radio handbook

twenty-first edition

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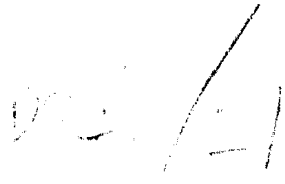

"Radio Handbook" is also available on special order in Spanish.

Preface to the 21st Edition

Electronic circuitry and radio communication are in the midst of a profound technological revolution as significant as the massive shift from the vacuum tube to the transistor only one short decade ago. The device responsible for today's impressive new technology is the integrated circuit which has reduced the complexity of multistage design and fabrication to a single chip smaller than a postage stamp. The tiny IC, in turn, has led to the phase-locked loop, digital readout, inexpensive home computers—and simpler, more reliable construction.

While the vacuum tube still reigns supreme in high power amplifier service, the transistor even now is entering the twilight era of its utility since its circuits demand the discrete components of old. But with his intricate integrated circuit, the designer simply applies input and power to the chip and extracts the output signal—in a hand-held f-m transceiver, a complex guided missle, or a "hockey game" played on the home television set. Circuit sophistication which was a laboratory curiosity only a few years ago is commonplace today in communication equipment and home entertainment devices. A far cry from only 50 years ago when the radio amateur was forced to build many of his components before he could assemble his equipment!

Those experimenters who faithfully saved their old editions of *Radio Handbook* have enjoyed a front-row seat at this remarkable transition. Since its inception in 1934, *Radio Handbook* has remained the acknowledged leader in the field of communications technology, and this new edition is no exception. Recent technological breakthroughs of interest to the radio amateur are discussed at length and practical circuits making use of the latest techniques are included in this volume.

Because of the recent decision of the Federal Communications Commission restricting the design of linear r-f amplifiers in the amateur service, and the limitations placed on commercially manufactured amplifiers, additional amplifier theory and construction material for the home builder is included in this edition. Coverage of the 10-meter band in full is provided in these designs and effective harmonic suppression circuits are included to preclude interference to home entertainment devices.

In the increasingly important world of vhf, effective new amplifier designs are included in this edition for the advanced experimenter, along with circuit theory and useful construction information. Detailed analysis of various vhf circuits of interest to the amateur are also included.

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GLOSSARY OF TERMS

Symbol	Notation
A	Amperes (ac, rms, or dc)
A	Amplifier voltage gain
Å	Angstrom unit
a	Amperes (peak)
ac	Alternating current
a-m	Amplitude modulation
C	Capacitance
c.f.m.	Cubic feet per minute
C_{gg}	Capacitance grid to ground
C_{gk}, C_{gp}, etc.	Tube capacitance between indicated electrodes
C_{in}	Input capacitance
C_k	Capacitance between cathode and ground
cm	Centimeter
C_N	Neutralizing capacitance
C_{out}	Output capacitance
C_{pg2}	Capacitance, plate to screen
c-w	Continuous wave
dB	Decibel
dc	Direct current
E	Voltage (ac, rms, or dc)
e	Peak voltage
E_b	Average plate voltage
e_b	Instantaneous plate voltage
$e_{b\ max}$	Peak plate voltage
$e_{b\ min}$	Minimum instantaneous plate voltage referenced to ground
e_{cmp}	Maximum positive grid voltage
E_{co}	Cutoff-bias voltage
E_{c1}	Average grid #1 voltage
E_{c2}	Average grid #2 voltage
E_{c3}	Average grid #3 voltage
e_{c1}	Instantaneous grid #1 voltage
e_{c2}	Instantaneous grid #2 voltage
e_{c3}	Instantaneous grid #3 voltage
E_f	Filament voltage
e_g	Rms value of exciting voltage
e_p	Instantaneous plate voltage (ac) referenced to E_b
$e_{p\ max}$	Peak ac plate voltage referenced to E_b
E_{sig}	Applied signal voltage (dc)
e_{sig}	Applied signal voltage (ac)
e_k	Instantaneous cathode voltage
$e_{k\ max}$	Peak cathode voltage
emf	Electromotive force

