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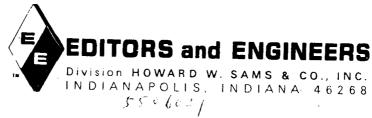
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radio handbook

twenty-first edition

William I. Orr, W65AI





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RADIO HANDBOOK

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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 handheld 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	Symbol	Notation
Α	Amperes (ac, rms, or dc)	F	Farad, magnetomotive force
A	Amplifier voltage gain	f	Frequency (in Hertz)
Â	Angstrom unit	fil	Filament
a	Amperes (peak)	Ğ	Giga (10°)
ac	Alternating current	g, g;, g ₂ , etc.	Grid (number to identify,
a-m	Amplitude modulation	g, g,, g,, e.c.	starting from cathode)
č	Capacitance	9 2,4	Grids having common pin
c.f.m.	Cubic feet per minute	94,7	connection
C ₉₉	Capacitance grid to ground	GHz	Gigahertz (10° cycles per
C _{gk} , C _{gp} , etc.	Tube capacitance between	O1 12	second)
Ogr, Ogp, O.C.	indicated electrodes	G_m or S_m	Transconductance
Cin	Input capacitance	G m 0: G m	(grid-plate)
C,	Capacitance between	Н	Henry
Ck	cathode and ground	Hz	Hertz
	Centimeter	i i	
cm		'	Peak current
C [*]	Neutralizing capacitance	•	Current (ac, rms or dc)
C _{∞+}	Output capacitance Capacitance, plate to screen	I _b	Average dc plate current
C _{pg2}		/b max	Peak signal dc plate
C-W	Continuous wave Decibe!		current
dВ		i _b	Instantaneous plate current
₫c	Direct current	I _{b max}	Peak plate current
Ε	Voltage (ac, rms, or dc)	/ _{bo}	Idling plate current
e	Peak voltage	<i>1</i> _c	Average do grid current
E ₀	Average plate voltage		current
e ₅	Instantaneous plate voltage	$i_{\mathfrak{p}}$	Instantaneous ac plate
e _{b max}	Peak plate voltage		current referred to lb
e b min	Minimum instantaneous	ip max	Peak ac plate current
	plate voltage referenced		referred to lb
	to ground	i_{\perp} etc.	Fundamental component of
e cmp	Maximum positive grid		r-f plate current
	voltage	i max	Peak fundamenta!
E _{co}	Cutoff-bias voltage		component of r-f plate
E_{ci}	Average grid #1 voltage		current
E.2	Average grid #2 voltage	7 ,	Single tone dc plate current
E .:	Average grid #3 voltage	I₂ etc.	Two-tone, etc., dc plate
e c₁	Instantaneous grid #1	•	current
	voltage	I €1, €2, etc.	Average grid #1, #2, etc.
€ <2	Instantaneous grid #2		current
	voltage	1,	Filament current
0 ₆₃	Instantaneous grid #3	$i_{g_1} i_{g_2}$ etc.	Instantantous grid current
	voltage	Igi mar, etc.	Peak grid current
E _f	Filament voltage	Ik	Average cathode current
θα	Rms value of	\vec{i}_k	Instantaneous cathode
- 9	exciting voltage	r k	current
e _p	Instantaneous plate voltage	/k max	Peak cathode current
Oβ	(ac) referenced to E _b		
⊝ p max	Peak ac plate voltage	K k	Cathode, dielectric constant
−µ mex	referenced to E _b	ĸ	Kilo(103), coefficient of
Esig	Applied signal voltage (dc)	1.1.1.	coupling
e:ia	Applied signal voltage (gc)	kHz	Kilohertz
€;ig €v	Applied signal voltage (ac)	kV	Peak kilovolts
C+	Instantaneous cathode	kVac	Ac kilovolts
	voltage	kVdc	Dc kilovolts
•	Parit cathoda valta		
e _{k max} emf	Peak cathode voltage Electromotive force	kW λ	Kilowatts Wavelength

Symbol	Notation	Symbol	Notation
L _.	Inductance	R _k	Resistance in series with
M	Mutual inductance		the cathode
M	Mega (1 0 °)	R_{ι}	Load resistance
m	Meter	rms	Root mean square
m	One thousandth	R _o	Resistance in series with
mm .	Millimeter	•	plate
mA '	Milliamperes	Γρ	Dynamic internal plate
Meg or meg	Megohm	.,	resistance
mH	Millihenry	Sc or Gc	Conversion transconductance
MHz	Megahertz	S _m or G _m	Transconductance
m.m.f.	Magnetomotive force	SSB	Single sideband
Mu or μ	Amplification factor, micro	SWR	Standing-wave ratio
mV	Millivolts	T	Temperature (°C)
MW	Megawatts	t	Time (seconds)
mW	Milliwatts	θ	Conduction anale
NF	Noise figure		Micro (10 ⁻⁶) or amplification
N _o	Efficiency	μ	
$\Omega_{\mathbf{p}}$	Ohms		factor
D	Pico (10 ⁻¹²)	μ	Amplification Factor
Pd	Average drive power	μA	Microampere
p _d	Peak drive power	⊬mho	Micromho
P _t ,	Average feedthrough power	μF	Microfarad
p _{tt}	Peak feedthrough power	μ H	Microhenry
pF	Picofarad	μs	Microsecond
PEP		μ∨	Microvolt
	Peak envelope power	μ_2	Grid-screen amplification
P_{g^1} , P_{g^2} , etc.	Power dissipation of		factor
n	respective grids	V	Volt(s), (ac, rms, or dc)
<i>P.</i>	Power input (average)	V	Peak volts
p_i	Peak power input	Vac	Ac volts
P _o	Power output (average)	Vdc	Dc volts
p.	Peak power output	VSWR	Voltage standing-wave
P _p	Plate dissipation		ratio
Q	Figure of merit	W	Watts
Q_{L}	Loaded Q	Ζ	Impedance
R	Resistance	Z.	Grid impedance
r	Reflector	Ζį	Input impedance
r-f	Radio frequency	Z_{k}	Cathode impedance
R_{q}	Resistance in series with	$\vec{z_i}$	Load impedance
	the grid	Ź.	Output impedance
r q	Dynamic internal grid	Ž.	Impedance in plate circuit
•	resistance	W Z Z; Z, Z, Z, Z,	Screen bypass impedance
	·	-:	ocicen bypass impedance

CONTENTS

Glossary of Terms	. 17
Chapter One. INTRODUCTION TO AMATEUR RADIO COMMUNICATIONS 1-1 Amateur Radio 1-2 Amateur Station and Operator Licenses 1-3 The Amateur Bands	1.1 1.2 1.4
1-4 Starting Your Study	
Chapter Two. DIRECT CURRENT CIRCUITS 2-1 The Atom 2-2 Fundamental Electrical Units and Relationships 2-3 Electrostatics and Capacitors 2-4 Magnetism and Electromagnetism 2-5 RC and RL Transients	. 2.1 . 2.2 . 2.13
Chapter Three. ALTERNATING CURRENT, IMPEDANCE, and RESONANT CIRCUITS	. 3.1
3-1 Alternating Current 3-2 Reactive Circuits 3-3 Resonant Circuits 3-4 Coupled Circuits 3-5 Transformers 3-6 Wave Fifters 3-7 Modern Filter Design	3.1 3.6 3.15 3.19 3.25
Chapter Four. SEMICONDUCTOR DEVICES	4 1
4-1 Atomic Structure of Germanium and Silicon 4-2 Mechanism of Conduction 4-3 The PN Junction 4-4 Diode Power Devices 4-5 The Bipofor Transistor 4-6 Transistor Characteristics 4-7 Transistor Audio Circuitry 4-8 R-F Circuits 4-9 Field Effect Devices 4-10 Circuitry 4-11 Integrated Circuits 4-12 Digital-Logic ICs 4-13 MOS Logic 4-14 Linear ICs 4-15 Solid-State Light Sources and Numeric Displays 4-16 The Microprocessor Chapter Five. VACUUM-TUBE PRINCIPLES 5-1 Thermionic Emission	. 4.1 4.2 4.3 4.8 4.12 4.16 4.22 4.32 4.37 4.39 4.43 4.46 4.51
