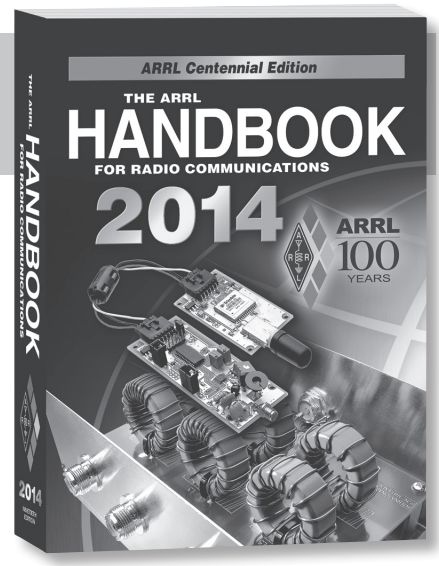
2014

The ARRL Handbook

For Radio Communications



About the Cover: The blue toroid cores belong to an HF triplexer described in the Transmission Lines chapter by George Cutsogeorge, W2VJN, of International Radio. The availability of professional-quality filter design software, such as the programs provided by Tonne Software on the *Handbook's* CD-ROM, have enabled amateurs to design and build such advanced equipment. Above and to the left of the triplexer you see the balloon payload package by Bill Brown, WB8ELK. It transmits position and sensor information from high-altitude platforms, such as balloons, via the APRS network. The use of Amateur Radio in support of experiments and vehicle tracking is a rapidly growing activity. The new Handbook chapter on Telemetry and Navigation provides supporting information for building and using these systems.

Ninety-First Edition

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Ninety-First Edition

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Foreword

Welcome to the 91st edition — the 2014 *ARRL Handbook*! In this ARRL centennial year, you'll find the book contains up-to-date information on the latest amateur technologies, along with solid and reliable electronic information that has been an integral part of the hobby through the decades. You'll particularly enjoy a special graphic-filled *Handbook* history written specially for this edition by one of the ARRL's favorite authors and editors, Joel Hallas, W1ZR. Complemented by a CD-ROM that is full of supplemental articles and projects, this edition has plenty for every ham.

We've updated many of the chapters — three-quarters of them have new or rewritten sections to keep them up-to-date. And there is an addition to the *Handbook* family — a completely new chapter on **Telemetry and Navigation**! Written by experts Paul Verhage, KD4STH, and Bill Brown, WB8ELK, this chapter is going to grow along with the rapid increase in the use of Amateur Radio in partnership with scientific experiments on land, sea, and in the atmosphere and even in space.

Key updates include the new material on batteries and battery charging in the **Power Sources** chapter — renamed to reflect the broad range of ways in which we get power for our radios. The **Oscillators and Synthesizers** chapter has been updated by industry expert Earl McCune, WA6SUH. To help out on the repair bench, the **Troubleshooting and Maintenance** chapter has been updated and reorganized to address the current needs of amateurs.

Speaking of that CD-ROM, more and more material is added to this valuable resource every year, including the full text and graphics from the current edition as convenient and searchable PDF files. This year, we've made a special effort to make sure you'll want to open the envelope inside the back cover and install it on your computer right away. There are more projects than ever on the CD-ROM, full construction details to complete projects in the printed book, and supporting articles that extend the technical material of the regular chapters.

Here are some highlights of what you'll find on this year's CD-ROM:

- W1ZR's annual transceiver model review organized by type and frequency coverage — if you are considering purchasing a radio, this is a great place to start!
- Historical development of amateur receivers and transmitters — W1ZR explains how our radio designs came to be as various challenges and needs were met.
- Jim Tonne, W4ENE, has contributed the latest amateur versions of his professional filter design software, *ELSIE*, along with several other filter and filter-related programs. We are once again very fortunate to include such high-quality software tools.
- Chapters providing operating guidance and station information on **Space Communications** by Joe Taylor, K1JT, and Steve Ford, WB8IMY; **Digital Communications** by Steve Ford, WB8IMY; and **Image Communications** by Tom O'Hara, W6ORG, and Dave Jones, KB4YZ

Projects have been added throughout the *Handbook* but the new ones on the transmit side are sure to catch your eye:

- The Everyham's Amplifier — a simple and flexible design by John Stanley, K4ERO, that is within reach of beginning builders who would like to add some output power to their signal.
- QSK Controllers for Amplifiers — one is an analog design by Jim Colville, W7RY, that can be adapted to many common linear amplifiers. The companion Arduino-based design by Paul Christensen, W9AC, provides the ultimate in flexibility.
- VHF signal sources by long-time amateur design guru Rick Campbell, KK7B, are a great way to start your 6 meter or 2 meter project.
- In addition, on the CD-ROM, you'll find a set of VHF/UHF amplifier designs from the pages of *QST* and *Ham Radio* magazine.

Even after more than 90 editions, the *ARRL Handbook* continues to pursue its mission of providing a technical reference for hams of all interests and abilities. Whether you choose to pursue public service communications, engage in technical experimentation, hone your operating skills, or just explore the magic of wireless communication, "the *Handbook*" has a place in your library and at your workbench.

David Sumner, K1ZZ
Chief Executive Officer
Newington, Connecticut
August 2013

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.

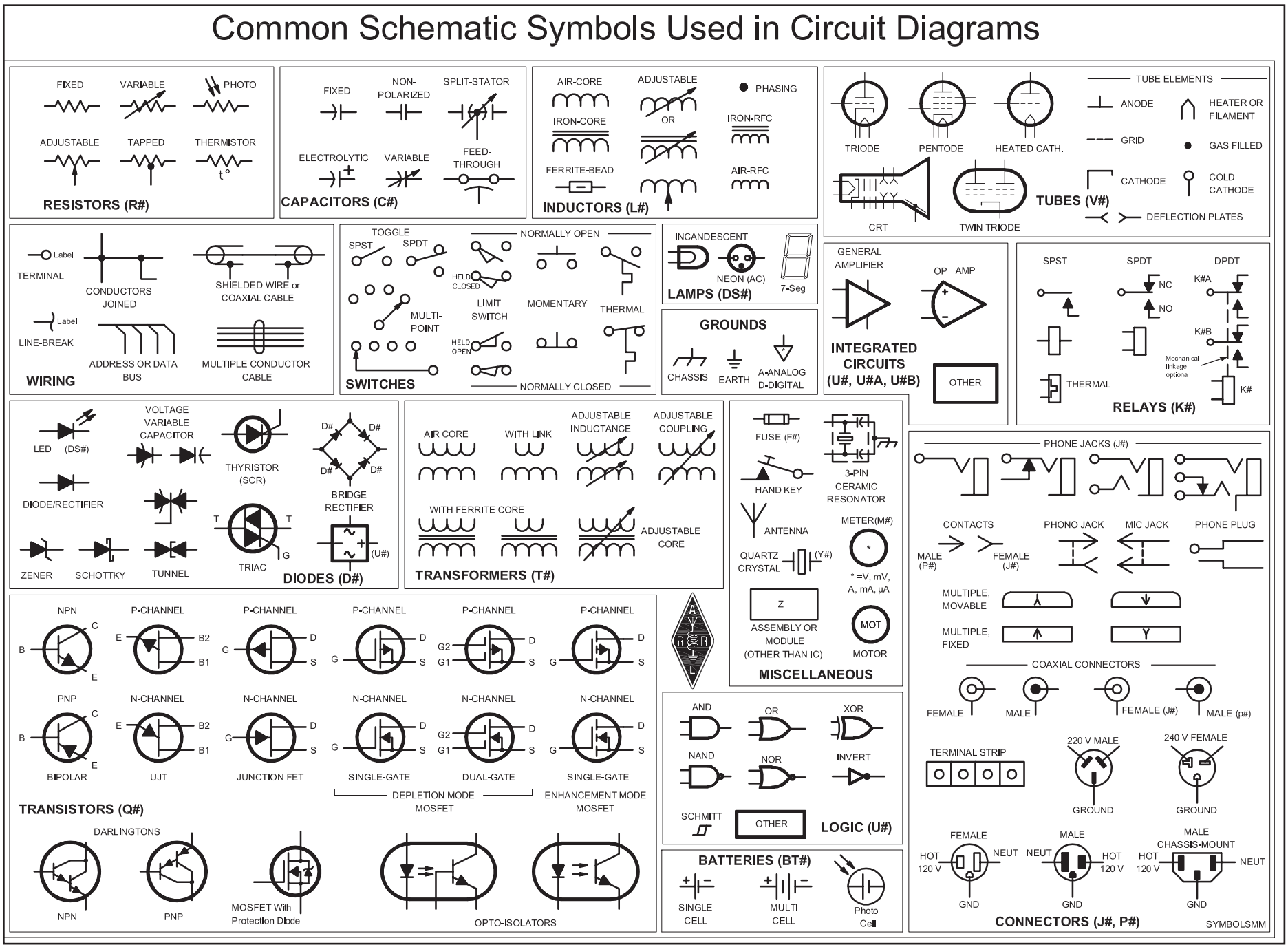
FRIENDLY…slow and patient operating when requested; friendly advice and counsel to the beginner; kindly assistance, cooperation and consideration for the interests of others. These are the hallmarks of the amateur spirit.

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



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Membership Benefits

Your ARRL membership includes ***QST*** magazine, plus dozens of other services and resources to help you **Get Started**, **Get Involved** and **Get On the Air**. ARRL members enjoy Amateur Radio to the fullest!

Members-Only Web Services

Create an online ARRL Member Profile, and get access to ARRL members-only Web services. Visit **www.arrl.org/myARRL** to register.

- ***QST*** **Digital Edition – www.arrl.org/qst**
  All ARRL members can access the online digital edition of *QST*. Enjoy enhanced content, convenient access and a more interactive experience. An app for *iOS* devices is also available.
- ***QST*** **Archive and Periodicals Search** – **www.arrl.org/qst**
  Browse ARRL's extensive online *QST* archive.
  A searchable index for *QEX* and *NCJ* is also available.
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  Subscribe to a variety of ARRL e-newsletters and e-mail announcements: ham radio news, radio clubs, public service, contesting and more!
- **Product Review Archive** – **www.arrl.org/qst**
  Search for, and download, *QST* Product Reviews published from 1980 to present.
- **E-Mail Forwarding Service**
  E-mail sent to your **arrl.net** address will be forwarded to any e-mail account you specify.
- **Customized ARRL.org home page**
  Customize your home page to see local ham radio events, clubs and news.
- **ARRL Member Directory**
  Connect with other ARRL members via a searchable online Member Directory. Share profiles, photos and more with members who have similar interests.

ARRL Technical Information Service — www.arrl.org/tis

Get answers on a variety of technical and operating topics through ARRL's Technical Information Service. ARRL Lab experts and technical volunteers can help you overcome hurdles and answer all your questions.

ARRL as an Advocate — www.arrl.org/regulatory-advocacy

ARRL supports legislation and regulatory measures that preserve and protect access to Amateur Radio Service frequencies. Members may contact the **ARRL Regulatory Information Branch** for information on FCC rules; problems with antenna, tower and zoning restrictions; and reciprocal licensing procedures for international travelers.

ARRL Group Benefit Programs* — www.arrl.org/benefits

- **ARRL "Special Risk" Ham Radio Equipment Insurance Plan**
  Insurance is available to protect you from loss or damage to your station, antennas and mobile equipment by lightning, theft, accident, fire, flood, tornado, and other natural disasters.
- **The ARRL Visa Signature® Card**
  Every purchase supports ARRL programs and services.
- **MetLife® Auto, Home, Renters, Boaters, Fire Insurance and Banking Products**
  ARRL members may qualify for up to a 10% discount on home or auto insurance.

* ARRL Group Benefit Programs are offered by third parties through contractual arrangements with ARRL. The programs and coverage are available in the US only. Other restrictions may apply.

Programs

★ New! ARRL Centennial 2014 — ARRL2014.org
Second Century Campaign for the ARRL Endowment – **www.arrl.org/scc**
National Centennial Convention, July 17-20, 2014 – **ARRL2014.org**

Public Service — www.arrl.org/public-service

Amateur Radio Emergency Service® – **www.arrl.org/ares**
Emergency Communications Training – **www.arrl.org/emcomm-training**

Radiosport

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Contests – **www.arrl.org/contests**
QSL Service – **www.arrl.org/qsl**
Logbook of the World – **www.arrl.org/lotw**

Community

Radio Clubs (ARRL-affiliated clubs) – **www.arrl.org/clubs**
Hamfests and Conventions – **www.arrl.org/hamfests**
ARRL Field Organization – **www.arrl.org/field-organization**

Licensing, Education and Training

Find a License Exam Session – **www.arrl.org/exam**
Find a Licensing Class – **www.arrl.org/class**
ARRL Continuing Education Program – **www.arrl.org/courses-training**
Books, Software and Operating Resources – **www.arrl.org/shop**

Quick Links and Resources

QST – ARRL members' journal – **www.arrl.org/qst**
QEX – *A Forum for Communications Experimenters* – **www.arrl.org/qex**
NCJ – *National Contest Journal* – **www.arrl.org/ncj**
Support for Instructors – **www.arrl.org/instructors**
Support for Teachers – **www.arrl.org/teachers**
ARRL Volunteer Examiner Coordinator (ARRL VEC) – **www.arrl.org/vec**
Public and Media Relations – **www.arrl.org/media**
Forms and Media Warehouse – **www.arrl.org/forms**
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Foundation, Grants and Scholarships – **www.arrl.org/arrl-foundation**

Interested in Becoming a New Ham?

www.arrl.org/newham • **newham@arrl.org** • 1-800-326-3942 (US)

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website – **www.arrl.org/contact-arrl**

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twitter.com/arrl_dxcc

YouTube
www.youtube.com/ARRLHQ

The American Radio Relay League, Inc.

The American Radio Relay League, Inc. is a noncommercial association of radio amateurs, organized for the promotion of interest in Amateur Radio communication and experimentation, for the establishment of networks to provide communication in the event of disasters or other emergencies, for the advancement of the radio art and of the public welfare, for the representation of the radio amateur in legislative matters, and for the maintenance of fraternalism and a high standard of conduct.

ARRL is an incorporated association without capital stock chartered under the laws of the State of Connecticut, and is an exempt organization under Section 501(c)(3) of the Internal Revenue Code of 1986. Its affairs are governed by a Board of Directors, whose voting members are elected every three years by the general membership. The officers are elected or appointed by the directors. The League is noncommercial, and no one with a pervasive and continuing conflict of interest is eligible for membership on its Board.

"Of, by, and for the radio amateur," the ARRL numbers within its ranks the vast majority of active amateurs in the nation and has a proud history of achievement as the standard-bearer in amateur affairs.

A *bona fide* interest in Amateur Radio is the only essential qualification of membership; an Amateur Radio license is not a prerequisite, although full voting membership is granted only to licensed amateurs in the US.

Membership inquiries and general correspondence should be addressed to the administrative headquarters: ARRL, 225 Main Street, Newington, Connecticut 06111-1494.

About the ARRL

The seed for Amateur Radio was planted in the 1890s, when Guglielmo Marconi began his experiments in wireless telegraphy. Soon he was joined by dozens, then hundreds, of others who were enthusiastic about sending and receiving messages through the air—some with a commercial interest, but others solely out of a love for this new communications medium. The United States government began licensing Amateur Radio operators in 1912.

By 1914, there were thousands of Amateur Radio operators—hams—in the United States. Hiram Percy Maxim, a leading Hartford, Connecticut inventor and industrialist, saw the need for an organization to band together this fledgling group of radio experimenters. In May 1914 he founded the American Radio Relay League (ARRL) to meet that need.

Today ARRL, with approximately 155,000 members, is the largest organization of radio amateurs in the United States. The ARRL is a not-for-profit organization that:

- promotes interest in Amateur Radio communications and experimentation
- represents US radio amateurs in legislative matters, and
- maintains fraternalism and a high standard of conduct among Amateur Radio operators.

At ARRL headquarters in the Hartford suburb of Newington, the staff helps serve the needs of members. ARRL is also International Secretariat for the International Amateur Radio Union, which is made up of similar societies in 150 countries around the world.

ARRL publishes the monthly journal *QST* and an interactive digital version of *QST*, as well as newsletters and many publications covering all aspects of Amateur Radio. Its headquarters station, W1AW, transmits bulletins of interest to radio amateurs and Morse code practice sessions. The ARRL also coordinates an extensive field organization, which includes volunteers who provide technical information and other support services for radio amateurs as well as communications for public-service activities. In addition, ARRL represents US amateurs with the Federal Communications Commission and other government agencies in the US and abroad.

Membership in ARRL means much more than receiving *QST* each month. In addition to the services already described, ARRL offers membership services on a personal level, such as the Technical Information Service—where members can get answers by phone, email or the ARRL website, to all their technical and operating questions.

Full ARRL membership (available only to licensed radio amateurs) gives you a voice in how the affairs of the organization are governed. ARRL policy is set by a Board of Directors (one from each of 15 Divisions). Each year, one-third of the ARRL Board of Directors stands for election by the full members they represent. The day-to-day operation of ARRL HQ is managed by an Executive Vice President and his staff.

No matter what aspect of Amateur Radio attracts you, ARRL membership is relevant and important. There would be no Amateur Radio as we know it today were it not for the ARRL. We would be happy to welcome you as a member! (An Amateur Radio license is not required for Associate Membership.) For more information about ARRL and answers to any questions you may have about Amateur Radio, write or call:

ARRL—the national association for Amateur Radio®
225 Main Street
Newington CT 06111-1494
Voice: 860-594-0200
Fax: 860-594-0259
E-mail: **hq@arrl.org**
Internet: **www.arrl.org**

Prospective new amateurs call (toll-free):
800-32-NEW HAM (800-326-3942)
You can also contact us via e-mail at **newham@arrl.org**
or check out the ARRL website at **www.arrl.org**

US Amateur Radio Bands

Effective Date
March 5, 2012

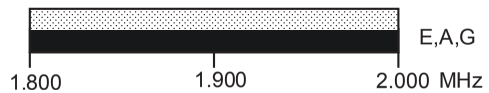
Published by:
ARRL The national association for AMATEUR RADIO®
www.arrl.org
225 Main Street, Newington, CT USA 06111-1494

US AMATEUR POWER LIMITS

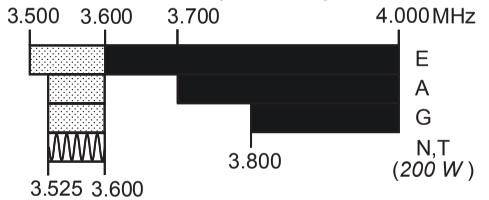
FCC 97.313 An amateur station must use the minimum transmitter power necessary to carry out the desired communications. (b) No station may transmit with a transmitter power exceeding 1.5 kW PEP.

160 Meters (1.8 MHz)

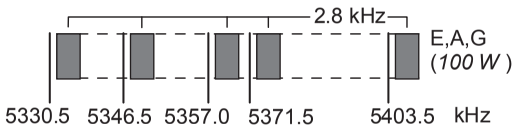
Avoid interference to radiolocation operations from 1.900 to 2.000 MHz



80 Meters (3.5 MHz)

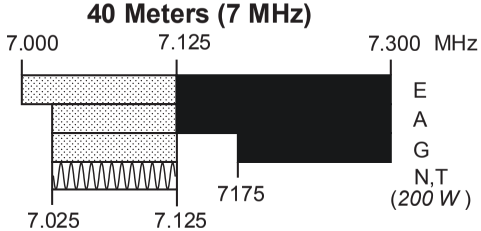


60 Meters (5.3 MHz)



General, Advanced, and Amateur Extra licensees may operate on these five channels on a secondary basis with a maximum effective radiated output of 100 W PEP. Permitted operating modes include upper sideband voice (USB), CW, RTTY, PSK31 and other digital modes such as PACTOR III as defined by the FCC Report and Order of November 18, 2011. USB is limited to 2.8 kHz centered on 5332, 5348, 5358.5, 5373 and 5405 kHz. CW and digital emissions must be centered 1.5 kHz above the channel frequencies indicated above. Only one signal at a time is permitted on any channel.

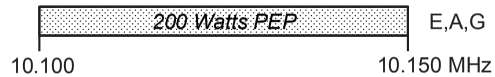
40 Meters (7 MHz)



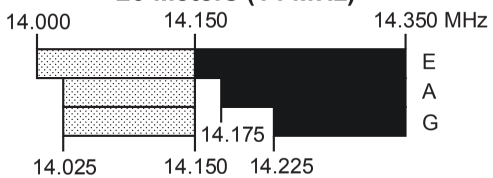
Phone and Image modes are permitted between 7.075 and 7.100 MHz for FCC licensed stations in ITU Regions 1 and 3 and by FCC licensed stations in ITU Region 2 West of 130 degrees West longitude or South of 20 degrees North latitude. See Sections 97.305(c) and 97.307(f)(11).
Novice and Technician licensees outside ITU Region 2 may use CW only between 7.025 and 7.075 MHz and between 7.100 and 7.125 MHz. 7.200 to 7.300 MHz is not available outside ITU Region 2. See Section 97.301(e). These exemptions do not apply to stations in the continental US.

30 Meters (10.1 MHz)

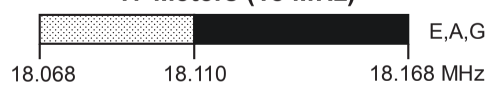
Avoid interference to fixed services outside the US.



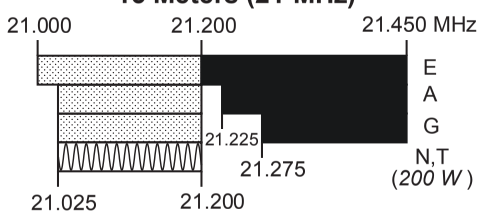
20 Meters (14 MHz)



17 Meters (18 MHz)

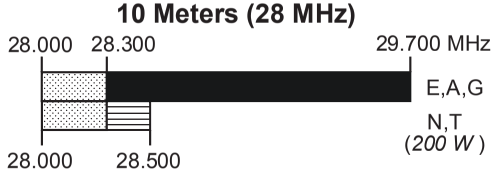


15 Meters (21 MHz)

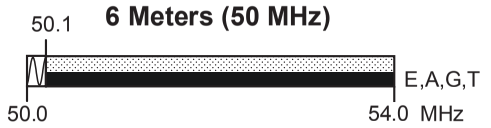


12 Meters (24 MHz)

10 Meters (28 MHz)

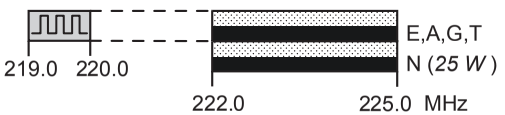


6 Meters (50 MHz)



2 Meters (144 MHz)

1.25 Meters (222 MHz)

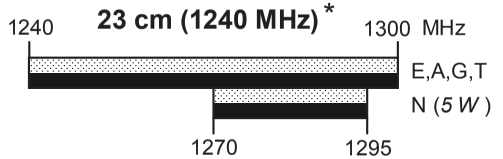


*Geographical and power restrictions may apply to all bands above 420 MHz. See *The ARRL Operating Manual* for information about your area.

70 cm (420 MHz)*

33 cm (902 MHz)*

23 cm (1240 MHz)*



All licensees except Novices are authorized all modes on the following frequencies:

2300-2310 MHz	10.0-10.5 GHz *	122.25-123.0 GHz
2390-2450 MHz	24.0-24.25 GHz	134-141 GHz
3300-3500 MHz	47.0-47.2 GHz	241-250 GHz
5650-5925 MHz	76.0-81.0 GHz	All above 275 GHz

* No pulse emissions

KEY

Note:
CW operation is permitted throughout all amateur bands.

MCW is authorized above 50.1 MHz, except for 144.0-144.1 and 219-220 MHz.

Test transmissions are authorized above 51 MHz, except for 219-220 MHz

= RTTY and data
= phone and image
= CW *only*
= SSB phone
= USB phone, CW, RTTY, and data.
= Fixed digital message forwarding systems *only*

E = Amateur Extra
A = Advanced
G = General
T = Technician
N = Novice

See *ARRLWeb at www.arrl.org* for detailed band plans.

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email: newham@arrl.org

Exams: 860-594-0300 email: vec@arrl.org

 rev. 4/9/2013

ARRL Handbook CD-ROM Contents

On the CD-ROM included with this book you'll find this entire edition of the *Handbook*, including text, drawings, tables, illustrations and photographs — many in color. Using Adobe *Reader*, you can view and print the text of the book, zoom in and out on pages, and copy selected parts of pages to the clipboard. A powerful search engine helps you find topics of interest. Also included is supplemental information and articles, PC board template packages, construction details for many projects, and companion software mentioned throughout. A README file is included on the CD-ROM for more information. The CD-ROM is included in protective envelope attached inside the back cover of the book.

Supplemental Files for Each Chapter

The CD-ROM provides supplemental information for most chapters of this book. This includes articles from *QST* and other sources, material from previous editions of the *ARRL Handbook*, tables and figures in support of the chapter material, and files that contain PC board layout and other design information to build and test the projects provided in the chapters. The supplemental information is arranged in folders, and a list of relevant CD-ROM content is included at the beginning of each chapter in this book.

Companion Software

TubeCalculator, a *Windows* application by Bentley Chan and John Stanley, K4ERO, accompanies the tube type RF power amplifier discussion in the **RF Power Amplifiers** chapter.

The following *Windows* programs by Tonne Software **(www.tonnesoftware.com)** are provided by Jim Tonne, W4ENE.

ClassEinstall204.exe — Designs single-ended Class E RF amplifiers.

DiplexerInstall209.exe — Designs both high-pass/low-pass and band-pass/band-stop types of diplexer circuits.

HelicalInstall206.exe — Designs and analyzes helical-resonator bandpass filters for the VHF and UHF frequency ranges.

JJSmithInstall210.exe — A graphics-intensive transmission-line calculator based on the Smith chart.

LCinstall257.exe — The free student edition of *Elsie,* a lumped-element filter design and analysis program.

MeterBasicInstall304.exe — Designs and prints professional-quality analog meter scales on your printer. The full-featured version of *Meter* is available from Tonne Software.

OptLowpassInstall203.exe — Designs and analyzes very efficient transmitter output low-pass filters.

PIELinstall217.exe — Designs and analyzes pi-L networks for transmitter output.

QuadNetInstall203.exe — Designs and analyzes active quadrature ("90-degree") networks for use in SSB transmitters and receivers.

SVCFilterInstall212.exe — Standard-value component routine to design low-pass and high-pass filters and delivers exact-values as well as nearest-5% values.