Symbol	Notation
F	Farad, magnetomotive force
f	Frequency (in Hertz)
fil	Filament
G	Giga (10^9)
g, g_1, g_2, etc.	Grid (number to identify, starting from cathode)
$g_{2,4}$	Grids having common pin connection
GHz	Gigahertz (10^9 cycles per second)
G_m or S_m	Transconductance (grid-plate)
H	Henry
Hz	Hertz
i	Peak current
I	Current (ac, rms or dc)
I_b	Average dc plate current
$I_{b\ max}$	Peak signal dc plate current
i_b	Instantaneous plate current
$i_{b\ max}$	Peak plate current
I_{bo}	Idling plate current
I_c	Average dc grid current current
i_p	Instantaneous ac plate current referred to I_b
$i_{p\ max}$	Peak ac plate current referred to I_b
i_1 etc.	Fundamental component of r-f plate current
$i_{1\ max}$	Peak fundamental component of r-f plate current
I_1	Single tone dc plate current
I_2 etc.	Two-tone, etc., dc plate current
$I_{c1,\ c2}$, etc.	Average grid #1, #2, etc. current
i_f	Filament current
i_{g1} i_{g2} etc.	Instantantous grid current
$i_{g1\ max}$, etc.	Peak grid current
I_k	Average cathode current
i_k	Instantaneous cathode current
$i_{k\ max}$	Peak cathode current
K	Cathode, dielectric constant
k	Kilo(10^3), coefficient of coupling
kHz	Kilohertz
kV	Peak kilovolts
kVac	Ac kilovolts
kVdc	Dc kilovolts
kW	Kilowatts
λ	Wavelength

Symbol	Notation
L	Inductance
M	Mutual inductance
M	Mega (10^6)
m	Meter
m	One thousandth
mm	Millimeter
mA	Milliamperes
Meg or meg	Megohm
mH	Millihenry
MHz	Megahertz
m.m.f.	Magnetomotive force
Mu or μ	Amplification factor, micro
mV	Millivolts
MW	Megawatts
mW	Milliwatts
NF	Noise figure
N_p	Efficiency
Ω	Ohms
p	Pico (10^{-12})
P_d	Average drive power
p_d	Peak drive power
P_{ft}	Average feedthrough power
p_{ft}	Peak feedthrough power
pF	Picofarad
PEP	Peak envelope power
P_{g1}, P_{g2}, etc.	Power dissipation of respective grids
P_i	Power input (average)
p_i	Peak power input
P_o	Power output (average)
p_o	Peak power output
P_p	Plate dissipation
Q	Figure of merit
Q_L	Loaded Q
R	Resistance
r	Reflector
r-f	Radio frequency
R_g	Resistance in series with the grid
r_g	Dynamic internal grid resistance

Symbol	Notation
R_k	Resistance in series with the cathode
R_L	Load resistance
rms	Root mean square
R_p	Resistance in series with plate
r_p	Dynamic internal plate resistance
S_c or G_c	Conversion transconductance
S_m or G_m	Transconductance
SSB	Single sideband
SWR	Standing-wave ratio
T	Temperature (°C)
t	Time (seconds)
θ	Conduction angle
μ	Micro (10^{-6}) or amplification factor
μ	Amplification Factor
μA	Microampere
μmho	Micromho
μF	Microfarad
μH	Microhenry
μs	Microsecond
μV	Microvolt
μ_2	Grid-screen amplification factor
V	Volt(s), (ac, rms, or dc)
v	Peak volts
Vac	Ac volts
Vdc	Dc volts
VSWR	Voltage standing-wave ratio
W	Watts
Z	Impedance
Z_g	Grid impedance
Z_i	Input impedance
Z_k	Cathode impedance
Z_L	Load impedance
Z_o	Output impedance
Z_p	Impedance in plate circuit
Z_s	Screen bypass impedance

CONTENTS

CHAPTER ONE

Introduction to Amateur Radio Communication

The field of *radio* is a division of the much larger field of electronics. Radio itself is such a broad study that it is still further broken down into a number of smaller fields of which only short-wave or high-frequency radio is covered in this book. Specifically the field of communication on frequencies from 1.8 to 1296 MHz is taken as the subject matter for this work.

The largest group of persons interested in the subject of high-frequency communication is the more than 750,000 radio amateurs located in nearly all countries of the world. Strictly speaking, a *radio amateur* is anyone noncommercially interested in radio, but the term is ordinarily applied only to those hobbyists possessing transmitting equipment and a license to operate from the Government.

It was for the radio amateur, and particularly for the serious and more advanced amateur, that most of the equipment described in this book was developed. The design principles behind the equipment for high-frequency and vhf radio communication are of course the same whether the equipment is to be used for commercial, military, or amateur purposes. The principal differences lie in construction practices, and in the tolerances and safety factors placed on components.

With the increasing complexity of high-frequency and vhf communication, resulting primarily from increased utilization of the available spectrum, it becomes necessary to delve more deeply into the basic principles underlying radio communication, both from the standpoint of equipment design and operation and from the standpoint of signal propagation. Thus, it will be found that this edition of the RADIO HANDBOOK has been devoted in greater proportion to the teaching of the principles of equipment design and signal propagation. Also included are expanded and revised sections covering solid state devices and the principles of operation of modern equipment. The mathematics chapter, in addition, has been revised in the light of the modern pocket electronic calculator. All of these factors, of course, are reflected in the changing picture of amateur radio today.