3-2 lube Types	5.2
5-3 Special Microwave Electron Tubes 5-4 The Cathode-Ray Tube 5-5 Miscellaneous Tube Types	. 5.9
Chapter Six. VACUUM-TUBE AMPLIFIERS	. 6.1
6-1 Classes and Types of Vacuum-Tube Amplifiers 6-2 Interstage Coupling Circuits 6-3 The Triode Amplifier 6-4 The Class-B Audio-Frequency Power Amplifier 6-5 The Cathode-Follower Amplifier 6-6 The Feedback Amplifier 6-7 DC Amplifiers 6-8 The Single-Ended Triode Amplifier 6-9 Single-Ended Pentade Amplifiers 6-10 Push-Pull Audio Amplifiers 6-11 Class-B Audio-Frequency Power Amplifiers 6-12 Cathode-Follower Power Amplifiers 6-13 Feedback Amplifiers	6.1 6.3 6.4 3.7 6.8 6.9 6.10 6.11 6.12
Chapter Seven. RADIO-FREQUENCY POWER AMPLIFIERS	
7-1 Class-C R-F Power Amplifier 7-2 Constant-Current Curves 7-3 Class-C Amplifier Calculations	. 7.1

7-4	Class-B Radio-Frequency Power Amplifier	7.13
7-5	Grounded-Grid and Cathode-Follower R-F Power Amplifier Circuits	7.13
7-6	Clare AB. Bodie France Brown Amplifier Circuits	7.16
	Class AB, Radio Frequency Power Amplifier	7.20
7-7	Grounded-Grid Linear Amplifiers	7.22
7-8	Intermodulation Distortion	7.24
		7.26
Chapter Ei	ght. SPECIAL CIRCUITRY FOR SEMICONDUCTORS	
Chapter Li	git. SPECIAL CIRCUITRY FOR SEMICONDUCTORS	
	AND VACUUM TUBES	8.1
8-1	Timiting Cincita	0.1
	Limiting Circuits	8.1
8-2	Clamping Circuits	
8-3	Positive Feedback Amplifier	0.2
8-4	The Blocking Oscillator	8.3
8-3	Counting Cincile	8.4
	Counting Circuits	8.5
8-6	RESISTANCE-CADACITANCE OSCIILATORS	0 /
8-7	Closed-Loop Feedback	8.7
		8.7
Chapter N	ing SINGLE SIDERAND TRANSPASSION AND PROPERTY.	
		9.1
9-1	The SSB System	
9-2	A Basic Single-Sideband Transmitter	9.1
9-3	The Delenge Medicates	9.9
	ine balance Modulator	9.10
9-4	ine Sideband Filter	0.10
9-5	ine Ludziud IAD6 770 FXCiter	
9-6	Single-Sideband Frequency Conversion	9.14
9-7	Single-Sideband Frequency Conversion	9.17
	Selective Tuned Circuits	9.19
9-8	Distortion Products Due to Nonlinearity of R.F. amplifiers	
9-9	33D Keception	-
9-10	The SSB Transceiver	9.24
		9.28
Chashau T	- COMMINICATION PEGEDIES - INC.	
Chapter T	en. COMMUNICATION RECEIVER FUNDAMENTALS	101
Port I-	—The HF Receiver	
	· · · · · · · · · · · · · · · · · · ·	
10-1	Types of Receivers	10.1
10-2	Receiver Performance Requirements	10.1
10-3	The Superhoterodus Possivos	10.2
10-4	The Superheterodyn Receiver	10.9
	The R-F Amplifier Stage	10.12
10-5	ine mixer stage	10.1
10-6	The Mixing Oscillator	10.17
10-7	The LE Amelities	10.19
10-8	The I-F Amplifier	10.21
	A Solid-State 1-7 Strip	70.04
10-9	The Beat-Frequency Oscillator	10.20
10-10	The Detector or Demodulator	10.20
10-11	Automatic Cala Cantral	10.29
10-12	Automatic Gain Control	10.31
	ine Signal-Strength Indicator	10 25
10-13	IMPUISE NOISE Limiting	10.24
10-14	Direct Frequency Readout	10.30
10-15	The Audio System	10.37
	The Audio System	10.40
D 4 11	VUP and time by a	
	YHF and UHF Receivers	
10-16	VHF/UHF Noise Sources	
10-17	Receiver Noise Performance	10.41
10-18	Receiver Noise Performance	10.43
10-19	THE RECEIVER CIRCUITY	10.44
	i-r Strips and Conversion Oscillators	10.47
10-20	Band-Scanning Receivers	10.40
		10.46
Ch 4 El -	OPLIED AMERICAN AND AND AND AND AND AND AND AND AND A	
Chapter Ele		
	FREQUENCY ENERGY	
David I	-HF Circuits	11.1
11-1	Self-Controlled Oscillator	_
11-2	Quarty-Crystal Oscillators	11.1
11-3	Quartz-Crystal Oscillators	11.6
	Crystal-Oscillator Circuits	77 74
11-4	Spurious Frequencies	
11-5	K-r vacuum-lube Amplitiers	
11-6	Neutralization of P.E. Amplificer	11.14
11-7	Neutralization of R-F Amplifiers	11.15
	reutralizing Procedures	
11-8	Grounded-Grid Ampfitters	11 21
17-9	riequency Multipliers	
11-10	Tank-Circuit Design	11.22
11-11	Tank-Circuit Design	11,23
	m, ii, unu ri-L Matchina Networks	
11-12		
17-13	Grid Bias	11.34
		1122

11-14	Protective Circuits for Transmitting Tubes	11.36
11-15	Interstage Coupling	
11-16	Solid-State HF Power Circuits	
11-17	Solid-State Power Amplifiers	11.44
Dort II	VHF Circuits	
11-18	Vacuum-Tube Limitations	11.50
11-19	Input and Output Circuitry	
11-20	Solid-State VHF Circuitry	11 55
11-21	Promote the telegraphic transfer of the telegraphic transf	11.33
11-21	Frequency Multipliers	11.59
Part III	R-F Feedback	
11-22	R-F Feedback Circuits	11.60
Chapter T	welve. FREQUENCY SYNTHESIS	12.1
12-1	Synthesis Techniques	
12-2	The Voltage Controlled Controlled	12.1
1 2-2	The Voltage-Controlled Oscillator	12.5
A:		
Chapter Th	nirteen. FREQUENCY MODULATION AND REPEATERS	13.1
13-1	Frequency Modulation	
13-2	Direct E-M Circuite	13.1
13-3	Direct F-M Circuits	13.6
	rnose McQuigtion	120
13-4	Reception of F-M Signals	12 12
13~5	The F-M Repeater	13.20
		. J . A. U
Chapter Fo	urteen. SPECIALIZED ANATEUR COMMUNICATIONS	
onspici io	STATISTICS ANALYSIS COMMUNICATIONS	
	SYSTEMS AND TECHNIQUES	14.1
14-1	Amateur Space Communication	14.1
14-2	FMF (Moorhounes) Communication	14.1
14-3	EME (Moonbounce) Communication	14.13
	Radioteletype Systems	14.15
14-4	RTTY Transmission	14.18
14-5	RTTY Reception	14 21
14-6	Slow-Scan Television	14.21
14-7	Amateur Facsimile	14.25
14-8	American Polantian	14.36
	Amateur Television	14.37
14-9	Narrow-Bana voice modulation (NBVM)	14.38
	Narrow-Band Voice Modulation (NBVM)	
Chapter Fi	fteen. AMPLITUDE MODULATION AND AUDIO PROCESSING	15.1
Chapter Fi	ffeen. AMPLITUDE MODULATION AND AUDIO PROCESSING	15.1
Chapter Fi 15-1 15-2	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING	15.1 15.1
Chapter Fi	fteen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Mechanics of Modulation Audio Processing	15.1 15.1 15.2
Chapter Fi 15-1 15-2	fteen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Mechanics of Modulation Audio Processing	15.1 15.1 15.2
Chapter Fi 15-1 15-2 15-3 15-4	fteen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation	15.1 15.1 15.2 15.4
Chapter Fi 15-1 15-2 15-3 15-4 15-5	ffeen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System	15.1 15.1 15.2 15.4 15.8
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6	ffeen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Dolierty and the Terman-Wasdward Modulated Amplifiers	15.1 15.1 15.2 15.4 15.8
