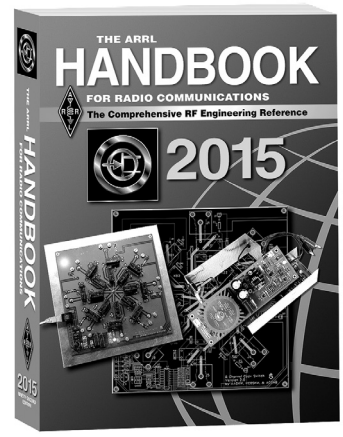
2015

The ARRL Handbook

For Radio Communications



About the Cover:

Michael Dzado, AC0HB designed the "Eight-Channel Remote Control Antenna Selector" shown on the Handbook cover. Using a single control cable to the station, up to eight separate antennas can be selected. The switch can also be used to switch single antennas between several radios.

Michael used special coplanar waveguide design techniques to insure a 50-ohm signal path impedance while providing better than 70 dB of port-to-port isolation.

The Sealed Lead-Acid (SLA) Battery Charger was designed by Bob Lewis, AA4PB to work with batteries in use with the typical amateur transceiver. Commercial SLA chargers are unsuitable for use with a battery experiencing intermittent loads such as during amateur operation so Bob designed a charging circuit to accommodate those conditions. The charger features a maximum bulk-charge current of 500 mA and uses battery voltage to select the proper charging rate.

Ninety-Second Edition

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Ninety-Second Edition

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CD-ROM OPERATING SUPPLEMENTS
Space Communications
Digital Communications
Image Communications
The ARRL Radio Amateur's Handbook — From Its Beginning
2015 Annual Transceiver Survey

Foreword

Congratulations on your purchase of the *2015 ARRL Handbook*. This 92nd edition of the book continues the technical traditions of Amateur Radio. Topics range from very simple electronics and radio wave basics all the way to sophisticated digital communications protocols. In fact, this book is a lot like the Amateur Radio you hear on the air every day. The more than 700,000 active hams in the United States and more than 3,000,000 around the world use all types of technology to communicate.

If you are just getting into Amateur Radio or wireless technology, you will find the section on Fundamental Theory provides great training on electrical and electronic fundamentals, both analog and digital. The practical side of technology follows with a large section of chapters covering the techniques required of RF circuitry, the types of circuits that are used in radio, receivers and transmitters, and the latest digital topics. Antennas are a critical part of successful radio communication so you'll find chapters showing how they work and how to build practical designs. Other chapters explain transmission lines and illustrate the many ways in which signals proagate from point to point.

Since a big part of Amateur Radio is building, repairing, adapting, and otherwise performing hands-on work with radio technology, the final section of the book covers everything from workshop basics to station assembly and troubleshooting. The book's CD-ROM includes Joel Hallas, W1ZR's Annual Transceiver Survey and several more chapters on Space, Digital, and Image Communication practices and equipment. Many supplemental articles and references are also provided.

One of the primary extra values that is provided on the *Handbook*'s CD-ROM is the collection of updated software from Jim Tonne, W4ENE (**www.tonnesoftware.com**). Jim's professional-quality software is used by hams around the world for a variety of purposes:

Elsie — LC filter designer

SVC Filter Designer — Designs filters using standard value components

OptLowpass Designer — Optimized low-pass filters for amateurs

Helical Filter Designer — Creates high-performance filters for VHF and UHF

Pi-El — A tool to design Pi-L network matching circuits

JJSmith — Use the Smith Chart to design matching circuits

QuadNet — A handy way to design active all-pass circuits for SSB generators

ClassE — Design Class E (switch mode) amplifiers with this tool

Diplexer Designer — Simplifies the job of designing circuits to share antennas

MeterBasic — Design and print custom meter scales

Be sure to open the CD-ROM envelope and install the contents on your computer. The complete *Handbook* is included in searchable PDF form, as well!

The *Handbook* is also full of projects that hams can use to construct a functional and effective station. Projects range from simple accessories and small power supplies to legal-limit amplifiers and high-gain antennas. Mobile and portable stations aren't left out either! There is something for every level of experience and every style of operation.

Here are the new projects you'll find in the pages of this year's *Handbook*:

- Workbench-style bipolar tracking power supply by Bryant Julstrom, KCØZNG, for circuits requiring balanced positive and negative voltages. You can use this supply with op-amps and other analog electronic circuits.
- The Antennas chapter presents a tri-band Moxon-style antenna, a 25-pound beam for 20, 15 and 10 meters easily made from wire and fiberglass. Designed by Brian Machesney, K1LI, for portable operating, it's a great introduction to these popular antennas.
- To help reduce cabling costs, an eight-channel remote antenna switch project is included. You can buy boards and parts from the author, Michael Dzado, ACØHB, or build it yourself.
- Getting power to those antenna-mounted electronics can be a problem, too, or just require yet another expensive run of control cable. A dc power bias-Tee project from Phil Salas, AD5X, solves the problem effectively and inexpensively.
- Carl Luetzelschwab, K9LA, updates us on the status and progress of solar Cycle 24 and Joe Eisenberg, KØNEB, contributes a very valuable table of recommended electronic components for all RF builders.

As Amateur Radio begins its second century, "the *Handbook*" is more relevant, useful, and practical than ever. No matter what type or style of operating you prefer, there is plenty of material here for you. Keep turning the pages and you might find something new catching your eye! You may be a technical professional or student in need of practical electronic and RF know-how — you'll find excellent technical value for the price. Why not take one more step and join the ranks of hams from around the world? After more than 90 editions, the *ARRL Handbook* is still here for you, on your workbench, operating shelf, or technical bookshelf.

Dave Sumner, K1ZZ
Chief Executive Officer
Newington, Connecticut
August 2014

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.

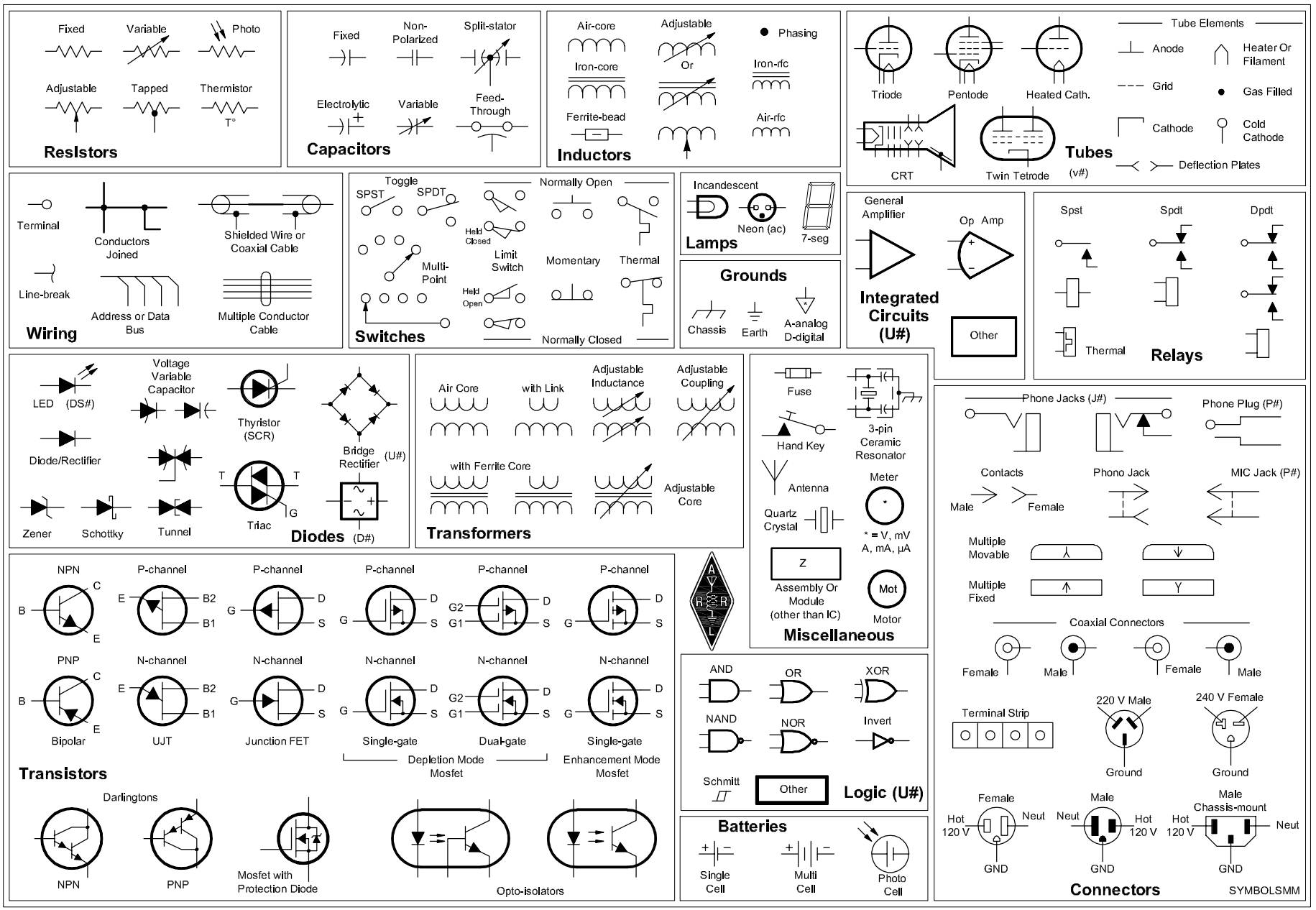
FRIENDLY…slow and patient operating when requested; friendly advice and counsel to the beginner; kindly assistance, cooperation and consideration for the interests of others. These are the hallmarks of the amateur spirit.

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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- **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.
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* 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

★ ARRL Centennial 2014

Second Century Campaign for the ARRL Endowment – **www.arrl.org/scc**
Centennial QSO Party – **www.arrl.org/centennial-qso-party**

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

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

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Logbook of The World – **www.arrl.org/lotw**

Community

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ARRL Field Organization – **www.arrl.org/field-organization**

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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**
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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 165,000 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:

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Prospective new amateurs call (toll-free):
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US Amateur Radio Bands

Effective Date
March 5, 2012

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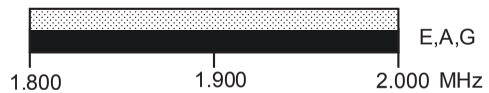
ARRL The national association for AMATEUR RADIO®
www.arrl.org
225 Main Street, Newington, CT USA 06111-1494

US AMATEUR POWER LIMITS

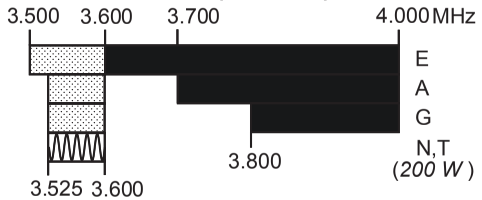
FCC 97.313 An amateur station must use the minimum transmitter power necessary to carry out the desired communications. (b) No station may transmit with a transmitter power exceeding 1.5 kW PEP.

160 Meters (1.8 MHz)

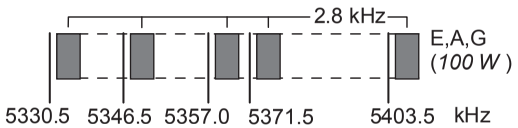
Avoid interference to radiolocation operations from 1.900 to 2.000 MHz



80 Meters (3.5 MHz)

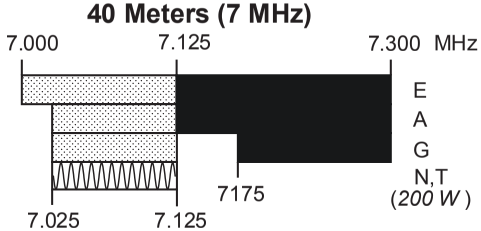


60 Meters (5.3 MHz)



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.

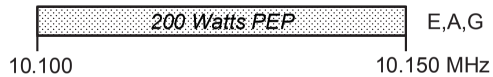
40 Meters (7 MHz)



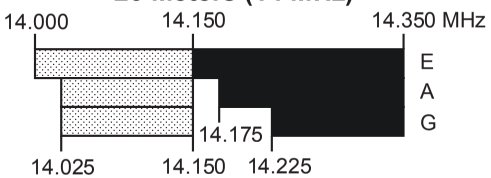
Phone and Image modes are permitted between 7.075 and 7.100 MHz for FCC licensed stations in ITU Regions 1 and 3 and by FCC licensed stations in ITU Region 2 West of 130 degrees West longitude or South of 20 degrees North latitude. See Sections 97.305(c) and 97.307(f)(11).
Novice and Technician licensees 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)

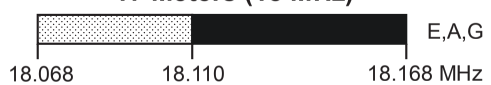
Avoid interference to fixed services outside the US.



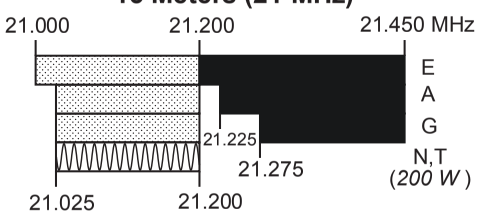
20 Meters (14 MHz)



17 Meters (18 MHz)

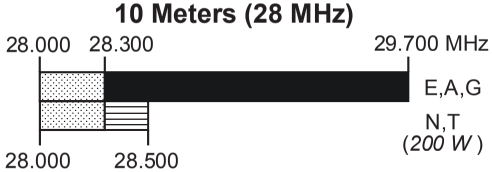


15 Meters (21 MHz)

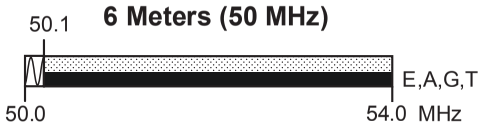


12 Meters (24 MHz)

10 Meters (28 MHz)

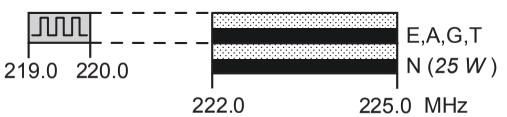


6 Meters (50 MHz)



2 Meters (144 MHz)

1.25 Meters (222 MHz)

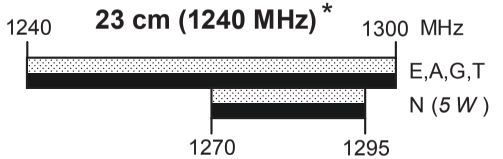


*Geographical and power restrictions may apply to all bands above 420 MHz. See *The ARRL Operating Manual* for information about your area.

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

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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. Using Adobe *Reader*, you can view, print or search the entire book. Also included is supplemental information and articles, PC board template packages, construction details for many projects, and companion software mentioned throughout. 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 for each chapter.

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.

ClassEinstall205.exe — Designs single-ended Class E RF amplifiers.

DiplexerInstall210.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.

LCinstall267.exe — The free student edition of *Elsie,* a lumped-element filter design and analysis program.

MeterBasicInstall306.exe — Designs and prints professional-quality analog meter scales on your printer. The full-featured version of *Meter* is available from Tonne Software.

OptLowpassInstall204.exe — Designs and analyzes very efficient transmitter output low-pass filters.

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

QuadNetInstall204.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.