1-1 Amateur Radio

Amateur radio is a fascinating scientific hobby with many facets. At the same time it is a public service as well as a recognized Radio Service and, as such, is assigned specific bands of frequencies by the *International Telecommunications Union*, to which body the United States of America is a signatory power.

From a few thousand amateurs at the end of World War I, amateur radio has grown into a world-wide institution of communicators and experimenters joined in the common interest of communication by means of radio. So strong is the fascination offered by this hobby that many executives, engineers and military and commercial electronic

experts, as well as students and citizens not otherwise engaged in the field of electronics are united by the common bond of amateur radio.

Radio amateurs have rendered much public service, especially in the United States, through furnishing emergency communications to and from the outside world in cases where a natural disaster has isolated an area by severing all normal means of communication. Amateurs have innumerable records of service and heroism on such occasions. The amateur's fine record of performance with the "wireless" equipment of World War I was surpassed by his outstanding service in World War II.

The induction of thousands of radio amateurs in the Armed Forces during 1940-1945 and the explosion of electronic technology during that period created an expansion of amateur radio, the direct result of which is that many of those amateurs are now the leaders of our modern electronics industry. It is through the continuing expansion of amateur radio in the future that many of tomorrow's engineers, technicians and electronic executives will come.

The Amateur Radio Service has been proven to be a national and international resource of great benefit to all nations and to mankind. In addition, of equal importance is the effect of the service as a stimulus to economic growth and scientific knowledge. Radio amateurs continue to play a significant role in the development of the state of the radio art and are continuing to make major contributions both to basic radio theory and to practical applications thereof.

In recent years radio amateurs have contributed to the state of the art in numerous ways including the discovery in 1934 of reflection and refraction of vhf signals in the lower atmosphere, the development and adaptation of SSB techniques for widespread usage, the achievement of random "moon-bounce" communication between amateurs and the development of the OSCAR series of satellites and the relatively inexpensive equipment and technique for communicating through the satellites.

Continuing into the closing quarter of the Twentieth Century, the status of amateur radio in the communities of the world emphasize to the beginning radio amateur that his hobby is the gateway to a career in the expanding field of electronics, if he wishes it, and that amateur radio is indeed an impressive introduction to one of the most exciting fields of endeavor in this century.

1-2 Amateur Station and Operator Licenses

Every radio transmitting station in the United States (with the exception of certain low-power communication devices) must have a license from the Federal Government before being operated; some classes of stations must have a permit from the government even before being constructed. And every operator of a licensed transmitting station must have an operator's license before operating a transmitter. There are no exceptions. Similar laws apply in practically every major country.

Classes of Amateur Operator Licenses The Amateur Radio Service in the United States is in the process of going through a major change in the license structure. At the time of publication of this Handbook, there exist six classes of amateur operator licenses authorized by the Federal Communications Commission. These classes differ in many important respects, so each will be discussed briefly.

Novice Class—The Novice Class license is available to any U.S. citizen or national who has not previously held an amateur license of any class issued by any agency of the U.S. Government, military or civilian. The license is valid for a period of five years and is renewable.

The examination may be taken only by mail, under the direct supervision of an amateur holding a General Class license or higher, or a commercial radiotelegraph licensee. The examination consists of a code test at a speed of 5 words per minute, plus a written examination on the rules and regulations essential to beginners operation, including sufficient elementary radio theory for the understanding of these rules. Restricted c-w privileges in segments of the 80-, 40-, 15- and 10-meter amateur bands are currently available to the Novice li-

censee, whose transmitter is limited to an input power not exceeding 250 watts.

Technician Class—The Technician Class exists for the purpose of encouraging a greater interest in experimentation and development of the higher frequencies among experimenters and would-be radio amateurs. This Class of license is available to any U.S. Citizen or national. The examination is similar to that given for the General Class license, except that the code test in sending and receiving is at a speed of 5 words per minute.

The holder of a Technician Class license is accorded all authorized amateur privileges in all amateur bands above 50 MHz. This class of license may be taken only by mail, under the direct supervision of an amateur (18 years of age, or older) holding a General Class License, or higher, or a commercial radiotelegraph license. The license is valid for a period of five years, and may be renewed on proper application.

General Class—The General Class license is the standard radio amateur license and is available to any U.S. Citizen or national. The license is valid for a period of five years and is renewable on proper application. Applicants for the General Class license must take the examination before an FCC representative (with certain exceptions discussed under the Conditional Class license). The examination consists of a code test at a speed of 13 words per minute, plus a written examination in basic theory and regulations. It conveys all amateur privileges, *with the exceptions noted for the Advanced and Extra Class licenses.*

Conditional Class—The Conditional Class license is equivalent to the General Class license in the privileges accorded by its use. This license is issued to an applicant who: (1) lives more than 175 miles airline distance from the nearest point at which the FCC conducts examinations twice yearly, or oftener; (2) is unable to appear for examination because of physical disability to travel; (3) is unable to appear for examination because of military service; (4) is temporarily resident outside the United States, its territories, or possessions for a year or more. The Conditional Class license may be taken only by mail and is renewable.

