerly of McGraw-Hill.

In transforming my manuscript and figures into a wonderful book, I owe much gratitude to project manager Patricia Wallenburg, copyeditor Claire Span, proofreader Alison Shurtz, and indexer Stephen Ingle.

Writing this book required many suggestions, and Andrew Mellows not only proofread the entire manuscript but also gave me very helpful comments on the technical matter. Thank you very much, Andrew, for reviewing my work over the past two years.

Some material in this book pertaining to building circuits and entry-level electronics came from working with many students and Professor Robert W. Dutton at Stanford University. I give my greatest thanks to Bob Dutton for inviting me into the Electrical Engineering Department as a mentor and as a lecturer for his classes.

Also, I owe immense gratitude to Professor Thomas H. Lee at Stanford University, who was responsible for my meeting with Bob Dutton in the first place and who throughout the years has encouraged me in my electronics research. And, of course, thank you to Stanford University.

Another person who inspired me is Professor Robert G. Meyer at the University of California, Berkeley. His class notes, books, and lectures played an important role for me in writing about distortion analysis. So thank you, Bob Meyer!

With much appreciation, I also need to mention my two mentors from industry, John O. Ryan and Barrett E. Guisinger. Both gave me a world-class education in analog and video circuits design. One other mentor I need to thank is John Curl.

During this whole process I have been indebted to the following friends for encouraging and supporting me: Alexis DiFirenzi Swale, Germano Belli, Jeri Ellsworth, Phil Sittner, Edison Fong, and Amy Herndon.

I really got into my second career as an author/writer because of Paul Rako. He connected me with Roger Stewart and that started all this. Thanks to you, Paul and Roger.

William K. Schwarze, who was my best teacher at Galileo High School, also deserves thanks for his ability to convey mathematical concepts in a very clear manner to me. Also, my friend James D. Lee continues to be an inspiration to me.

Finally, I acknowledge a big debt of gratitude to members of my family: William, George, Thomas, and Frances, for their support.

And, of course, I dedicate this third book to my parents, Nee and Lai.

Troubleshooting Electronic Circuits

This page intentionally left blank

CHAPTER 1
Introduction

This book will cover mostly analog circuits and will include a few timer and logic circuits.

Troubleshooting electronic circuits takes a great deal of detective work. We must have a good idea of how the circuit should work. For example, in an amplifier, we would expect that the amplifier's output provides a larger voltage or current compared to the input signal.

When a circuit does not work as expected, we should check the wiring and solder connections, then double-check the components' value (e.g., correct value resistors and capacitors) along with confirming that the power supply is connected properly. With other test equipment such as a voltmeter or oscilloscope, we begin to trace parts of the circuit for direct current (DC) voltages and alternating current (AC) signals. Eventually we may find where the AC signal disappears, which then allows us to replace a part or confirm whether the original part was connected correctly.

I am writing this book based on observations from my students and colleagues. In most cases, you do not have to be an electrical engineer to troubleshoot circuits. As a matter of fact, many fresh-out-of-school graduates will have limited skill in troubleshooting if they did not have electronics as a hobby most of their lives.

For the hobbyist, just a basic knowledge of using electronic components and test equipment goes a long way. It is more likely that sometimes a hobbyist or a technician will be a better troubleshooter than a young engineering graduate. The reason is that troubleshooting is more of an experience-based skill. If you have been working with many different circuits by building them and probing them (e.g., with a voltmeter and oscilloscope) you will have learned some essential practical knowledge. And if you start learning some electronics theory combined with practical electronics knowledge that includes understanding how to use volt-ohm-meters, oscilloscopes, and signal generators, then you will be able to troubleshoot circuits even better.

To troubleshoot analog circuits, we need to understand components very well via their data sheets (e.g., maximum voltage or power ratings), know how to use test equipment, and understand signals.

Goals of this Book

We will start with components because understanding their specifications and limitations is key to troubleshooting. For example, if you are using a 12-volt circuit but your component is rated at 10 volts, then most likely that component will fail at some point. Also, in some cases, which are rare, an integrated circuit's (IC's) pinouts may be different between its through-hole version (e.g., 8-pin DIP, dual inline package) and its surface mount SO-8 (small outline, 8-pin) counterpart, such as the AD633 analog multiplier chip.

Therefore, the first six chapters are devoted to passive devices, breadboards, and volt ohm milliamp meters. We show how to test these types of components, which is really essential these days because a 10 pf capacitor and a 1 µf capacitor may look nearly identical (e.g., in size) with really small print that is hard to read and easy to mistake one for the other.

When building circuits, we should verify the components' value by inspection and sometimes by measuring them (e.g., for resistance, capacitance, and polarity or confirming NPN or PNP transistors) before soldering or placing them into a circuit board. A variation of the old saying of "measure twice and cut once" can be readapted to "measure twice and solder once."

From Chapters 7 to 15, amplifying devices, integrated circuits, and some electronic systems are presented as examples for troubleshooting audio, RF (radio frequency), timer, and power supply circuits. Some of these circuits come from older hobbyist magazines, books, or postings on the web. We will explore circuits that "kind of work," which can be improved, debugged, or modified for better performance.

Quick Notes: Replacing Electrolytic Capacitors and Soldering

For now, here's a short summary on troubleshooting techniques for the experienced hobbyist concerning (aluminum) electrolytic capacitors.

If you are restoring older electronic devices such as radios, tape recorders, stereos, power supplies, signal generators, etc., you should most likely replace all the electrolytic capacitors with the same (or sometimes larger) capacitance and voltage rating. For example, if there is a 100 µf, 10-volt electrolytic capacitor that has lost its capacitance or became leaky, you can replace it with a new 100 µf, 16-volt version. Of course, make sure that the replacement capacitor is installed correctly in terms of polarity. Also, if the device runs off the power outlet (e.g., 110 volts AC or 220 volts AC), then make sure you completely disconnect its 110v/220v power cord from the wall (or mains) outlet before repairing the device.

Even in many newer devices, you can spot a bad electrolytic capacitor by noticing if the case is bulging. For example, normally the top of an aluminum electrolytic capacitor is flat, but a bad one might be curved up like having a mound added on top of the capacitor. Also, if there are chemical residues near the leads (e.g., white or blue powder, gel, or liquid), these are telltale signs of a bad electrolytic capacitor. See Figure 1-1 that shows a residue leak.

FIGURE 1-1 A bad capacitor on the left side (A), and a good capacitor on the right side (B).

Should you decide to repair or restore older electronic devices from the 1950s to 1980s, keep in mind that aluminum capacitors have about a 15-year life. However, if they are in a warmer environment such as in a TV camera, electrolytic capacitors can fail within 5 years.

Soldering Problems (Cold Solder Connections)

If you are starting out in electronics, then you can build circuits with solderless breadboards, solder your own circuits, or purchase preassembled soldered boards. For troubleshooting, sometimes you will be required to solder when working with new circuits, replacing components, or repairing/modifying printed circuit assemblies. When soldering connections, we must avoid making cold solder joints where the solder may have been "tacked" or "dabbed" onto the circuit, or the solder had not melted sufficiently. See Figure 1-2.

In Figure 1-2, we see that all connections can be improved by just reheating and adding a little more solder until the connections create a smooth mound of solder. If your connections have a "spiky" look similar to number 3 in Figure 1-2, then you may only have a temporary connection that can easily be disconnected with a slight pull on the wire. Generally, spend an extra few seconds on the solder joint to allow the solder to flow all around the connection. See Figure 1-3.

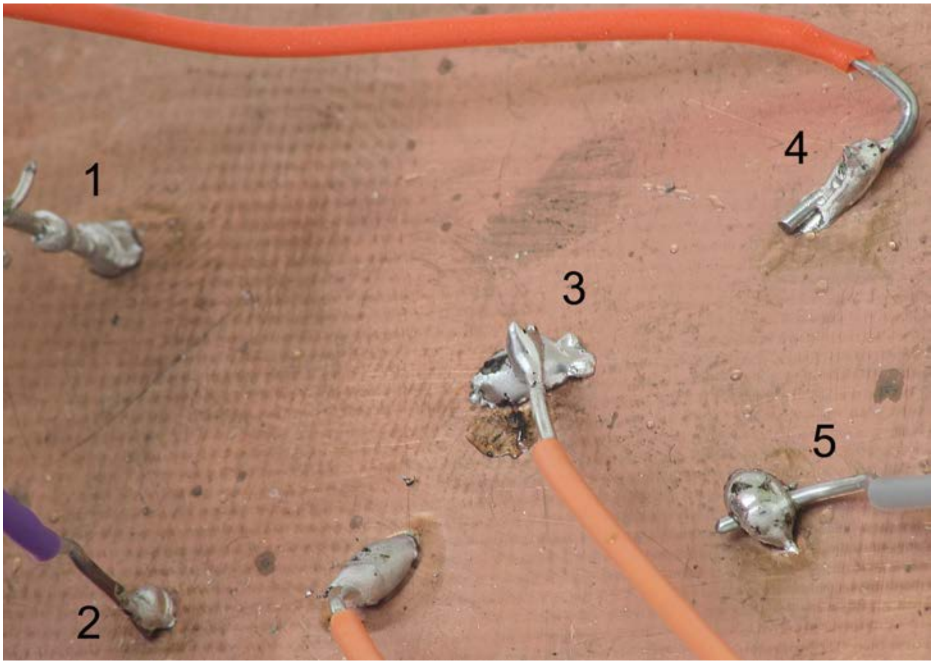


FIGURE 1-2 Bad solder connection examples.

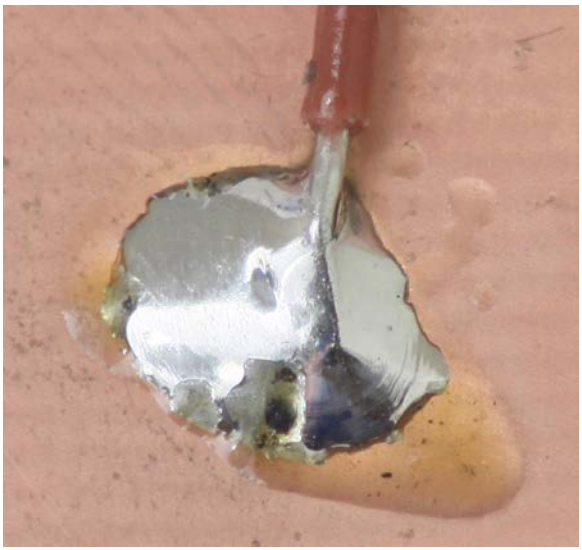


FIGURE 1-3 A good connection where the solder has been heated sufficiently to flow properly.

Summary

Throughout this book we will include basic electronics circuit theory such as Ohm's Law applied to the associated circuits that are discussed.

Finally, do not forget to read Appendix A, which covers choosing test equipment (e.g., power supplies, oscilloscopes, and generators) and shows some of their limitations.

And now let's proceed to Chapter 2.

This page intentionally left blank

CHAPTER 2
Basic Breadboards

This chapter will examine various breadboards for constructing circuits. We will cover solderless breadboards, copper clad bare printed circuit boards, and perforated or vector boards.

Let's first look at solderless breadboards, which can vary in size and quality.

Solderless Breadboards

In Figures 2-1 and 2-2, we see two different types of solderless breadboards. Note that each of them has tabs (e.g., Tab1, Tab2, and Tab3) that allow multiple boards of the same type/size to be expanded.

Let's start with Figure 2-1's solderless breadboard. In each column, there is a column number (e.g., 1 to 30) and five rows (a to f and g to l).

Each column (e.g., column 1 to 30) is connected from rows a to f in the upper portion of the breadboard. And on the lower portion each column (e.g., column 1 to 30) from rows g to l is connected.

The columns 1 to 30 from the upper portions with rows a to f are independent and not connected to any of the columns in the lower portion, such as columns 1 to 30 and row g to l.

Stated in other words, each column is independent and not connected to any other column, even if they are on the upper or lower portion of the breadboard. For example, column 1 is insulated and not connected to any other column such as column 2.

For the example in Figure 2-2, each column from 0 to 60 on the top rows, and on the lower rows the five locations in rows A to E and F to J are connected together. For example, the hole in column 1 row A is only connected to column 1 rows B, C, D, and E. The same connections apply to the other columns, for example, column 3 row F is only connected to column 3 rows G, H, I, and J.

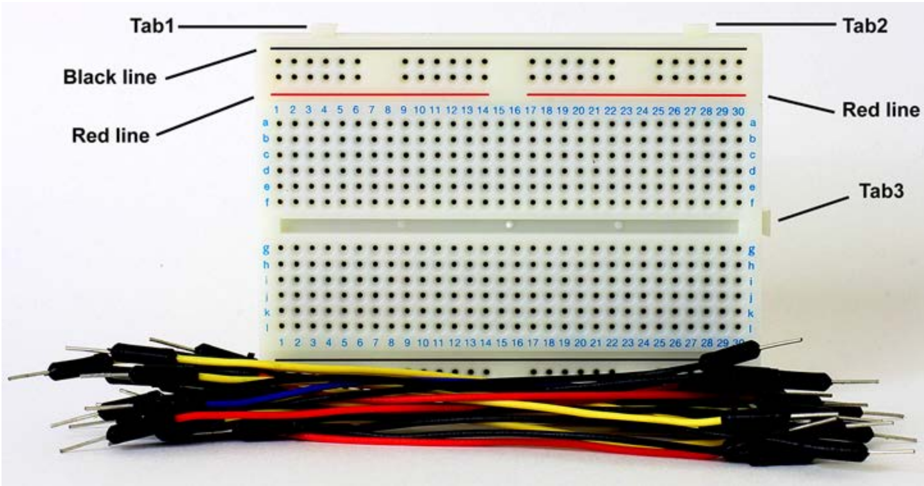


FIGURE 2-1 A small 30-column solderless breadboard with wire jumper connectors.

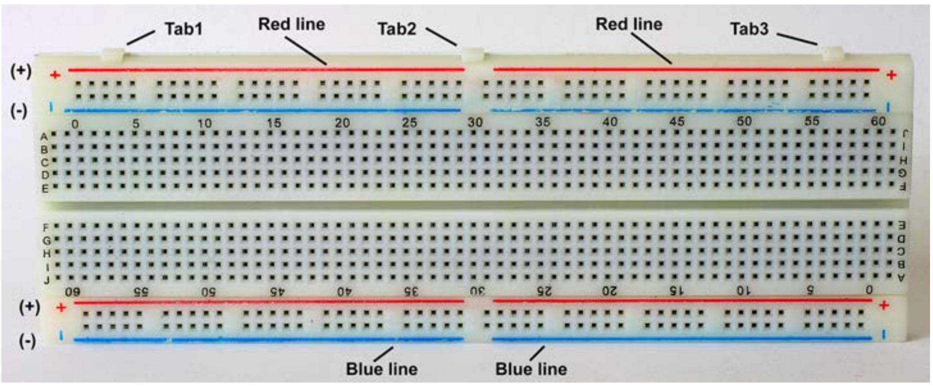


FIGURE 2-2 A larger-sized solderless jumper board with 60 columns. The power buses are denoted by the red and blue lines running across the solderless breadboard.

There are two power buses denoted by red and blue lines toward the edge of the board. We will discuss power buses in more detail later; some are broken into "sectors" within the board, and others are not.

Quality

Figure 2-3 shows a high-quality solderless breadboard where the connectors inside the wells or holes do not cause wire or leads from electronic parts to be jammed.

As we can see in Figure 2-4, the holes or wells labeled "Bad" are closed off, leaving less area to insert wire leads from components. The metal connector clips inside the holes should be expanded outward to allow a larger hole or well size for easier lead or wire insertion.

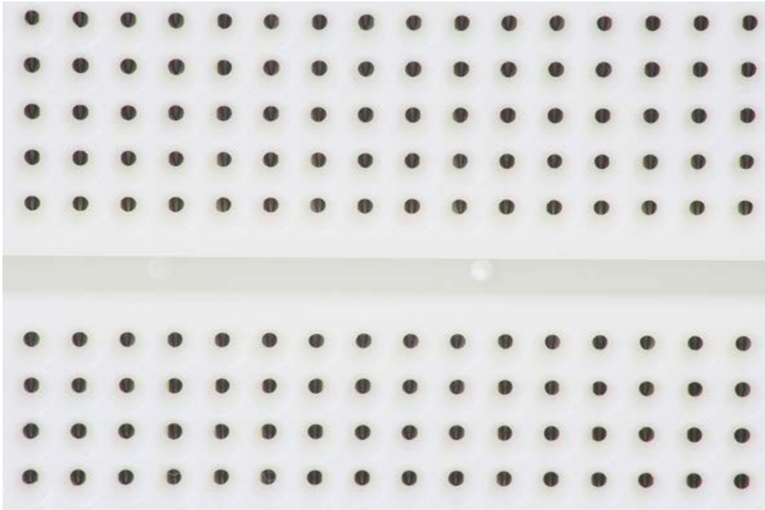


FIGURE 2-3 A high-quality solderless breadboard where the wells or holes are clear and allow for easy insertion of wire leads from electronics components such as resistors, capacitors, etc.

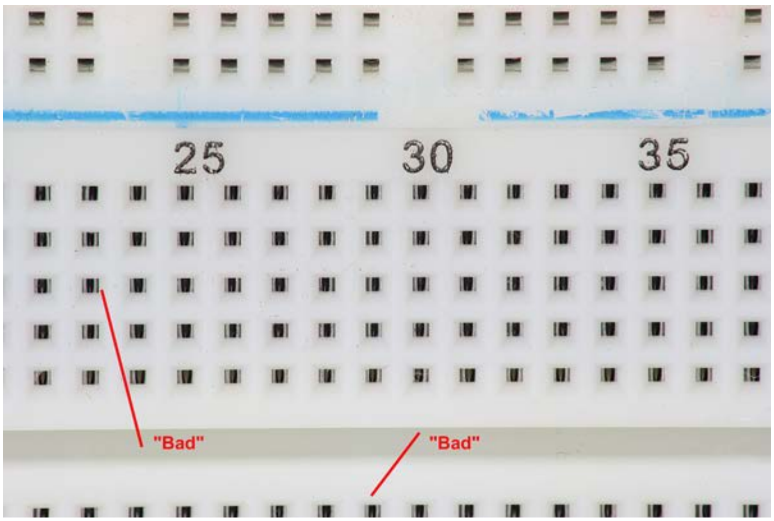


FIGURE 2-4 A lower-quality solderless breadboard with internal connectors or "blades" narrowing the pathways for inserting wires or electronic components.

So be on the lookout for these and avoid them because plugging in resistors, capacitors, and wires will be difficult. One possible workaround on this is to order parts (e.g., resistors and capacitors) with thinner leads. However, you may find that the standard solderless jumper wires may have difficulty plugging in with these partially blocked or narrowed wells.