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7	ffeen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation	15.1 15.2 15.4 15.8 15.12
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8	fteen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission	15.1 15.2 15.4 15.8 15.12 15.14
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9	ffeen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Mechanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9	ffeen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Mechanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9	fteen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI)	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Mechanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S	ffeen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S	ffeen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.1
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 of Chapter S 16-1 16-2 16-3 16-4	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.4
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.1 16.4 16.6
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Mechanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.1 16.6
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Mechanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.1 16.6
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 of Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.11 16.12 16.15 16.15
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.11 16.12 16.15 16.15
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 of Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S Chapter S	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.17 16.15 16.15 16.15
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S Chapter S Chapter S Chapter S	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.17 16.12 16.15 16.15
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-5 16-6 16-7 Chapter S	ffeen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Madulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.1 16.6 16.11 16.12 16.15 16.15 16.16
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors	15.1 15.1 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.11 16.12 16.15 16.16
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-5 16-6 16-7 Chapter S	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry inteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.17 16.15 16.15 16.15 16.16
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry inteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.17 16.15 16.15 16.15 16.16
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 • Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3 17-4 17-5	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators Relays	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.13 16.12 16.15 16.15 17.1 17.1 17.1 17.1
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3 17-4 17-5 17-6	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Madulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators Relays Grounds	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.1 16.1 16.1 16.1 16.15 16.15 16.15 17.1 17.1 17.1 17.1 17.1 17.1 17.1 1
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3 17-4 17-5 17-6	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators Relays Grounds Holes, Leads, and Shafts	15.1 15.1 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.4 16.6 16.17 16.12 16.15 16.16 17.1 17.1 17.1 17.1 17.1 17.14 17.14 17.15
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 of Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3 17-4 17-5 17-6 17-7 17-8	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Fifters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators Relays Grounds Holes, Leads, and Shafts Pagasitic Resonances	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.1 16.4 16.6 16.13 16.12 16.15 16.15 16.16 17.1 17.1 17.1 17.1 17.1 17.14 17.14 17.14 17.14 17.15
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3 17-4 17-5 17-6 17-7 17-8 17-9	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators Relays Grounds Holes, Leads, and Shafts Parasitic Resonances Parasitic Oscillation in R-F Amplifiers	15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.1 16.1 16.1 16.1 16.1 17.1 17.1
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 of Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3 17-4 17-5 17-6 17-7 17-8	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI Eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators Relays Grounds Holes, Leads, and Shafts Parasitic Resonances Parasitic Oscillation in R-F Amplifiers	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.1 16.1 16.1 16.1 16.15 16.15 16.16 17.1 17.1 17.1 17.1 17.1 17.1 17.
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3 17-4 17-5 17-6 17-7 17-8 17-9	Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI Eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators Relays Grounds Holes, Leads, and Shafts Parasitic Resonances Parasitic Oscillation in R-F Amplifiers	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.1 16.1 16.1 16.1 16.15 16.15 16.16 17.1 17.1 17.1 17.1 17.1 17.1 17.
Chapter Fi 15-1 15-2 15-3 15-4 15-5 15-6 15-7 15-8 15-9 15-10 Chapter S 16-1 16-2 16-3 16-4 16-5 16-6 16-7 Chapter S 17-1 17-2 17-3 17-4 17-5 17-5 17-7 17-8 17-9 17-10	freen. AMPLITUDE MODULATION AND AUDIO PROCESSING Sidebands Machanics of Modulation Audio Processing Systems of Amplitude Modulation Input Modulation System The Doherty and the Terman-Woodyard Modulated Amplifiers Spread-Spectrum Modulation A-M Stereo Transmission Practical High Level Modulation Solid-State Modulation Circuitry ixteen. RADIO INTERFERENCE (RFI) Television Interference Harmonic Radiation Low Pass Filters Stereo F-M Interference Broadcast Interference Other Forms of Interference Help in Solving TVI eventeen. EQUIPMENT DESIGN The Resistor The Capacitor Wire and Inductors Insulators Relays Grounds Holes, Leads, and Shafts Parasitic Resonances Parasitic Oscillation in R-F Amplifiers	15.1 15.1 15.2 15.4 15.8 15.12 15.14 15.16 15.17 15.18 15.20 16.1 16.1 16.1 16.1 16.1 16.15 16.15 16.16 17.1 17.1 17.1 17.1 17.1 17.1 17.

17-12		17 25
17-13	Conduction Cooling	
17-14	Transient Protection	17.20
Chapter E	ighteen. TRANSMITTER KEYING AND CONTROL	101
18-1	Reying Requirements	
18-2	Transmitter Keying	18.1
18-3	pieak-iu Keliud	
18-4	The Electronic Key	18.4
18-5	The COSMOS Keyer—MARK II	18./
18-6	The Reybodio Rever	10 10
18-7	VOX CIPCUITY	10 10
18-8	An K-r Uperated Keving Monitor	10 14
18-9	The Phone Patch	10.10
Chapter N	ineteen. MOBILE AND PORTABLE EQUIPMENT	101
19-1	Mobile and Portable Power Saures	17.1
19-2	Mobile and Portable Power Sources	19.1
19-3	Transistor Supplies Antennas for Mobile Operation	19.5
19-4	Construction of Mobile Equipment	19.10
19-5	Vehicular Noise Suppression	19.17
19-6	A Portable Amateur Band Receiver	19.18
19-7	A Solid-State 10-Watt Linear Amplifier for 420 MHz	19.21
19-8	Two Solid-State Linear Amplifiers for Mobile SSB	19.32
	Amplifiers for Mobile 33B	19.36
Chapter T	WENTY RECEIVERS AND EXCITEDS	
20-1		20.1
20-2	A Deluxe, Solid-State Amateur Band Receiver-Mark II	20.2
20-3	An Advanced, Solid-State HF Communications Receiver	20.25
20-4	An Advanced Six-Band Solid-State SSB Exciter	20.40
20-5	A High Performance Conversion Module for the 23-cm Band	20.57
20-6	A Very Low Noise Programation for the 23-th build	20.64
20-7	A Very Low Noise Preamplifier for 144 MHz	20.66
	A Tunable 2-Meter Receiver With Digital Readout	20.69
Chapter T	wenty-One. HE AND VHE POWER-AMPLIFIER DESIGN	
21-1		21.1
	Triode Amplifier Design	21.2
21-2 21-3	retroug Amplifier Design	217
21-3 21-4	Curnode-Driven Amplitier Design	21 14
21-4	Neutralization of the Cathode-Driven Stage	21.18
Chanter T		
		22.1
Part I-	—HF Amplifiers	
22-1	Amplifier Safety Summary	
22-2	Ampirtier Schematics	
22-3	The KW-1 Mark III Linear Amplifier Using the 8875	22.2
22-4	The 500Z 2-kW PEP Linear Amplifier for 10-80 Meters	22.12
22-5	A INV-STAGE DIGR-WALL AMPLIFIER DEING THE 3.10007	~~ ~=
22-6	A RIIOWOTT Linear Amplitier for Six Meters	22 24
22-7	~ Compact 1-kw 7th Linear Amplities With the 8877	22 20
22-8	A MOUNT 3-10004 Linear Amplities for 20-10 Meters	22 44
22-9	A 4CAISUUB 2-KW PEP Linear Amplifiar	22 52
22-10	A DIST FOWER LINEAR AMBILTIES WITH THE 8877	20 40
22-11	A 2-kW Linear Amplifier for 6 Meters	22.02
		44.71
	—VHF Amplifiers	
22-12	An 80-Watt Base Station Amplifier for 2-Meter F-M Service	22
22-13	~ INVITED TO TOTAL TO THE CONTRACT OF THE PROPERTY OF THE PROP	
44-14	A DIGHTOWER AMPLIFIER FOR 220 MMz	22 65
22-15	A TOURT/ADDUTIES TO ATT AND	
22-16	A 3VV-WOTT AMBILITIES for 420-450 MMZ	222
22-17	A Practical 2-kW PEP Amplifier for 432 MHz	44.73 77 1 0 4
		-4.100
Chapter T	wenty-Three. POWER SUPPLY	
23-1		23.1
23-1 23-2	ine Primary Circuit	
23-2	irunimiter Control Methods	
23-4	· oucl-aupply Venditellielle	
23-5	tower-amply Components	
23-6	Rectification Circuits Series Diode Character	23.14
	Series Diode Operation	23.19

23 23 23 23 23	3-9 3-10 3-11 3-12	Solid-State Supplies for SSB A 1-Kilowatt IVS Power Supply A 2-Kilowatt PEP Supply for SSB IVS Bridge-Rectifier Supplies A Heavy-Duty Primary Supply Regulated Power Supplies Transceiver Power Supply	23.25 23.26 23.27 23.29 23.29
		venty-Four. RADIATION AND PROPAGATION	24.1
24 24 24	4-1 4-2 4-3 4-4 4-5	The Antenna System The Electromagnetic Wave The Standing Wave General Antenna Properties The Antenna Above A Ground Plane	24.3 24.6 24.8
P	art II-	HF and VHF Propagation	
24 24 24 24	4-6 4-7	Propagation—2 to 30 MHz Cycles in Ionospheric Activity Ionospheric Disturbance Propagation in the VHF Region Forecast of High-Frequency Propagation	24.19 24.21 24.23
Chapte	er Tw	renty-Five. THE TRANSMISSION LINE	25.1
2: 2: 2: 2: 2:	5-1 5-2 5-3 5-4 5-5 5-6	Characteristic Impedance Transit Time and Wave Reflection Waves and Fields Along a Transmission Line The Standing-Wave Ratio Impedance Matching with Resonant Lines Transmission Lines	25.1 25.2 25.5 25.8 25.8
Chapte	er Tw	venty-Six. ANTENNA MATCHING SYSTEMS	24.1
20 20 20 20 20 20	6-1 6-2 6-3 6-4 6-5 6-6 6-7	SWR and Impedance Compensation The Smith Chart Practical Wideband Balun Transformers Antenna Matching Devices Coupling to the Antenna System A Single-Wire Antenna Tuner Antenna Support	26.1 26.2 26.5 26.9 26.15 26.19
Ch 4	- T	C LIP OPLIED AL DUDDOG ANDROVALO	
-		venty-Seven. HF GENERAL PURPOSE ANTENNAS	27.1
	7-1 7-2	The Angle of Radiation	27.1
	7-2 7-3	The Center-Fed Antenna	27.5
	7-4	The Vertical Antenna The Marconi Antenna	27.8
2	7-5	The Loop Antenna	27 15
_	7-6 7-7	Space-Conserving Antennas Multiband Antennas	27 14
Chapte	er Tw	renty-Eight. HIGH-FREQUENCY FIXED DIRECTIVE ANTENNAS	20.1
21	8-1	Directive Antennas	
	8-2	ine Long-Wire Antenna	20.2
	8-3	ine Knompic Antenna	20.7
	8-4 8-5	The Multielement Fixed Array Combination End-Fire and Broadside Arrays	28.8 28.15
Chapte	er Tw	venty-Nine. HF ROTARY BEAM ANTENNAS	20.1
	9-1	The Parasitic Beam	20.1
_	9-2	The Multielement Parasitic Array	~~ 4
	9-3 0-4	Building The Yaqi Beam	20.4
	9-4 9-5	reed systems for paracitic Arrays	~~ ~
_	9-6	The Miniature Beam Three-Band Beams	29.9
29	9-7	ine Cubical Quad Beam	20 12
_	9-8	The Driven Array	20 15
	9-9 9-10	luning the ratasitic Array	20 10
	9-11	Indication of Direction Antenna Rotators	29.20 29.21

30-1 Antenna Requirements 30-2 Base Station Antennas 30-2 Base Station Antennas 30-30-3 Base Station Antennas 30-1 The Log-Periodic Antennas 30-1 The Log-Periodic Antennas 30-1 The Corner-Reflector and Mon-Type Antennas 30-2 The Corner-Reflector and Mon-Type Antennas 30-3 Stended, Expanded VHF Arrays 30-8 Extended, Expanded VHF Arrays 30-9 A VHF SWR Mater 30-3 The Corner Reflector and Mon-Type Antennas 30-2 The Corner Reflector Antennas 30-2 The Corner Reflector	Chapter 1	hirty. VHF AND UHF ANTENNAS		30 1
30-2 Fosis Station Antennos 30-1 The Log-Periodic Antennos 30-1 30-3 The Log-Periodic Antennos 30-1 The Log-Periodic Antennos 30-1 The Correct Retricts of the Correct Retricts Retricts of the Correct Retricts R	30-1	Antenna Requirements		20.5
30-11 Helical Seam Antenna 30.17 30-2 The Helical Seam Antenna 30.17 30-3 The Helical Seam Antenna 30.22 30-5 The Helical Seam Antenna 30.22 30-6 The Company Seam Antenna 30.22 30-7 Stocking VHF Antennas 30.22 30-8 Extended, Expended VHF Arrays 30.37 30-9 A VHF SWR Meter 30.31 31-1 Voltage, Current, and Resistance Measurements 31.1 31-1 Voltage, Current, and Resistance Measurements 31.1 31-2 The Digital Voltager (DVM) 31.4 31-3 Electronic Voltmeter (DVM) 31.4 31-3 Electronic Voltmeter (DVM) 31.4 31-3 Measurement of Circuit Constants 31.8 31-5 Measurement of the Constants 31.10 31-6 Reference of Circuit Constants 31.11 31-7 The R-F Bridge 31.11 31-7 The R-F Bridge 31.11 31-10 Frequency and Time Measurements 31.11 31-11 A Precision Crystal Calibrator 31.12 31-12 A Silicon Diode Noise Generator 31.12 31-13 The R-F Roise Bridge 31.13 31-14 A Universal Crystal Calibrator 31.13 31-15 A measurement of Cricuit Strain 31.14 31-16 A Transistorized Coppositance Meter 31.3 31-17 A 2-Tone Generator for SSB Testing 31.3 31-17 A 2-Tone Generator for SSB Testing 31.3 31-19 A Constant Strain 31.3 31-10 A Transistorized Coppositance Meter 31.3 31-11 A Universal Crystal Test Unit 31.3 31-12 A Silicon Diode Noise Generator 31.3 31-13 A Particular Properties of Strain 31.3 31-14 A Universal Crystal Test Unit 31.3 31-15 A Interpretator for SSB Testing 31.3 31-16 A Transistorized Coppositance Meter 31.3 31-17 A 2-Tone Generator for SSB Testing 31.3 31-17 A 2-Tone Generator for SSB Testing 31.3 31-17 A 2-Tone Generator for SSB Testing 31.3 31-3-17 A 2-Tone Generator for SSB Testing 31.3 31-3-17 A 3-Tone Generat	30-2	base Station Antennas		34 7
30-3 The Melical Beam Antenna 30.17	30-3	The Log-Periodic Antenna		30.7
30-2 Ine Corner-Reflector and Horn-Type Antennas 30-27 30-7 Brackhind Viff Yagi Beem Antennas 30-27 30-7 Brackhind Viff Yagi Beem Antennas 30-27 30-7 Brackhind Viff Yagi Beem Antennas 30-27 30-9 A VHF 3WR Meter 30-30-9 A VHF 3WR Meter 30-31 30-9 A VHF 3WR Meter 30-31 30-9 A VHF 3WR Meter 30-31 31-1 Voltage, Current, and Resistance Measurements 31-1 Voltage, Current, and Resistance Measurements 31-1 Voltage, Current, and Resistance Measurements 31-1 Pre Digital Voltameter (DVM) 31-1 Antenna and Constants 31-1 A Digital Voltameter (DVM) 31-1 A Resurement of Circuit Constants 31-1 Measurement of Circuit Constants 31-1 A Resurement of Circuit Constants 31-1 The R-F Bridge 31-1 A Precision Crystal Colliboration 31-1 Prequency and Transmission-Line Instrumentation 31-1 A Universal Crystal Celepacition and Transmission-Line Instrumentation 31-1 A Juniversal Crystal Celepacition and Transmission and Transmissio	30-4	ine Melical Beam Antenna		20 27
30-2 YFF Togs Beam Antennas 30.27 30-8 Extended, Expanded VHF Arrays 30.31 30-9 AVIF 3WR Meter 30.34 Auppier Thirty-One. ELECTRONIC TEST EQUIPMENT 31.1 31-1 Voltage, Current, and Resistance Measurements 31.1 31-2 The Digital Voltmeter (DVM) 31.4 31-3 Exetronic Voltmeter (DVM) 31.4 31-3 Exetronic Voltmeter 31.5 31-4 Power Measurements 31.1 31-5 Measurement of Circuit Constants 31.1 31-6 Measurement of Circuit Constants 31.1 31-7 Fig. 11-7 31-1 Variety of Circuit Constants 31.1 31-7 Fig. 11-7 31-7 Fig. 11-7 31-1 Variety of Circuit Constants 31.1 31-1 A Precision Crystal Collibrator 31.1 31-1 A Universal Crystal Test Unit 31.1 31-1 A 2-Tone Generator for SSB Testing 31.3 31-1 A 3-Tone Generator for SSB Testing	30-5	ine Corner-Ketlector and Horn-Type A	ntennas	20.01
30-8 Extended, Expanded VHF Arrays 30-8 and Extended, Expanded VHF Arrays 30-8 and Sterended Start SWR Meter 30-8 and SWR Meter 30-8 and SWR Meter 30-8 and SWR Meter 31-1 Yoltage, Current, and Resistance Measurements 31.1 Yoltage, Current, and Resistance Measurements 31.1 SWR Meter 31.2 The Digital Voltmeter (DVM) 31.4 Parallel SWR Meter 31.5 Measurement of Circuit Constants 31.6 Measurement of Circuit Constants 31.7 The R-F Bridge 31.1 SWR Measurement of Circuit Constants 31.1 And Parallel SWR Instruments 31.1 And Parallel SWR Instruments 31.1 A Pracision Crystal Calibrator 31.1 A Precision Crystal Calibrator 31.1 A Precision Crystal Calibrator 31.1 A Precision Crystal Calibrator 31.1 Fine R-F Noise Bridge 31.1 A Universal Crystal Test Unit 31.1 Fine R-F Noise Bridge 31.1 A Universal Crystal Test Unit 31.1 A Universal Crystal Test Unit 31.1 A Pracision Generator for SSB Testing 31.1 A 2-Tone Generator for SSB Testing 31.1 A 1-Tone Generator for SSB Testing 31.1 A 3-Tone Generator for SSB Testing 31.1 A 3-Tone Generator Multimeter 31.1 A 3-Tone Generator Multimeter 31.2 A 2-Tone Generator Multimeter 31.3 An Bettionic Multimeter 31.3 An Bettionic Multimeter 32.2 The Sampling Oscilloscope 32.2 The Sampling Oscilloscope 32.2 The Sampling Oscilloscope 32.3 Display of Waveforms 32.4 Lissigus Figures 32.7 And Application 32.8 The Spectrum Analyzer 32.1 Tools 33.1 Tools 33.2 The Material 33.2 The Material 33.3 The Spectrum Analyzer 33.4 Inclosure Openings 34.5 Fine Spectrum Analyzer 34.6 Fine Spectrum Analyzer 34.7 Fine Material 34.9 Fine Material 34.9 Fine Material 34.1 Fine Material 34.2 Algebra 34.3 Fine Material 34.3 Fine Material 34.3 Fine Material 34.4 Fine Material 34.5 Fine Material 34.6 Fine Material 34.7 Fine Material 34.8 Fine Material 34.9 Fine Material 34.9 Fine Material 34.1 Fine Material 34.2 Algebra 34.3 Fine Material 34.3 Fine Material 34.4 Fine Material 34.5 Fine Material 34.5 Fine Material 34.6 Fine Material 34.7 Fine	30-6	VMr Tagi Beam Antennas		20.33
30-9 A VHF SWR Meter 30.34 hapter Thirty-One. ELECTRONIC TEST EQUIPMENT 31.1 31-1 Yoltage, Current, and Resistance Measurements 31.1 31-2 The Digital Voltmeter (DVM) 31.4 31-3 Electronic Voltmeter (DVM) 31.4 31-3 Electronic Voltmeter (SVM) 31.5 31-5 Measurement of Circuit Constants 31.6 31-5 Measurement of Circuit Constants 31.1 31-6 Measurement of Circuit Constants 31.1 31-7 The R-F Bridge 31.1 31-8 Antenna and Trensmission-Line Instrumentation 31.1 31-1 For Practical SWR Instruments 31.1 31-9 Practical SWR Instruments 31.1 31-1 Frequency and Time Measurements 31.1 31-10 Frequency and Time Measurements 31.1 31-11 A Precision Crystal Calibrator 31.2 31-12 A Silicon Diode Noise Generator 31.2 31-13 A Instruments 31.1 31-14 A Universal Crystal Test Unit 31.1 31-15 A Transistorized Capacitance Meter 31.1 31-16 A Transistorized Capacitance Meter 31.1 31-17 A 2-Tone Generator for SSR Testing 31.1 31-18 A Variable-Frequency Audio Generator 31.3 31-18 A Punction Generator for SSR Testing 31.1 31-19 A Inection Construction Multimeter 31.4 31-10 An Electronic Multimeter 31.4 31-10 A Machine Stilloscope 32.1 32-2 A Modern Oscilloscope 32.1 32-2 The Sampling Oscilloscope 32.7 32-2 The Sampling Oscilloscope 32.1 32-3 Display of Waveforms 32.1 32-5 Single-Sideband Application 32.1 32-6 Single-Sideband Application 32.1 32-7 A-M Application 32.1 32-7 The Material 33.2 32-7 The Material 33.2 33-1 Tools 33.1 33-1 Tools 33.1 33-2 The Material 33.3 33-3 Tools 4.1 33-4 Transitorized Construction Practices 33.1 33-1 Tools 4.1 33-1 Tools 5.1 33-1 Tools 5.1 33-1 Tools 5.1 33-1 Tools 6.1 33-1	30-7	Stacking VHF Antennas		30.22
30.34 A VHF SWR Meter 30.34 In hoter Thirty-One. ELECTRONIC TEST EQUIPMENT 31.1 31-1 Voltage, Current, and Resistance Measurements 31.1 31-2 The Digital Voltmeter (DVM) 31.4 31-3 Electronic Voltmeter (DVM) 31.4 31-3 Electronic Voltmeter (DVM) 31.5 Power Measurements 31.8 31.7 Power Measurements 31.8 31.7 Power Measurements 31.8 31.10 Application 31.10 Power Measurements 31.10 State Stat	30-8	Extended, Expanded VHF Arrays		30.27
Name	30-9	A VHF SWR Mater		30.31
31-1				30,34
31-1	Chapter T	hirty-One. ELECTRONIC TEST EOU	IPMENT	21 1
11-2 The Digital Voltimeter (DVM)		Voltage, Current, and Resistance Measu	uromanêc	31.1
31.7	31-2	The Digital Voltmeter (DVM)	arements	31.1
31-5	31-3	Electronic Voltmeter		31.4
31-16 Measurement with a Bridge 31.11 31-7 The R-F Bridge 31.11 31-8 Antenna and Transmission-Line Instrumentation 31.14 31-19 Practical SWR Instruments 31.18 31-10 Frequency and Time Measurements 31.12 31-11 A Precision Crystal Calibroto 31.26 31-12 A Silican Diode Noise Generator 31.26 31-13 The R-F Noise Bridge 31.30 31-14 A Universal Crystal Test Unit 31.30 31-15 An Inexpensive Transistor Tester 31.31 31-16 A Transistorized Capacitance Meter 31.32 31-17 A 2-Tone Generator for SSB Testing 31.31 31-18 A Variable-Frequency Audio Generator 31.36 31-19 A Function Generator 31.36 31-20 An Electronic Multimeter 31.40 another Thirty-Two. THE OSCILLOSCPE 32.1 32-1 A Modern Oscilloscope 32.2 32-2 The Sampling Oscilloscope 32.2 32-3 Display of Waveforms 32.9 32-4 Lisagious Figure 32.10 32-5 Receiver I-F Alignment with on Oscilloscope 32.10 32-6 The Spectrum Analyzer 32.11 33-1 Tools 33.1 33-1 Tools 33.1 33-3 Tyl-Proof Inclosures 33.4 33-4 Inclosure Openings 33.5 33-5 Printed Circuits 33.5 33-6 Printed Circuits 33.1 33-7 Arithmetic 33.1 34-8 Electronic Construction Practices 33.5 33-7 Arithmetic 34.1 34-1 Arithmetic 34.1 34-2 Algebra 34.1 34-3 Tyl-Proof Inclosures 34.1 34-4 Arithmetic 34.2 34-5 The Material 34.1 34-7 Calibra Arithmetic 34.2 34-8 Electronic Computers 34.4 34-9 Arithmetic 34.2 34-1 Arithmetic 34.2 34-2 Algebra 34.1 34-3 Arithmetic 34.2 34-4 Calibra 34.1 34-6 Arithmetic 34.2 34-7 Calibra 34.1 34-8 Electronic Computers 34.2 34-9 Calibra 34.1 34-1 Arithmetic 34.2 34-2 Algebra 34.1 34-3 Algebra 34.1 34-1 Algebra 34.2 34-2 Algebra 34.2 34-3 Computers 34.2 34-5 Computers 35.9 35-1 C		Power Measurements		31.7
31-17 The R-F Bridge 31.13		Measurement of Circuit Constants		31.8
11-12 11-1		Measurement with a Bridge		31.10
31-9		The R.F Rridge		31.11
31-10 Frequency and Time Measurements 31.18 31-10 7-requency and Time Measurements 31.22 31-11 A Precision Crystal Calibrator 31.24 31-12 A Precision Crystal Calibrator 31.26 31-13 The R-F Noise Bridge 31.28 31-14 A Universal Capacitance Meter 31.30 31-15 An Inexpensive Transistor Tester 31.31 31-16 A Transistorized Capacitance Meter 31.31 31-16 A Transistorized Capacitance Meter 31.32 31-17 A 2-Tone Generator for SSB Testing 31.34 31-18 A Variable-Frequency Adio Generator 31.36 31-19 A Function Generator 31.36 31-19 A Function Generator 31.36 31-20 An Electronic Multimeter 31.40 31-20 An Electronic Multimeter 31.20 31-20 An Electronic Multimeter 31.30		Antenno and Transmission Line Instrum	*************	31.13
31-12 A Precision Crystal Calibrator 31.24	31-9	Practical SWP Instruments	entation	31.14
31-12 A Precision Crystal Calibrator 31.24		Frequency and Time Massacraments		31.18
31-12 A Silican Diode Noise Generator 31.26		A Provision Country College		31.22
31-13 Ine K-F Noise Bridge 31.28		A Silican Diada Naise Consesses		31.24
31-15		The Par Noise Reiden		31.26
31-15		A Universal Courted Task Units		31.28
31-16		A Universal Crystal lest Unit		31 30
31-17		A Transistation Consistor Tester		31.31
31-17		A Iransistorized Capacitance Meter		31.32
31-19 A Function Generator 31.36 31-20 An Electronic Multimeter 31.40 napter Thirty-Two. THE OSCILLOSCPE 32.1 32-1 A Modern Oscilloscope 32.2 32-2 The Sampling Oscilloscope 32.7 32-3 Display of Waveforms 32.9 32-4 Lissajous Figures 32.10 32-5 Receiver I-F Alignment with an Oscilloscope 32.13 32-6 Single-Sideband Application 32.13 32-7 A-M Application 32.15 32-8 The Spectrum Analyzer 32.17 Anupter Thirty-Three. CONSTRUCTION PRACTICES 33.1 33-1 Tools 33-1 Tools 33.1 33-2 The Material 33.1 33-2 The Material 33.2 33-3 TVI-Proof Inclosures 33.3 33-4 Inclosure Openings 33.5 33-5 Sheet Metal Construction Practices 33.5 33-6 Printed Circuits 33.8 33-7 Coaxial Cable Terminations 33.11 33-8 Workshop Layout 33.13 33-9 Components and Hardware 33.13 34-1 Arithmetic 34.1 34-1 Arithmetic 34.1 34-2 Algebra 34.1 34-3 Tools 34.1 34-4 B Jean Algebra 34.1 34-7 Jonometry 34.9 34-8 Electronic Computers 34.9 34-8 Electronic Computers 34.9 34-8 Electronic Computers 34.9 Al-8 Standardization 34.12 Al-9 MISCELLANEOUS DATA 35.1 35-1 Comp tent Standardization 35.9		A 4-10ne Generator for 358 Testina		21 24
31-20		A Variable-Frequency Audio Generator		31.36
32-1		A function Generator		31.36
32-1 A Modern Oscilloscope 32-2 32-2 The Sampling Oscilloscope 32-7 32-3 Display of Waveforms 32-9 32-4 Lissajous Figures 32-10 32-5 Receiver 1-F Alignment with on Oscilloscope 32-13 32-6 Single-Sideband Application 32-13 32-7 A-M Application 32-15 32-8 The Spectrum Analyzer 32-17 Anupter Thirty-Three CONSTRUCTION PRACTICES 33-1 Tools 33-1 Tools 33-2 The Material 33-3 TVI-Proof Inclosures 33-3 TVI-Proof Inclosures 33-4 Inclosure Openings 33-5 Sheet Metal Construction Practices 33-6 Printed Circuits 33-7 Cooxial Cable Terminations 33-8 Workshop Layout 33-9 Components and Hardware 33-13 33-9 Components and Hardware 33-13 34-1 Arithmetic 34-1 Arithmetic 34-1 Arithmetic 34-2 Algebra 34-3 7-3 onometry 34-1 Arithmetic 34-3 7-3 onometry 34-1 Arithmetic 34-2 Algebra 34-3 7-3 onometry 34-1 Arithmetic 34-3 7-3 onometry 34-1 Arithmetic 34-3 7-3 onometry 34-1 Arithmetic 34-1 Arithmetic 34-2 Algebra 34-3 7-3 onometry 34-1 Arithmetic 35-1 Arithmet	31-20	An Electronic Multimeter		31.40
32-1 A Modern Oscilloscope 32-2 32-2 The Sampling Oscilloscope 32-7 32-3 Display of Waveforms 32-9 32-4 Lissajous Figures 32-10 32-5 Receiver 1-F Alignment with on Oscilloscope 32-13 32-6 Single-Sideband Application 32-13 32-7 A-M Application 32-15 32-8 The Spectrum Analyzer 32-17 Anupter Thirty-Three CONSTRUCTION PRACTICES 33-1 Tools 33-1 Tools 33-2 The Material 33-3 TVI-Proof Inclosures 33-3 TVI-Proof Inclosures 33-4 Inclosure Openings 33-5 Sheet Metal Construction Practices 33-6 Printed Circuits 33-7 Cooxial Cable Terminations 33-8 Workshop Layout 33-9 Components and Hardware 33-13 33-9 Components and Hardware 33-13 34-1 Arithmetic 34-1 Arithmetic 34-1 Arithmetic 34-2 Algebra 34-3 7-3 onometry 34-1 Arithmetic 34-3 7-3 onometry 34-1 Arithmetic 34-2 Algebra 34-3 7-3 onometry 34-1 Arithmetic 34-3 7-3 onometry 34-1 Arithmetic 34-3 7-3 onometry 34-1 Arithmetic 34-1 Arithmetic 34-2 Algebra 34-3 7-3 onometry 34-1 Arithmetic 35-1 Arithmet	hanter T	THE OSCILLOSOR		
32-7 The Sampling Oscilloscope 32-7 Display of Waveforms 32-9 32-4 Lissajous Figures 32-10 32-5 Receiver I-F Alignment with an Oscilloscope 32-13 32-6 Single-Sideband Application 32-15 32-7 A-M Application 32-15 32-8 The Spectrum Analyzer 32-17 stupter Thirty-Three. CONSTRUCTION PRACTICES 33-1 Tools 33-1 Tools 33-2 The Material 33-3 TYI-Proof Inclosures 33-3 TYI-Proof Inclosures 33-5 Sheet Metal Construction Practices 33-5 Sheet Metal Construction Practices 33-7 Coaxial Cable Terminations 33-8 Workshop Layout 33-9 Components and Hardware 33-19 Components and Hardware 33-10 34-1 Arithmetic 34-1 Arithmetic 34-2 Algebra 34-3 7 ponometry 34-4 B tean Algebra 34-5 T. Smith Chart 34-6 G. hical Representation 34-7 Cc. ulus 34-8 Electronic Computers 34-9 AISCELLANEOUS DATA 35-1 Comp tent Standardization 35-1 35-2 Useful Reference Data 35-9	20.1	Miny-1wo. The Oscilloscre		32.1
32-9 32-9 32-9 32-10 32-10 32-10 32-5 Receiver 1-F Alignment with on Oscilloscope 32.13 32-6 Single-Sideband Application 32.13 32-7 A-M Application 32.15 32-8 The Spectrum Analyzer 32.17 32.17 32-17		A Modern Oscilloscope		32.2
32-9 32-9 32-9 32-10 32-10 32-10 32-5 Receiver 1-F Alignment with on Oscilloscope 32.13 32-6 Single-Sideband Application 32.13 32-7 A-M Application 32.15 32-8 The Spectrum Analyzer 32.17 32.17 32-17		The Sampling Oscilloscope		32.7
32-14		Display of Waveforms		22 G
32-5 Single-Sideband Application 32.13 32-6 Single-Sideband Application 32.15 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 32.17 33.1 33.1 33.1 33.1 33.1 33.2 33.1 33.2 33.3 TVI-Proof Inclosures 33.2 33.4 33.4 Inclosure Openings 33.5 33.5 33.5 33.6 Printed Circuits 33.8 33.7 Sheet Metal Construction Practices 33.8 33.7 Coaxial Cable Terminations 33.11 33.8 Workshop Layout 33.13 33.9 Components and Hardware 33.13 33.19 33.		Lissalous riquies		22 10
32-0 Single-Sideband Application 32.13 32-7 A-M Application 32.15 32.6 The Spectrum Analyzer 32.17 32.17 32.17 32.17 32.17 33.1 33.1 33.2 Tools 33.1 33.2 The Material 33.2 33.2 33.3 TVI-Proof Inclosures 33.4 33.4 Inclosure Openings 33.5 33.5 33.5 Sheet Metal Construction Practices 33.5 33.5 33.6 Printed Circuits 33.8 33.7 Coaxial Cable Terminations 33.11 33.8 Workshop Layout 33.13 33.9 Components and Hardware 33.13 33.13 33.14 Arithmetic 34.1 Arithmetic 34.1 Arithmetic 34.2 Algebra 34.9 34.3 7-30nometry 34.9 34.3 7-30nometry 34.17 34.4 B Sean Algebra 34.27 34.4 Sean Algebra 34.32 34.4 Sean Algebra 34.4 34.4 34.5 Sean Algebra 35.1 35.2 Sean A		Receiver I-F Alignment with an Oscillos	cope	22 12
32-15 32-6 The Spectrum Analyzer 32.15 32.17 32-18 32.17 32-18 32.17 32-18 32.17 32-18 32.17 32-18 32-18 32-18 33-18 33-18 33-28 33-18 33-29		Single-Sideband Application		27 12
Sacration Spectrum Analyzer Sacratic		A-M Application		77 15
33-1 Tools 33-2 The Material 33-2 The Material 33-3 TVI-Proof Inclosures 33-4 Inclosure Openings 33-5 Sheet Metal Construction Practices 33-5 Sheet Metal Construction Practices 33-6 Printed Circuits 33-7 Coaxial Cable Terminations 33-8 Workshop Layout 33-9 Components and Hardware 33-13 33-9 Components and Hardware 33-13 34-1 Arithmetic 34-2 Algebra 34-2 Algebra 34-3 7-3 ponometry 34-4 B fean Algebra 34-3 7-3 ponometry 34-4 B fean Algebra 34-5 T Smith Chart 34-6 G hical Representation 34-7 Cc alus 34-7 Cc alus 34-8 Electronic Computers 35-1 35-1 Comp ment Standardization 35-1 35-2 Useful Reference Data 33-1 33-2 Standardization 35-1 35-2 Steep Standardization 35-1 35-2 Steep Standardization 35-1 35-2 Standardization 35-1 35-2 Steep Standardization 35-1 35-1 35-2 Standardization 35-1 35-2 Standardization 35-1 35-2 Standardization 35-1 35-1 35-1 Standardization 35-1	32-8	The Spectrum Analyzer		32.17
33-1 Tools 33-2 The Material 33-2 The Material 33-3 TVI-Proof Inclosures 33-4 Inclosure Openings 33-5 Sheet Metal Construction Practices 33-5 Sheet Metal Construction Practices 33-6 Printed Circuits 33-7 Coaxial Cable Terminations 33-8 Workshop Layout 33-9 Components and Hardware 33-13 33-9 Components and Hardware 33-13 34-1 Arithmetic 34-2 Algebra 34-2 Algebra 34-3 7-3 ponometry 34-4 B fean Algebra 34-3 7-3 ponometry 34-4 B fean Algebra 34-5 T Smith Chart 34-6 G hical Representation 34-7 Cc alus 34-7 Cc alus 34-8 Electronic Computers 35-1 35-1 Comp ment Standardization 35-1 35-2 Useful Reference Data 33-1 33-2 Standardization 35-1 35-2 Steep Standardization 35-1 35-2 Steep Standardization 35-1 35-2 Standardization 35-1 35-2 Steep Standardization 35-1 35-1 35-2 Standardization 35-1 35-2 Standardization 35-1 35-2 Standardization 35-1 35-1 35-1 Standardization 35-1	hunter T	Linu Thee CONSTRUCTIONS DO A	- Tiare	