Advanced Class—The Advanced Class license is equivalent to the old Class-A license and is available to any U.S. Citizen or national. The license is valid for a period of five years and is renewable on proper application. Applicants for the Advanced Class license must take the examination before an FCC representative. The examination consists of a general code test at 13 words per minute, questions covering general amateur practice and regulations involving radio operation, and technical questions covering intermediate-level radio theory and operation as applicable to modern amateur techniques, including, but not limited to, radiotelephony and radiotelegraphy. An applicant for the Advanced Class license will be given credit for that portion of the examination and the code test covered by the General Class license, if a valid license of that grade is held at the time of examination.

The Advanced Class license accords certain radiotelephone privileges in the amateur bands between 80 and 6 meters, which are unavailable to holders of lower-grade amateur licenses.

Amateur Extra Class—The Amateur Extra Class license is the highest-grade amateur license issued by the FCC and the recipient, on request, may receive a special diploma-type certificate from the District FCC Engineer-in-Charge. The license is valid for a period of five years and is renewable. Applicants for the Amateur Extra Class license must take the examination before an FCC representative. The examination consists of a code test at a speed of 20 words per minute, a standard written examination in theory and regulations (credit will be given to holders of General and Advanced Class licenses for this requirement), and a written examination based on advanced radio theory and operation as applicable to modern amateur techniques, including, but not limited to, radiotelephony, radiotelegraphy, and transmission of energy for measurements and observations applied to propagation, for the radio control of remote objects, and for similar experimental purposes. An applicant for the Amateur Extra Class license will be given credit for that portion of the examination covered by the General and Advanced Class licenses, if a valid license of either grade is held at the time of examination.

The Amateur Extra Class license accords certain radiotelephone and radiotelegraph privileges in the amateur bands between 80

and 6 meters, unavailable to holders of lower-grade licenses.

The Amateur Station License The station license authorizes the radio apparatus of the radio amateur for a particular address and designates the official call sign to be used. The license is a portion of the combined station-operator license normally issued to the radio amateur. Authorization is included for portable or mobile operation within the continental limits of the United States, its territories or possessions, on any amateur frequency authorized to the class of license granted the operator. The station license must be modified on a permanent change in address. The station license is customarily renewed with the operator license.

International Regulations The domestic regulatory pattern of the United States agrees with the international agreements established by the International Telecommunications Union and to which the United States is a signatory power. The frequency bands reserved for the Amateur Radio Service are included in the ITU frequency allocations table, as one of the services to which frequencies are made available. In the lower-frequency amateur bands, the international allocations provide for joint use of the bands by several services in addition to the amateur service in various areas of the world.

Article I of the ITU Radio Regulations defines the amateur service as: *"A service of self-training, intercommunication, and technical investigations carried on by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without a pecuniary interest."* Within this concept, the U. S. radio regulations governing radio amateur licensing and regulation are formulated.

By reciprocal treaty, the United States now has a number of agreements with other countries permitting amateurs of one country to operate in the other. On the other hand, by international agreement, notification to the ITU may forbid international communications with radio amateurs of certain countries.

A comprehensive coverage of United States licensing procedure for radio amateurs and applicable rules and regulations may be found in *"The Radio Amateur's License Manual,"* published by the American Radio Relay League, Newington, Conn. 06111.

The World Administrative Radio Conference In the fall of 1979, or shortly thereafter, a World Administrative Radio Conference is scheduled to be held in Geneva, Switzerland by the International Telecommunications Union. One of the duties of this Conference will be to examine—and change if deemed necessary—the frequency allocations of all services in the radio spectrum. The possibility exists that the amateur bands will come under close scrutiny. The present bands, as summarized in the following section, may therefore be left unchanged or may be altered as a result of the Conference. Since the United States is a signatory power to the ITU, the results of that Conference will be binding and all radio services must be braced to expect some changes in their frequency allocations, the Amateur Radio Service included. It is quite possible that an expansion of some amateur bands could come about, but the reverse might be equally true. Only time will resolve this interesting speculation.

1-3 The Amateur Bands

Certain small segments of the radio-frequency spectrum between 1800 kHz and 22,000 MHz are reserved for operation of amateur radio stations. These segments are in general agreement throughout the world, although certain parts of different amateur bands may be used for other purposes in various geographic regions. In particular, the 40-meter amateur band is used legally (and illegally) for short-wave broadcasting by many countries in Europe, Africa and Asia. Parts of the 80-meter band are used for short distance marine work in Europe, and for broadcasting in Europe and Asia. The amateur bands available to United States radio amateurs are: