

2009

The ARRL Handbook

For Radio Communications

Editor

Mark J. Wilson, K1RO

Contributing Editor

Steven R. Ford, WB8IMY

Editorial Assistant

Maty Weinberg, KB1EIB

Technical Consultants

Michael E. Gruber, W1MG

Edward F. Hare, Jr., W1RFI

Zachary H.J. Lau, W1VT

Cover Design

Sue Fagan, KB1OKW

Bob Inderbitzen, NQ1R

Production

Michelle Bloom, WB1ENT

Jodi Morin, KA1JPA

David F. Pingree, N1NAS

**Additional Contributors to the
2008 Edition**

Dave Benson, K1SWL

Mike Bryce, WB8VGE

Rod Kreuter, WA3ENK

Aaron Lyons, N9SKN

John Raydo, KØIZ

Jim Tonne, WB6Bld

Edward Wetherhold, W3NQN

Cover Info: The cover photo of the 2009 *ARRL Handbook* includes ARRL Laboratory Engineer Bob Allison, WB1GCM and ARRL Customer Service Manager Amy Hurtado, KB1NXO, in an iconic “workbench” setting that represents the Amateur Radio spirit of technical innovation and inquiry.



Eighty-Sixth Edition

Published by:
**ARRL—the national association
for Amateur Radio**
Newington, CT 06111 USA

Copyright © 2008 by
The American Radio Relay League, Inc.

*Copyright secured under the Pan-American
Convention*

International Copyright secured

All rights reserved. No part of this work may be
reproduced in any form except by written permis-
sion of the publisher. All rights of translation are
reserved.

Printed in the USA

Quedan reservados todos los derechos

ISBN: 0-87259-000-0 Softcover
ISBN: 0-87259-000-0 Hardcover

Eighty-Sixth Edition

Contents

Foreword

Amateur's Code

Schematic Symbols

Chapter 1 — What is Amateur (Ham) Radio?

Hobby of Diversities	1.2
Your License	1.3
US Amateur Bands	1.4
Ham Radio Action	1.5
Getting Started	1.7
Governing Regulations	1.11
Resources	1.15
Glossary	1.16

Chapter 2 — Activities in Amateur Radio

Awards.....	2.1
Contests.....	2.2
Nets	2.3
Amateur Radio Education.....	2.4
Emergency Communications	2.5
Specialized Communications.....	2.6
Vintage Radio.....	2.11

Chapter 3 — Safety

Antenna and Tower Safety	3.1
Electrical Wiring Around the Shack	3.3
Station Power	3.6
Lightning/Transient Protection	3.7
Grounds.....	3.8
Safe Homebrewing.....	3.9
Other Hazards in the Ham Shack.....	3.10
RF Safety	3.12
FCC RF-Exposure Regulations.....	3.16

Chapter 4 — Electrical Fundamentals

DC Circuits and Resistance	4.1
Series and Parallel Resistances	4.3
Power and Energy	4.6
Circuits and Components	4.8
AC Theory and Reactance	4.11
Capacitance and Capacitors	4.18
Inductance and Inductors	4.25
Quality Factor (Q) of Components	4.32
Calculating Practical Inductors	4.32
Ohm's Law for Reactance	4.37
Impedance	4.42
Resonant Circuits	4.47
Transformers	4.54

Chapter 5 — Electrical Signals and Components

Analog Glossary	5.1
Analog Signal Processing	5.2
Analog Devices	5.6
Practical Semiconductors	5.17
Transistor Amplifier Design	5.26
Digital Fundamentals	5.38
Number Systems	5.39
Physical Rep. of Binary States	5.41
Combinational Logic	5.42
Sequential Logic	5.45
Digital Integrated Circuits	5.51
Computer Hardware	5.58

Chapter 6 — Real-World Component Characteristics

Lumped vs Distributed Elements	6.1
Low-Frequency Component Models	6.2
Components at RF	6.10
Thermal Considerations	6.16
The Thermistor in Homebrew Projects	6.20
Low-Frequency Transistor Models	6.23

Chapter 7 — Component Data and References

Component Values	7.1
Component Markings.....	7.1
Inductors and Core Materials.....	7.5
Other Sources of Component Data	7.11
Semiconductors.....	7.15
Integrated Circuits.....	7.28
Vacuum Tubes.....	7.32
Other	7.36
References.....	7.38
General/Electronics/Computers	7.38
Components/Equipment.....	7.45
Antennas/Transmission Lines	7.46
Modes.....	7.50
Operating and Interference	7.52
Message Handling.....	7.63

Chapter 8 — Circuit Construction

Shop Safety	8.1
Tools and their Uses.....	8.1
<i>Project: A Deluxe Soldering Station</i>	8.6
<i>Project: Soldering-Iron Temperature Control</i>	8.7
Electronic Circuits	8.7
Surface Mount Construction Techniques.....	8.12
From Schematic to Working Circuit	8.18
Microwave Construction Techniques.....	8.22
How to Buy Parts for Electronics Projects.....	8.24
Mechanical Fabrication.....	8.25

Chapter 9 — Modes and Systems

Issues Common to all Transmission Modes	9.1
Emission, Modulation & Transmission Characteristics.....	9.3
Major Modulation Systems.....	9.5
Morse Telegraphy (CW)	9.7
Digital Communications	9.8
Internetworking.....	9.21
Radio Control (R/C).....	9.22
Voice Modes.....	9.26
Facsimile	9.32
Slow-Scan Television (SSTV)	9.34
Fast-Scan Television	9.38
Spread Spectrum	9.43
Multimedia Systems.....	9.47

Chapter 10 — Oscillators and Synthesizers

How Oscillators Work.....	10.2
Phase Noise.....	10.5
Oscillator Circuits and Construction.....	10.12
VHF and UHF Oscillators	10.28
Frequency Synthesizers	10.32
Phase-Locked Loops	10.33
Synthesizer in an MF/HF Transceiver	10.49
Trends in Oscillator Applications	10.52

Chapter 11 — Mixers, Modulators and Demodulators

The Mechanism of Mixers and Mixing	11.1
Practical Building Blocks	11.13
Testing and Calculating IMD in Receivers	11.20

Chapter 12 — RF and AF Filters

Basic Concepts.....	12.1
Lumped-Element Filters	12.5
Filter Design Examples.....	12.11
Quartz Crystal Filters.....	12.17
<i>Project: Crystal Filter Evaluation</i>	12.18
Monolithic Crystal Filters	12.21
SAW Filters.....	12.21
Transmission-Line Filters	12.22
Helical Resonators	12.27
Active Filters.....	12.30
<i>Project: A Broadcast Band Rejection Filter</i>	12.32
<i>Project: A Wave Trap for Broadcast Stations</i>	12.33
<i>Project: Optimized Harmonic Filters</i>	12.34
<i>Project: The Diplexer Filter</i>	12.35
<i>Project: Band-Pass Filters for 144 or 222 MHz</i>	12.37
<i>Project: A High Performance 1.8 to 54 MHz Low Pass Filter</i>	12.37
<i>Project: High-Performance Passive CW Filter</i>	12.41

Chapter 13 — EMI/Direction Finding

The Scope of the Problem.....	13.1
Responsibility	13.2
EMC Fundamentals	13.3
Cures	13.5
TVI Troubleshooting Chart.....	13.8
Amateur Harmonics/CATV Chart.....	13.10
<i>Project: Finding Shack Noise Sources</i>	13.15
Radio Direction Finding	13.17
<i>Project: The Simple Seeker</i>	13.28
<i>Project: Active Attenuator for VHF-FM</i>	13.30

Chapter 14 — Receivers and Transmitters

A Single-Stage Building Block.....	14.1
Negative Feedback in RF Design.....	14.4
Receiver Design Techniques.....	14.14
The Superheterodyne Receiver.....	14.20
VHF and UHF Receivers.....	14.34
<i>Project</i> : GaAsFET Preamplifier for 430 MHz.....	14.36
<i>Project</i> : Microwave Receiver for 10 GHz.....	14.41
Transmitter Design.....	14.42
<i>Project</i> : A Rock-Bending Receiver for 7 MHz.....	14.61
<i>Project</i> : A Binaural I-Q Receiver.....	14.64
<i>Project</i> : MKII — Updated Universal QRP Transmitter.....	14.70
<i>Project</i> : MicroR2 — Easy to Build SSB or CW Receiver.....	14.75
<i>Project</i> : MicroT2 — Compact Single-Band SSB Transmitter.....	14.79
<i>Project</i> : A Drift-Free VFO.....	14.84

Chapter 15 — Transceivers, Transverters and Repeaters

Transceiver Example.....	15.1
<i>Project</i> : The Norcal Sierra — An 80-15 M CW Transceiver.....	15.9
<i>Project</i> : The RockMite — A Simple Single-Band CW Transceiver.....	15.15
Transverters.....	15.19
Repeaters.....	15.20

Chapter 16 — DSP and Software Radio Design

DSP Fundamentals.....	16.1
DSP Algorithms for Radio.....	16.5
Analytic Signals and Modulation.....	16.9
Digital Speech Processing.....	16.16
Interference-Reduction Techniques.....	16.17
Fourier Transforms.....	16.19
Radio Architectures for DSP.....	16.26
Software Radios.....	16.31
Hardware for Embedded DSP Systems.....	16.32
DSP System Software.....	16.34
DSP Projects.....	16.36
<i>Project A</i> : Decimation.....	16.36
<i>Project B</i> : FIR Filter Design Variations.....	16.36
<i>Project C</i> : Analytic Filter Pair Generation.....	16.39
<i>Project D</i> : Newton's Method for Square Roots.....	16.39
<i>Project E</i> : A Fast Square-Root Algorithm.....	16.39
<i>Project F</i> : A High-Performance DDS.....	16.41
<i>Project G</i> : Fast Binary Multiplier In High-speed CMOS Logic.....	16.42

Chapter 17 — Power Supplies

Glossary	17.1
Alternating-Current Power.....	17.2
Rectifier Types	17.4
Rectifier Circuits	17.5
Filtration.....	17.11
Regulation	17.12
High-Voltage Techniques	17.20
Batteries and Charging.....	17.20
Emergency Operations.....	17.24
Power-Supply Projects	17.24
<i>Project: Series-Regulated 4.5- to 25-V Supply</i>	17.25
<i>Project: A 12 V dc Boost Regulator</i>	17.28
<i>Project: 28-V, High-Current Supply</i>	17.36
<i>Project: Commercial-Quality, High-Voltage Supply</i>	17.40
<i>Project: Micro M+ Charge Controller</i>	17.41
<i>Project: The UPS — A Universal Supply</i>	17.44
<i>Project: A Portable Power Supply</i>	17.46

Chapter 18 — RF Power Amplifiers

Types of Power Amplifiers.....	18.1
Design Examples	18.19
<i>Project: 3CX1500D7 kW HF Amplifier</i>	18.29
<i>Project: A 6-Meter kW Amplifier</i>	18.37
<i>Project: A 144-MHz Amplifier</i>	18.40

Chapter 19 — Station Layout and Accessories

Fixed Stations.....	19.1
Mobile and Portable Installations	19.13
<i>Project: Tick-2 — A Tiny CMOS Keyer 2</i>	19.17
<i>Project: The ID-O-Matic</i>	19.20
<i>Project: The Universal Keying Adapter</i>	19.22
<i>Project: Tandem Match — Directional Wattmeter</i>	19.25
<i>Project: Automatic Antenna Switch for Yaesu or ICOM</i>	19.31
<i>Project: A Trio of Transceiver/Computer Interfaces</i>	19.35
<i>Project: A Simple Serial Interface</i>	19.38
<i>Project: USB Interfaces for Your Ham Gear</i>	19.39
<i>Project: QRP T-Match ATU</i>	19.43
<i>Project: A Switched Attenuator</i>	19.44
<i>Project: An Audio Interface Unit for Field Day and Contesting</i>	19.45
<i>Project: A Remote Power Controller</i>	19.47
<i>Project: Audible Antenna Bridge</i>	19.48
<i>Project: Remote Antenna Switch</i>	19.51
<i>Project: PIC-Based Power Meter</i>	19.53

Chapter 20 — Propagation of RF Signals

Fundamentals of Radio Waves.....	20.1
Propagation Summary by Band	20.4
MUF Prediction	20.18
Propagation in the Troposphere	20.19
Extraterrestrial Propagation	20.24

Chapter 21 — Transmission Lines

Basics	21.1
Matched Lines.....	21.3
Reflections on the Smith Chart	21.4
Matching the Antenna to the Line	21.10
Matching the Line to the Transmitter	21.13
Loads and Balancing Devices	21.14
Waveguides	21.17

Chapter 22 — Antennas

Antenna Polarization.....	22.1
Dipoles and the Half-Wave Antenna.....	22.4
<i>Project: 135-FT Multiband Dipole</i>	22.11
Antenna Modeling by Computer	22.12
<i>Project: A 40/15-M Dual-Band Dipole</i>	22.13
<i>Project: K8SYL 75/10-M Dual-Band Dipole</i>	22.14
<i>Project: W4RNL Inverted-U Antenna</i>	22.14
<i>Project: Two W8NX Multiband, Coax-Trap Dipoles</i>	22.19
Vertical Antennas	22.23
Optimum Ground Systems for Vertical Antennas	22.23
<i>Project: Top-Loaded Low-Band Antenna</i>	22.27
Inverted L and Sloper Antennas.....	22.29
<i>Project: 1.8-MHz Inverted L</i>	22.30
<i>Project: Half-Wave Vertical Dipole (HVD)</i>	22.30
<i>Project: The Compact Vertical Dipole (CVD)</i>	22.31
<i>Project: All Wire 30-M CVD</i>	22.33
Yagi and Quad Directive Antennas	22.33
Quad Antennas.....	22.38
<i>Project: Five-Band, Two-Element HF Quad</i>	22.39
<i>Project: Simple Quad for 40 M</i>	22.43
<i>Project: Simple Loop for 28 MHz</i>	22.45
HF Mobile Antennas.....	22.45
VHF/UHF Antennas	22.53
<i>Project: Simple Portable Groundplane Antenna</i>	22.56
<i>Project: Dual-Band Antenna for 146/446 MHz</i>	22.57
<i>Project: A Quick Antenna for 223 MHz</i>	22.58
<i>Project: An All-Copper 2-M J-Pole</i>	22.58
VHF/UHF Yagis	22.60
<i>Project: 3- and 5-Element Yagis for 6 M</i>	22.60
<i>Project: A Medium Gain 2-M Yagi</i>	22.61

Chapter 23 — Space Communications

An Amateur Satellite Primer	23.1
Amateur Satellite History	23.4
Satellite Ground Stations	23.10
<i>Project: Single Brick L-Band Amplifier</i>	23.13
<i>Project: Double Brick L-Band Amplifier</i>	23.13
Receiving Systems	23.15
Antennas	23.18
<i>Project: Parabolic Dish Construction</i>	23.23
<i>Project: Helix Feed for an Offset Dish</i>	23.24
<i>Project: Integrated Dual-Band Antenna System</i>	23.26
Glossary of Satellite Terminology	23.28
Earth-Moon-Earth (EME)	23.32

Chapter 24 — Web, Wi-Fi, Wireless and PC Technology

The Internet and World Wide Web	24.1
Ham's Guide to Useful Internet Sites	24.2
Wireless Fidelity (Wi-Fi)	24.4
Wireless Technology	24.5
Personal Computers in the Shack	24.10

Chapter 25 — Test Procedures

DC Instruments and Circuits	25.3
AC Instruments and Circuits	25.8
<i>Project: The Microwatter</i>	25.11
Frequency Measurement	25.14
<i>Project: Marker Generator with Selectable Output</i>	25.15
<i>Project: A Dip Meter with Digital Display</i>	25.17
Other Instruments and Measurements	25.20
<i>Project: A Wide-Range Audio Oscillator</i>	25.20
<i>Project: Measure Inductance and Capacitance with a DVM</i>	25.21
Oscilloscopes	25.22
<i>Project: HF Adapter for Narrow Bandwidth Scopes</i>	25.27
<i>Project: A Calibrated Noise Source</i>	25.27
<i>Project: Signal Generator for Receiver Testing</i>	25.31
<i>Project: Hybrid Combiners for Signal Generators</i>	25.34
<i>Project: Compensated Modular RF Voltmeter</i>	25.35
Receiver Performance Tests	25.41
Transmitter Performance Tests	25.49

Chapter 26 — Troubleshooting and Repair

Safety First	26.1
Where to Begin	26.5
Testing within a Stage	26.9
Typical Symptoms and Faults	26.12
Troubleshooting Hints	26.17
After the Repairs	26.27
Professional Repairs	26.28

Advertisers Index	A-1
--------------------------------	-----

Index

About the ARRL

About the Included CD-ROM

Foreword

Radio amateurs have countless resources available to them. No matter what your interest, there is a wealth of information and ideas available in the ARRL library — our many books as well as *QST* and *QEX* — plus Internet discussion groups and Web sites. *The ARRL Handbook for Radio Communications* is the one technical reference that has stood the test of time, going into its 86th edition this year. Developed and updated over the years by countless technically savvy writers and editors, there is no better wide-ranging source of technical information for amateurs. A copy belongs nearby to answer questions, stimulate thought and offer practical solutions.

The 2009 edition of the *Handbook* continues the tradition of exploring the many technical facets of Amateur Radio. Here you can learn about components and principles, and how they can be worked into circuits. Circuits become the building blocks of power supplies, transmitters, receivers and accessories. And these components, along with feed lines and antennas, come together to make up your station. We also cover licensing requirements, operating activities, troubleshooting and repair, station setup and radio propagation.

For the 2009 edition, Steve Ford, WB8IMY, has updated the section on amateur satellites. In Chapter 15, Dave Benson, K1SWL, presents his popular RockMite QRP CW transceiver that can be built for 80, 40, 30 or 20 meters. Chapter 19 has several new station accessories you can build — an audible antenna bridge from Rod Kreuter, WA3ENK; a remote power controller from Mike Bryce, WB8VGE; and a mic/headset splitter to let two operators share one radio by John Raydo, KØIZ.

The CD-ROM at the back of the book includes all of the text and illustrations in the printed book, as well as companion software, PC board templates and other support files. Jim Tonne, WB6BLD, has contributed a number of programs to help with filter design and analysis, creating meter scales, designing pi-L networks and more. Check it out.

We hope that the 2009 edition of *The ARRL Handbook* will find a place in your station, ready to provide some insight into whatever aspect of Amateur Radio catches your interest.

David Sumner, K1ZZ
Chief Executive Officer
Newington, Connecticut
September 2008



The Amateur's Code

The Radio Amateur is:

CONSIDERATE...never knowingly operates in such a way as to lessen the pleasure of others.

LOYAL...offers loyalty, encouragement and support to other amateurs, local clubs, and the American Radio Relay League, through which Amateur Radio in the United States is represented nationally and internationally.

PROGRESSIVE...with knowledge abreast of science, a well-built and efficient station and operation above reproach.

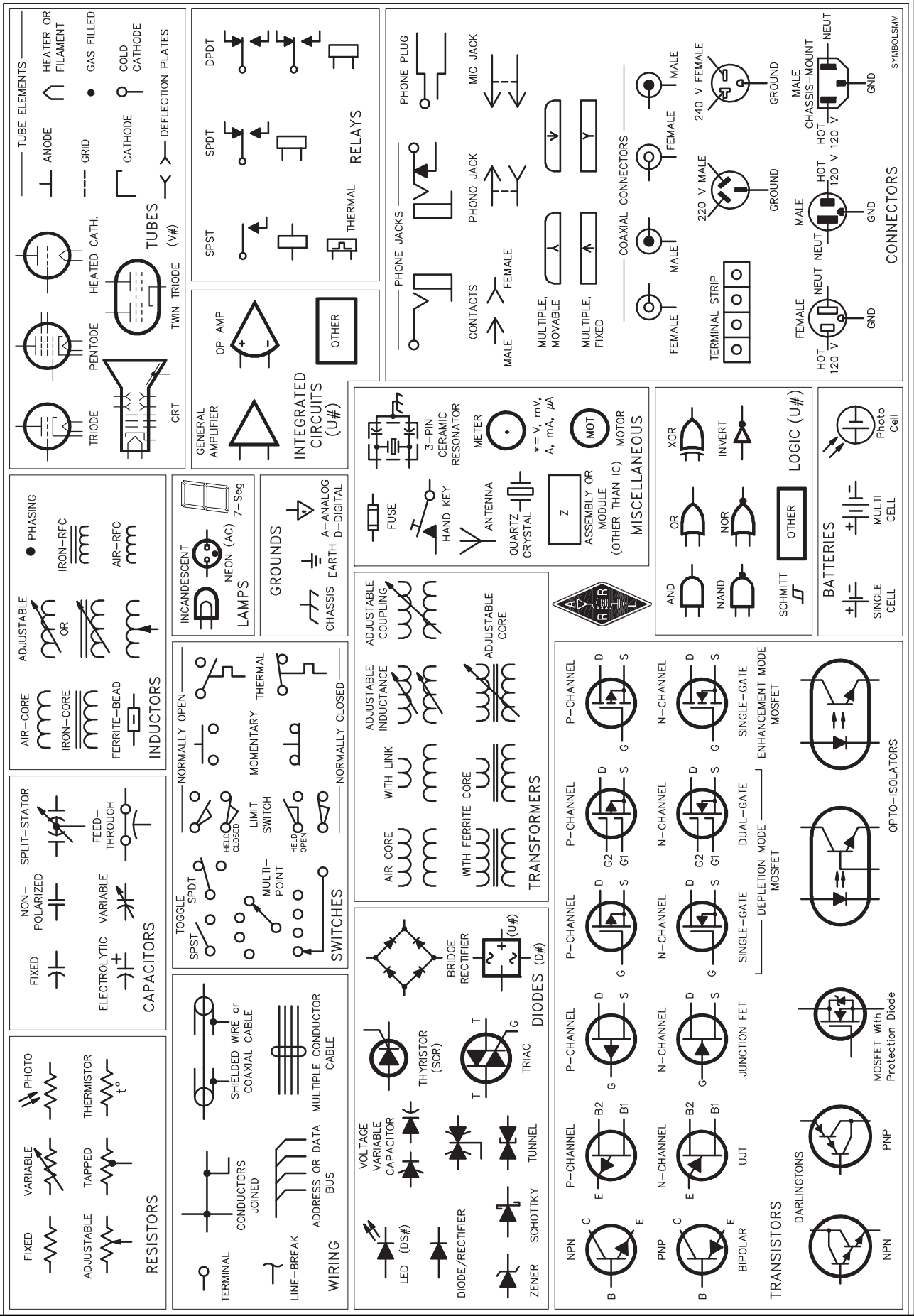
FRIENDLY...slow and patient operating when requested; friendly advice and counsel to the beginner; kindly assistance, cooperation and consideration for the interests of others. These are the hallmarks of the amateur spirit.

BALANCED...radio is an avocation, never interfering with duties owed to family, job, school or community.

PATRIOTIC...station and skill always ready for service to country and community.

—*The original Amateur's Code was written by Paul M. Segal, W9EEA, in 1928.*

Common Schematic Symbols Used in Circuit Diagrams



Public Service

Advocacy

Education

Membership

Guide to ARRL Member Services

ARRL, 225 Main Street Newington, Connecticut 06111-1494, USA

tel. 860-594-0200, Mon-Fri 8 AM to 5 PM ET (except holidays)

FAX: 860-594-0303 ♦ e-mail: hqinfo@arrl.org ♦ ARRLWeb: www.arrl.org

Interested in Becoming a Ham?

www.arrl.org/hamradio e-mail: newham@arrl.org
tel. 1-800-326-3942 (toll-free in the US)

News Center

ARRLWeb: www.arrl.org

ARRL Letter and Audio News:

www.arrl.org/arrlletter

Public Relations/Advocacy

Government Relations and

Spectrum Protection:

www.arrl.org/govrelations

e-mail: govrelations@arrl.org

Public and Media Relations:

www.arrl.org/pio

Membership Benefits

Membership Benefits (all):

www.arrl.org/benefits

ARRL "All Risk" Ham Radio Equipment-
Insurance:

www.arrl.org/insurance

ARRL Visa® Credit Card:

www.arrl.org/visa

ARRL.NET E-mail Forwarding:

www.arrl.org/arrlnet

Awards: www.arrl.org/awards

Contests: www.arrl.org/contests

FCC License Renewal / Modification:

www.arrl.org/arrlvec

QSL Service: www.arrl.org/qsl

Regulatory Information

www.arrl.org/regulations

Technical Information Service

www.arrl.org/tis

e-mail: tis@arrl.org

tel. 860-594-0214

Contributions, Grants and Scholarships

ARRL Development Office:

www.arrl.org/development

e-mail: mhobart@arrl.org

tel. 860-594-0397

♦ ARRL Diamond Club

♦ Spectrum Defense Fund

♦ Education & Technology Fund

♦ Planned Giving/Legacy Circle

♦ Maxim Society

ARRL Foundation Grants and
Scholarships:

www.arrl.org/arrlf

Public Service

Public Service Programs:

www.arrl.org/publicservice

Amateur Radio Emergency Service®
(ARES®):

www.arrl.org/ares

ARRL Field Organization:

www.arrl.org/volunteer

Clubs, Recruitment, Instructors and Teachers

Find an Affiliated Club:

www.arrl.org/clubsearch

Mentor Program:

www.arrl.org/mentor

Find a Licensing Class:

www.arrl.org/coursesearch

Support to Instructors:

www.arrl.org/instructor

Find an Exam Session:

www.arrl.org/examsearch

Volunteer Examiner Coordinator (VEC):

www.arrl.org/arrlvec

Publications & Education

QST — Official Journal of ARRL:

www.arrl.org/QST

e-mail: QST@arrl.org

QEX — Forum for Communications

Experimenters:

www.arrl.org/qex

e-mail: qex@arrl.org

NCJ — National Contest Journal:

www.arrl.org/ncj

e-mail: ncj@arrl.org

Books, Software and Operating

Resources:

tel. 1-888-277-5289

(toll-free in the US);

www.arrl.org/shop

Advertising:

www.arrl.org/ads

e-mail: ads@arrl.org

Certification and Continuing Education /

Online Courses: www.arrl.org/cce

**JOIN or RENEW
or ORDER Publications**

Toll Free 1-888-277-5289 (US)

International callers

tel. +1 (860) 594-0355