33-2 The Material 33.2 33.3 33.4 33.4 33.4 33.4 Inclosure Openings 33.5 33.5 33.5 Sheet Metal Construction Practices 33.5 33.5 33.6 Printed Circuits 33.8 33.7 Coaxial Cable Terminations 33.11 33.8 Workshop Layout 33.13 33.9 Components and Hardware 33.13 33.13 33.14 Arithmetic 34.1 Arithmetic 34.1 Arithmetic 34.2 Algebra 34.9 34.9 34.3 7 Jonometry 34.17 34.4 B Isan Algebra 34.26 34.5 T Smith Chart 34.27 34.6 G: hical Representation 34.32 34.7 Cc alus 34.8 Electronic Computers 34.45 apter Thirty-Ye. NOMENCLATURE OF COMPONENTS AND MISCELLANEOUS DATA 35.1 35.1 Compinent Standardization 35.1 35.2 Useful Reference Data 35.9	10 pier 1	Table	THEES	33.1
33-3 171-Proof Inclosures 33.4 33.4 33.4 33.4 33.4 1nclosure Openings 33.5 33.5 33.5 5 5 5 6 6 7 7 7 7 7 7 7 7		Tools		33.1
33-3 171-Proof Inclosures 33.4 33.4 33.4 33.4 33.4 1nclosure Openings 33.5 33.5 33.5 5 5 5 6 6 7 7 7 7 7 7 7 7		The Material		33 2
33-4 Inclosure Openings 33-5 Sheet Metal Construction Practices 33-5 Sheet Metal Construction Practices 33-6 Printed Circuits 33-7 Coaxial Cable Terminations 33-8 Workshop Layout 33-9 Components and Hardware 33-13 33-9 Components and Hardware 33-13 33-9 Components and Hardware 34-1 Arithmetic 34-1 Arithmetic 34-2 Algebra 34-9 34-3 7- Jonometry 34-4 B fean Algebra 34-9 34-5 T: Smith Chart 34-6 G: hical Representation 34-2 To Jonometry 34-8 Electronic Computers 34-8 Electronic Computers 35-1 Component Standardization 35-1 Component Standardization 35-1 Component Standardization 35-1 Useful Reference Data 33-5 33-5 33-5 33-5 33-5 33-5 33-5 33-		I VI-Proof Inclosures		32 4
33-5 Sheer Metal Construction Practices 33.5 33.6 Printed Circuits 33.8 33.7 Coaxial Cable Terminations 33.11 33-8 Workshop Layout 33.13 33.9 Components and Hardware 33.13 33.13 33.19 Components and Hardware 34.1 34.1 34.1 Arithmetic 34.1 34.2 Algebra 34.9 34.9 34.3 7 20nometry 34.17 34.4 B dean Algebra 34.26 34.5 T Smith Chart 34.27 34.5 T Smith Chart 34.27 34.6 G hical Representation 34.32 34.7 Cc alus 34.8 Electronic Computers 34.45 apter Thirty-Ve. NOMENCLATURE OF COMPONENTS AND MISCELLANEOUS DATA 35.1 35.1 Comp ment Standardization 35.9		Inclosure Openings		22 K
33-6 Printed Circuits 33.8 33.11 33-8 Workshop Layout 33.13 33.9 Components and Hardware 33.13 33.13 33.19 Components and Hardware 33.13 33.13 33.13 33.14 Arithmetic 34.1 Arithmetic 34.1 Arithmetic 34.2 Algebra 34.9 34.3 7-30nometry 34.17 34-4 B dean Algebra 34.26 34.5 T. Smith Chart 34.27 34-6 G: hical Representation 34.32 34-7 Cc. alus 34.42 34-8 Electronic Computers 34.45 34-8 Electronic Computers 34.45 35.1 35-1 Component Standardization 35.1 35-2 Useful Reference Data 35.9		aneer meral Construction Practices		22 5
33-7 Codatal Cable Terminations 33.11 33.32 33.13		Printed Circuits		220
33-3-9 Workshop Layour 33.13 33.9 Components and Hardware 33.13 33.13 33.19 Components and Hardware 34.1 34.1 Arithmetic 34.2 Algebra 34.9 34.3 7-30nometry 34.17 34.4 B Sean Algebra 34.26 34.5 T Smith Chart 34.27 34.6 G: hical Representation 34.32 34.7 Cc 21us 34.42 34.8 Electronic Computers 34.45 apter Thirty-Size NOMENCLATURE OF COMPONENTS AND MISCELLANEOUS DATA 35.1 35.1 Component Standardization 35.1 35.2 Useful Reference Data 35.9		Codxidi Cable Terminations		22 11
33-19 Components and Hardware 33-19 Components and Hardware 34-19 Algebra 34-1 34-2 Algebra 34-9 34-3 7 30 nometry 34-17 34-4 B fean Algebra 34-16 34-5 T Smith Chart 34-27 34-6 G hical Representation 34-32 34-7 Cc alus 34-32 34-8 Electronic Computers 34-45 apter Thirty-Se. NOMENCLATURE OF COMPONENTS AND MISCELLANEOUS DATA 35-1 35-1 Component Standardization 35-1 35-2 Useful Reference Data 35-9		Workshop Edyour		2212
Apple	33-9	Components and Hardware		33.13
34-1 Arithmetic 34.1 34-2 Algebra 34.9 34-3 7-3 ponometry 34.17 34-4 B fean Algebra 34.26 34-5 T Smith Chart 34.27 34-6 G hical Representation 34.32 34-7 Cc alus 34.42 34-8 Electronic Computers 34.42 apter Thirty-Se. NOMENCLATURE OF COMPONENTS AND MISCELLANEOUS DATA 35.1 35-1 Component Standardization 35.1 35-2 Useful Reference Data 35.9	hapter T			
34-3 34-9 34-4 B dean Algebra 34.17 34-5 To Smith Chart 34.26 34-6 G hical Representation 34.32 34-7 Cc alus 34.42 34-8 Electronic Computers 34.45 apter Thirty-Size NOMENCLATURE OF COMPONENTS AND MISCELLANEOUS DATA 35.1 35-1 Component Standardization 35.1 35-2 Useful Reference Data 35.9	34 1	Asiahmatia	THES AND CALCULATIONS	34. I
34-3 34-9 34-4 B dean Algebra 34.17 34-5 To Smith Chart 34.26 34-6 G hical Representation 34.32 34-7 Cc alus 34.42 34-8 Electronic Computers 34.45 apter Thirty-Size NOMENCLATURE OF COMPONENTS AND MISCELLANEOUS DATA 35.1 35-1 Component Standardization 35.1 35-2 Useful Reference Data 35.9		Allenberg		34.1
34-3 7 3000metry 34.17 34-4 B fean Algebra 34.26 34-5 T Smith Chart 34.27 34-6 G: hical Representation 34.32 34-7 Cc alus 34.42 34-8 Electronic Computers 34.45 apter Thirty- 2e. NOMENCLATURE OF COMPONENTS AND MISCELLANEOUS DATA 35.1 35-1 Component Standardization 35.1 35-2 Useful Reference Data 35.9		Algebra		2 A D
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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 cateer 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 The Amateur Radio
Operator Licenses
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.

Notice 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 diplomatype 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 Ameteur The station license author-Station License izes 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 The domestic regulatory pat-Regulations tern 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 In the fall of 1979, Radio Conference 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: