Glaser

NAVSHIPS 0900-005-8000
FIRST REVISION

(Non-Registered)

TECHNICAL MANUAL

for

RADIO-FREQUENCY

RADIATION HAZARDS

DEPARTMENT OF THE NAVY

NAVAL SHIP ENGINEERING CENTER

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This Manual supersedes NAVSHIPS 0900-005-8000, Dated 15 July 1966

DEPARTMENT OF THE NAVY

NAVAL SHIP ENGINEERING CENTER

APPROVED: 1 July 1971

FOREWORD

The purpose of this manual is to prescribe the operating procedures and precautions to prevent injury to personnel and to prevent spark ignition of fuel vapors from environmental radio-frequency fields. A short synopsis is included concerning the spurious initiation of electroexplosive devices by electromagnetic radiation when they are exposed to radio-frequency fields. No attempt is made to outline restrictions concerning the handling of ordnance items.

The procedures and precautions prescribed herein apply when personnel or flammable fuel vapor mixtures are exposed to environmental radio-frequency fields of potentially hazardous intensity. This manual extends or supersedes provisions of, and takes precedence when in conflict with, NAVSHIPS Technical Manual, Chapter 9670.

This manual provides technical guidance to assist commanding officers in carrying out their responsibilities for safety. Operational commanders may waive compliance with any provision of this manual when essential under emergency conditions. The resulting risks are considered acceptable in comparison with other risks.

Questions with respect to the information presented in this manual or regarding rf radiation hazards to personnel should be directed to the Commander, Naval Ship Engineering Center.

Films dealing with rf hazards are available for training purposes through regular channels. Film identification number for the series, titled "Radio Frequency Radiation Hazards," is MN 9682. Individual films in this series are as follows:

MN9682a - Radio Frequency Radiation Hazards - RF Hazards and Personnel Safety.

MN9682b - Radio Frequency Radiation Hazards - Hazards of Electromagnetic Radiation to Ordnance (HERO).

MN9682c - Radio Frequency Radiation Hazards - RF Hazards Calculation and Measurements.

MN9682d - Radio Frequency Radiation Hazards - RF Burns, Causes and Effects.

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SECTION 1

HAZARDS OF ELECTROMAGNETIC RADIATION TO PERSONNEL

1-1. BACKGROUND

This section deals with the hazards of radio-frequency energy to personnel. It presents the background of the problem and discusses the biological hazard level for exposure to rf radiation as established by the Bureau of Medicine and Surgery.

The development of rf transmitting systems with high power transmitting tubes and high gain antennas has increased the possibility of biological injury to personnel working in the vicinity of these rf systems. Presently, the known detrimental effects of over-exposure to rf radiation are associated with the average power of the absorbed radiation, are thermal in nature, and are observed as an increase in over-all body temperature or as a temperature rise in certain sensitive organs of the body. The nonthermal effects of rf radiation are neither well documented nor agreed upon by medical authorities at this time.

Existing radar systems utilize that portion of the electromagnetic spectrum within the approximate frequencies of 100 through 100,000 MHz. The term "microwave" is generally applied somewhat arbitrarily to a band of frequencies between 300 MHz and 300,000 MHz. Radars operating as low as 100 MHz and in the low P Band (220-390 MHz) are often incorrectly identified as being "microwave" radars.

The rf radiation from microwave antennas are far removed in frequency from the ionizing radiation region of x-rays and gamma rays. Microwave radiation has never been observed to cause ionization effects and consequently is classified as non-ionizing radiation.

Figure 1-1 is a frequency spectrum chart showing the region of rf radiation, laser radiation and ionizing radiation. Further information on laser and ionization radiation is presented in sections 4 and 5.

The Bureau of Medicine and Surgery has established safe limits based on the power density of the radiated beam and the exposure time of the human body in the radiation field as follows:

a. Continuous exposure - average power density not to exceed 10 milliwatts per square centimeter (10 mW/sq. cm.).

b. Intermittent exposure - incident energy level not to exceed 300 millijoules per square centimeter per 30-second interval (300 mj. /sq. cm. /30 sec.).

All areas in which the rf levels exceed the safe limits shall be considered hazardous.

The Naval Ship Engineering Center is responsible for determining hazardous shipboard areas and insuring that the possibility of biological injury to personnel from rf radiation is minimized or nonexistent. Theoretical calculations and power density measurements are used to establish the distances from radar antennas within which it is not biologically safe

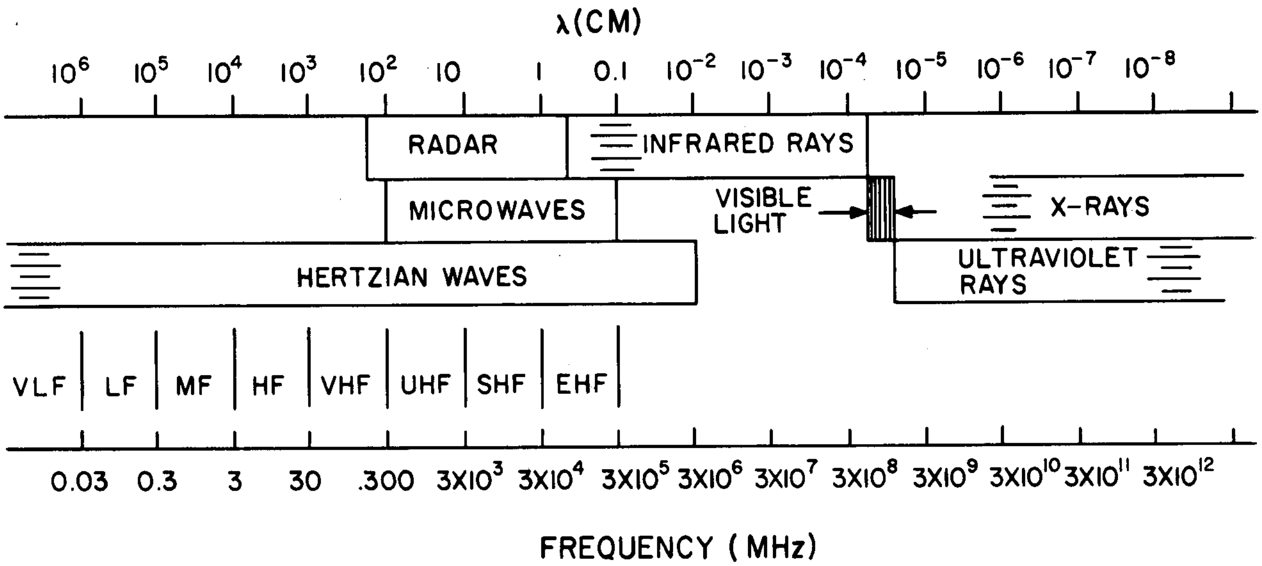


Figure 1-1 Frequency Spectrum Chart

for personnel to enter. This information, together with additional power density measurements, if necessary, is then used to determine whether or not hazardous shipboard areas exist. Cam cutouts (trigger kills) are installed to minimize the number of hazardous areas. All hazardous areas subject to entry by personnel are posted with warning signs and the ship's intercommunication system is used to warn personnel when the radars are operating.

1.2. LISTING OF RADARS AND THEIR HAZARDS TO PERSONNEL

Table 1-1 lists many of the radars and microwave-type devices which might be capable of producing harmful radiation. The minimum safe distances and maximum exposure times are premised on a "worst-case" condition, i.e., they do not take into account system loss between transmitter and antenna. These losses may range from 2 dB up to 8 dB in some special antenna installations. The information presented, therefore, is subject to modification by data obtained by qualified personnel who may be called upon to make a detailed shipboard survey of a specific equipment. Requests for the assistance of qualified shipboard survey personnel should be directed to the Naval Ship Engineering Center via the Naval Ship Systems Command.

TABLE 1-1. PERSONNEL HAZARDS FROM CONTINUOUS OR INTERMITTENT EXPOSURE TO MAIN BEAM RADIATION

RADAR	FIXED BEAM[1]		MOVING BEAM[2]		MAX. EXPOSURE TIME IN SEC. PER 30 SEC. INSIDE FIXED BEAM HAZARD DISTANCE
	Personnel Hazard	FT.	Personnel Hazard	FT.	
AN/ALQ-23	YES	10	-		30
AN/ALQ-41					
PULSE	NO	0	-		30
CW	NO	0	-		30
PULSE + CW	NO	0	-		30
AN/ALQ-49					
PULSE	NO	0	-		30
CW	NO	0	-		30
PULSE + CW	NO	0	-		30
AN/ALQ-51					
PULSE	NO	0	-		30
CW	NO	0	-		30
PULSE + CW	NO	0	-		30
AN/ALQ-69					
PULSE	NO	0	-		30
CW	NO	0	-		30
PULSE + CW	NO	0	-		30
AN/ALQ-92	YES	8	-		30
AN/ALQ-100					
PULSE	NO	0	-		30
CW	NO	0	-		30
PULSE + CW	NO	0	-		30
AN/ALT-2	YES	10	-		30
AN/ALT-6	YES	10	-		30
AN/ALT-16	YES	10	-		30
AN/ALT-19	YES	10	-		30
AN/APD-7	YES	7	-		18
AN/APG-30A	NO	0	-		30
AN/APG-51C	YES	40	-		2.5
AN/APG-53A	NO	0	-		30
AN/APG-56	NO	0	-		30
AN/APG-59					
PULSE	YES	180	-		0
CW	YES	90	-		3
PULSE + CW	YES	206	-		0
AN/APN-22	YES	10	-		30
AN/APN-59A	YES	52	-		5.5
AN/APN-97A	NO	0	-		30
AN/APN-117					
CW	YES	10	-		30
AN/APN-112					
(V) CW	NO		-		30
AN/APN-130,					
130A	NO		-		30

TABLE 1-1. PERSONNEL HAZARDS FROM CONTINUOUS OR INTERMITTENT EXPOSURE TO MAIN BEAM RADIATION

RADAR	FIXED BEAM[1] Personnel Hazard	FIXED BEAM[1] FT.	MOVING BEAM[2] Personnel Hazard	MOVING BEAM[2] FT.	MAX. EXPOSURE TIME IN SEC. PER 30 SEC. INSIDE FIXED BEAM HAZARD DISTANCE
AN/APN-141-CW	YES	10	-		30
AN/APN-153	YES	10	-		30
AN/APN-195	YES	20	-		10
AN/APQ-36	YES	57	YES	10	1
AN/APQ-41	YES	57	YES	10	1.5
AN/APQ-50	YES	67	YES	10	1
AN/APQ-72, 100,					
(Mk 76) PULSE	YES	75	-		2
CW		80	-		2
PULSE + CW	YES	111	-		0
AN/APQ-83	YES	23	-		6
AN/APQ-88, 112	YES	43	-		2
AN/APQ-92, 103					
SHAPED BEAM	YES	114	-		1.5
AN/APQ-94	YES	34	-		3.5
AN/APQ-99					
AN/APQ-102	YES	15	-		2
AN/APQ-109	YES	60	-		0
AN/APQ-116	YES	25	-		20
AN/APQ-124	YES	24	-		3.5
AN/APQ-126	NO	0	-		30
PENCIL BEAM	YES	25	-		10
SHAPED BEAM	YES	25	-		10
AN/APS-20E					
8-FOOT ANT.	YES	123	NO		1.5
AN/APS-20E					
17.5-FOOT ANT.	YES	87	NO		5.5
AN/APS-31A	YES	50	NO		4
AN/APS-33B	YES	41	NO		8
AN/APS-38, 38A, 38B	YES	32	NO		22
AN/APS-42	YES	21	NO		5
AN/APS-45	YES	120	NO		8.5
AN/APS-67	YES	15	NO		14
AN/APS-80, 80A, 80B					
PENCIL BEAM	YES	66	NO		3.5
SHAPED BEAM	YES	35	NO		8
AN/APS-82	YES	41	NO		12
AN/APS-88, 88A					
PENCIL BEAM	YES	10	NO		30
SHAPED BEAM	YES	21	NO		13
AN/APS-96	YES	49	NO		7
AN/APS-115	YES	75	-		0
AN/ASB-1, 1A, 7 PULSE	YES	35	NO		8
CW	NO		NO		30
AN/ASB-12					
PENCIL BEAM	YES	32	NO		30
SHAPED BEAM	YES	47	NO		13
AN/AWG-9					
HIGH PRF	YES	402	YES	212	0
LOW PRF	NO		NO		30
AN/AWG-10	YES	180	YES	47	0
AN/BPS-1	YES	5	NO		12
AN/BPS-2	NO		NO		30
AN/BPS-4	YES	15	NO		18
AN/BPS-5	YES	8	NO		12

TABLE 1-1. PERSONNEL HAZARDS FROM CONTINUOUS OR INTERMITTENT EXPOSURE TO MAIN BEAM RADIATION–Cont'd

RADAR	FIXED BEAM[1] Personnel Hazard	FIXED BEAM[1] FT.	MOVING BEAM[2] Personnel Hazard	MOVING BEAM[2] FT.	MAX. EXPOSURE TIME IN SEC. PER 30 SEC. INSIDE FIXED BEAM HAZARD DISTANCE
AN/BPS-9, 9A, 9B	YES	3	NO		25
AN/BPS-11, 11A	YES	15	NO		22
AN/BPS-12	YES	10	NO		30
AN/BPS-13	YES	10	NO		30
AN/BPS-14/15	YES	5	NO		30
AN/FPN-36	YES	20		-	17.5
AN/FPS-8	YES	21	NO		12
AN/FPS-16					
FIXED FREQ.	YES	480		-	2
TUNABLE FREQ	YES	280		-	20
AN/GPN-6	NO			-	30
AN/MPS-4	YES	34	NO		12
AN/MPS-11A	YES	21	NO		12
AN/MPS-16A	YES	5	NO		17
AN/SPG-34	YES	20		-	30
AN/SPG-48	YES	54		-	8
AN/SPG-49A, 49B, CW	YES	400		-	0.5
ACO & TRACK	YES	440		-	1
AN/SPG-50	YES	25		-	30
AN/SPG-51B, 51C, DCW	YES	1275		-	1
ACQUISITION	YES	340		-	3
TRACK	YES	250		-	4
AN/SPG-52	YES	21		-	8
AN/SPG-53, 53A	YES	72		-	25
AN/SPG-53B	YES	560		-	0.5
AN/SPG-55A CW	YES	870		-	1
TRACK	NO			-	30
CAPTURE	NO			-	30
GUIDANCE	NO			-	30
AN/SPG-55B CW	YES	900		-	1.5
TRACK	YES	660		-	0.5
CAPTURE	NO			-	30
GUIDANCE	NO			-	30
AN/SPG-60 TRACK	YES	320		-	5
AN/SPN-6	YES	140	NO		13
AN/SPN-8, 8A	YES	10	NO		30
AN/SPN-10, 10B, 10C, 10D, & 10F	NO			-	30
AN/SPN-12, 12A	YES	12		-	20
AN/SPN-35	YES	85	NO		5.5
AN/SPN-42	NO		NO		30.0
AN/SPN-43	YES	220	NO		6
AN/SPQ-5, 5A					
TRACK	NO			-	30
GUIDANCE	NO			-	30
CAPTURE	YES	20		-	8
AN/SPQ-6	YES	60		-	2
AN/SPQ-9	YES	65		-	5
AN/SPQ-10	YES	75		-	10

TABLE 1-1. PERSONNEL HAZARDS FROM CONTINUOUS OR INTERMITTENT EXPOSURE TO MAIN BEAM RADIATION—Cont'd

RADAR	FIXED BEAM[1]		MOVING BEAM[2]		MAX. EXPOSURE TIME IN SEC. PER 30 SEC. INSIDE FIXED BEAM HAZARD DISTANCE
	Personnel Hazard	FT.	Personnel Hazard	FT.	
AN/SPS-4	YES	10	NO		26
AN/SPS-5C, 5D	NO		NO		30
AN/SPS-6	YES	10	NO		30
AN/SPS-6B, 6C	YES	14	NO		30
AN/SPS-8	YES	43	NO		28
AN/SPS-8A	YES	84	NO		15
AN/SPS-8B	YES	180-280	NO		27
AN/SPS-10B, 10C, 10D, 10E, & 10F	YES	15	NO		23
AN/SPS-12, 12A	YES	20	NO		18
AN/SPS-21, 21A, 21B, 21C, & 21D	NO		NO		30
AN/SPS-28	NO		NO		30
AN/SPS-29, 29B, 29C, 29E	YES	35	NO		7
AN/SPS-30	YES	900	NO		5
AN/SPS-32	YES	40	NO		10
AN/SPS-33	YES	650**	*	-	
AN/SPS-35A	NO		NO		30
AN/SPS-36	NO		NO		30
AN/SPS-37 SMALL ANT.	YES	70	NO		1.5
AN/SPS-37A LARGE ANT.	YES	40	NO		9.5
AN/SPS-39, 39A	YES	220	NO		5
AN/SPS-40	YES	60	NO		5.5
AN/SPS-41	NO		NO		30
AN/SPS-42	YES	180	NO		8
AN/SPS-43 SMALL ANT.	YES	70	NO		1.5
AN/SPS-43A LARGE ANT.	YES	40	NO		9.5
AN/SPS-46	NO		NO		30
AN/SPS-48	YES	1150	NO		2.5
AN/SPS-51	NO		NO		30
AN/SPS-52	YES	430	NO		4
AN/SPS-53A, 53E	NO		NO		30
AN/SPS-55	YES	30	NO		8
AN/SPS-57	NO		NO		30
AN/SPS-58	NO		NO		30
AN/SPW-2A, 2B	NO			-	30
AN/SSC-3	YES	800		-	0.5
CRP-1500	NO		NO		30
AN/TPS-1D, 1G	YES	30	NO		15
AN/TPS-32	YES	1052	NO		4
AN/TPS-34A	YES	340	NO		7.5

*Not applicable this manual, computer controlled
**Based on Actual Measurements.

TABLE 1-1. PERSONNEL HAZARDS FROM CONTINUOUS OR INTERMITTENT EXPOSURE TO MAIN BEAM RADIATION—Cont'd

RADAR	FIXED BEAM[1]		MOVING BEAM[2]		MAX. EXPOSURE TIME IN SEC. PER 30 SEC. INSIDE FIXED BEAM HAZARD DISTANCE
	Personnel Hazard	FT.	Personnel Hazard	FT.	
AN/TPS-35	YES	45	NO		12
AN/TPS-40	YES	5	NO		17
AN/UPS-1, 1B 1D	YES	45	NO		12
CRP-1500	NO		NO		30
MR-4	NO		NO		30
MR-5	NO		NO		30
MK-13 MOD O	YES	20		-	25
MK-25, MOD 3	YES	100		-	17
MK-34, MOD 17	NO			-	30
M-34, MOD. 2, 6, 16	YES	20		-	10
MK-35	NO	0		-	30
MK-39 MOD 3	YES	24		-	7.5
MK-56	NO	0		-	30
MK-87 MOD 0	NO	0			
SEARCH	YES	60		-	6
TRACK	YES	35		-	22
SC SERIES	NO	0		-	30
SG-6B	YES	15	NO		22
SS SERIES	YES	2	NO		20
ST	NO	0		-	30
T-219 (DECCA)	NO	0	NO		30
TAC SAT					
SMALL ANT.	YES	9		-	30
LARGE ANT.	YES	12		-	30
RATHEON	YES	5	NO		30

NOTES:

1. Determination of the safe distance from radar antennas in fixed-beam operations is based on a continuous exposure level not to exceed a power density of 10 milliwatts per square centimeter.

   The minimum safe distances for airborne radars shown in table 1-1 have, in some cases, been derived from computations starting at 10 feet from the radar antenna. Radars in aircraft may not be hazardous at distances greater than a few feet from the antenna. If the calculated power distribution at the face of the antenna, increased by a factor of 4, does not exceed 10 milliwatts per square centimeter then it is reasonable to assume that no hazard exists within the 10 foot distance.

2. This is generally the normal operating mode such as rotating and or scanning but does not apply to steerable fire control radars. The techniques for determining the hazard from a moving beam are discussed in appendix B.

3. The maximum exposure time in seconds per 30 second period is based on the maximum power density inside of the fixed beam hazard distance and is calculated by the following equation.

   T Max. = 300 mJ/maximum average power density

4. A dash (-) indicates that the radar does not normally operate in this mode.

5. A zero (0) indicates that the radar is safe up to the face of the antenna for fixed beam or safe up to the swing circle of a rotating antenna.

1-3. PRECAUTIONS TO ENSURE THE SAFETY OF PERSONNEL

While every effort must be made to protect personnel from harmful exposure to rf radiation, it is not considered necessary or desirable, in general, that blanket restrictions on ship antenna radiation be imposed to achieve this end. The existence of such a policy will tend to restrict maintenance and checkout procedures which could otherwise be carried out in safety, providing proper precautions are taken to keep personnel clear of hazardous areas. These precautions include the following:

a. Visual inspection of feed horns, open ends of waveguides, and any opening emitting rf electromagnetic energy will not be made unless the equipment is definitely secured for the purpose of such an inspection.

b. Aircraft employing high power radars shall be parked, or the antennas oriented so that the beam is directed away from personnel working areas.

c. When operating or servicing a shipboard radar, operating and maintenance personnel shall observe all rf radiation hazard signs (BuShips Drawing RE-D2681228J) posted in the operating area to ensure that the radar is operating in such a manner that personnel on deck or in the superstructure are not subjected to hazardous levels of rf radiation.

d. All personnel shall observe rf hazards warning signs which point out the existence of rf radiation hazards in a specific location or area.

e. Ensure that those radar antennas which normally rotate are rotated continuously while radiating, or are trained to a known safe bearing.

f. Train and elevate non-rotating antennas away from inhabited areas, ships, piers, and such, while radiating.

g. Where the possibility of accidental exposure might still exist, have a man stationed topside, within view of the antenna (but well out of the beam) and in communication with the operator, while the antenna is radiating.

h. Ensure that radiation hazard warning signs are available and used, not only where required to be permanently posted, but also for temporarily restricting access to certain parts of the ship while radiating. Figure 1-2 illustrates the hazards warning signs to be used as specified in RE-D2681228J.

i. In areas where personnel must frequently pass near an antenna that is known to produce hazardous levels of radiation and it is not practical to secure radiation from the antenna, an RF screen or shield may be constructed as shown in Figure 1-3. This screen provides a safe zone in which personnel may pass or work.

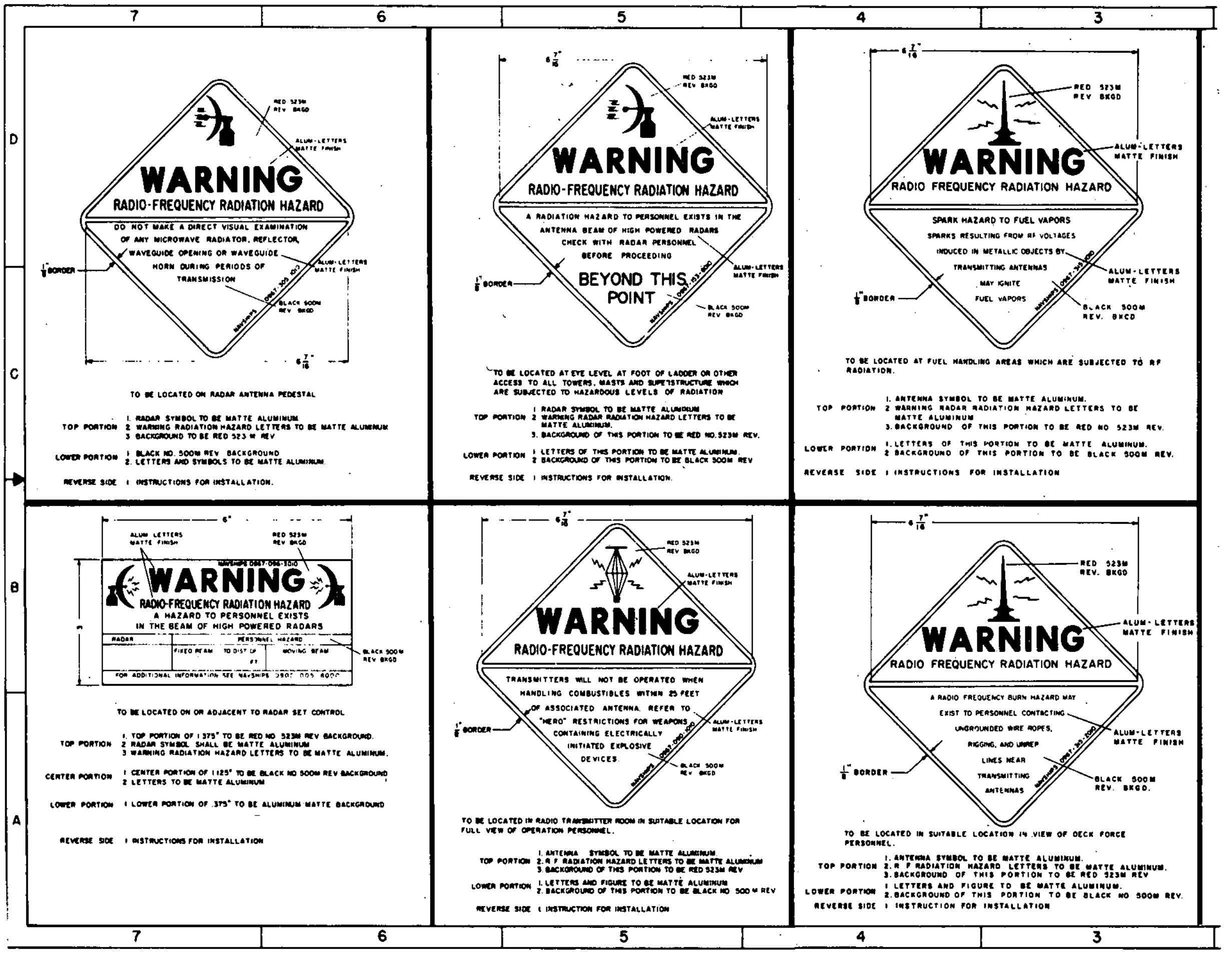
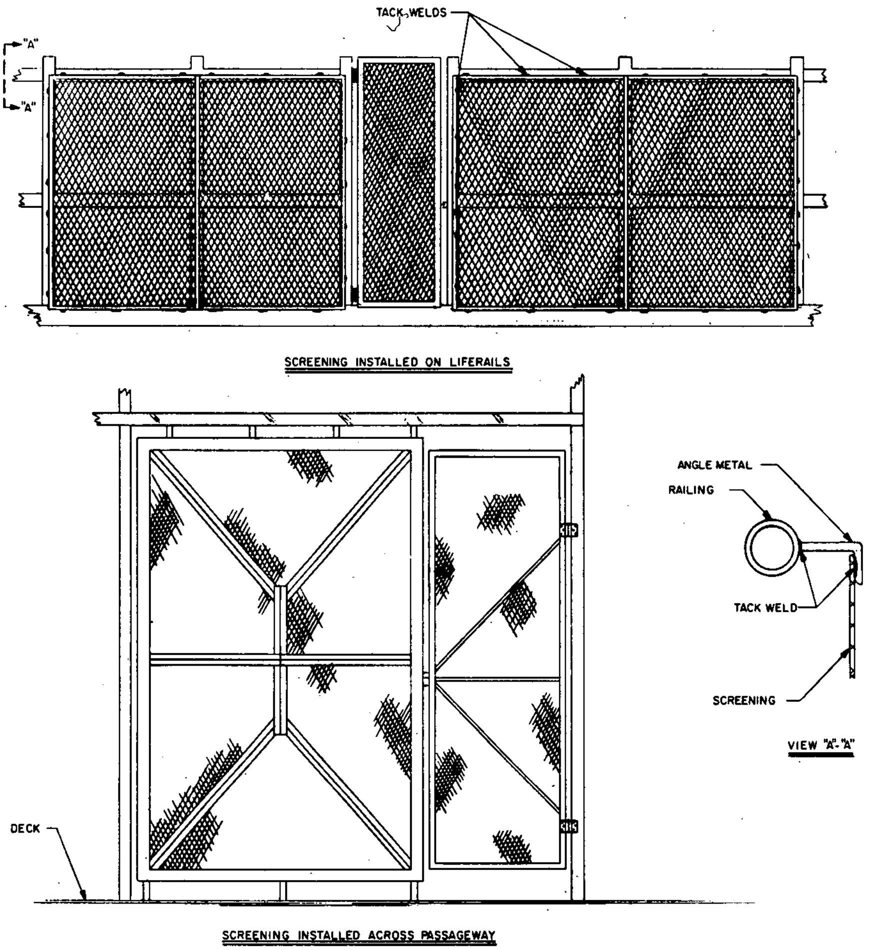

7
6
5
4
3
D
C
B
A
RED 523M REV BKGD
ALUM-LETTERS MATTE FINISH
WARNING
RADIO-FREQUENCY RADIATION HAZARD
DO NOT MAKE A DIRECT VISUAL EXAMINATION OF ANY MICROWAVE RADIATOR, REFLECTOR, WAVEGUIDE OPENING OR WAVEGUIDE HORN DURING PERIODS OF TRANSMISSION
1/8" BORDER
ALUM-LETTERS MATTE FINISH
BLACK 500M REV BKGD
NAVSHIPS 0967-303-1010
6 7/16"
TO BE LOCATED ON RADAR ANTENNA PEDESTAL
TOP PORTION 1. RADAR SYMBOL TO BE MATTE ALUMINUM
2 WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM
3 BACKGROUND TO BE RED 523 M REV
LOWER PORTION 1 BLACK NO. 500M REV BACKGROUND
2. LETTERS AND SYMBOLS TO BE MATTE ALUMINUM.
REVERSE SIDE 1 INSTRUCTIONS FOR INSTALLATION.
6 7/16"
RED 523M REV BKGD
ALUM-LETTERS MATTE FINISH
WARNING
RADIO-FREQUENCY RADIATION HAZARD
A RADIATION HAZARD TO PERSONNEL EXISTS IN THE ANTENNA BEAM OF HIGH POWERED RADARS CHECK WITH RADAR PERSONNEL BEFORE PROCEEDING
BEYOND THIS POINT
1/8" BORDER
ALUM-LETTERS MATTE FINISH
BLACK 500M REV BKGD
NAVSHIPS 0967-153-8010
TO BE LOCATED AT EYE LEVEL AT FOOT OF LADDER OR OTHER ACCESS TO ALL TOWERS, MASTS AND SUPERSTRUCTURE WHICH ARE SUBJECTED TO HAZARDOUS LEVELS OF RADIATION
TOP PORTION 1 RADAR SYMBOL TO BE MATTE ALUMINUM
2 WARNING RADAR RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM.
3. BACKGROUND OF THIS PORTION TO BE RED NO. 523M REV.
LOWER PORTION 1 LETTERS OF THIS PORTION TO BE MATTE ALUMINUM.
2 BACKGROUND OF THIS PORTION TO BE BLACK 500M REV
REVERSE SIDE 1 INSTRUCTIONS FOR INSTALLATION.
6 7/16"
RED 523M REV BKGD
ALUM-LETTERS MATTE FINISH
WARNING
RADIO FREQUENCY RADIATION HAZARD
SPARK HAZARD TO FUEL VAPORS
SPARKS RESULTING FROM RF VOLTAGES INDUCED IN METALLIC OBJECTS BY TRANSMITTING ANTENNAS MAY IGNITE FUEL VAPORS
1/8" BORDER
ALUM-LETTERS MATTE FINISH
BLACK 500M REV. BKCD
TO BE LOCATED AT FUEL HANDLING AREAS WHICH ARE SUBJECTED TO RF RADIATION.
TOP PORTION 1. ANTENNA SYMBOL TO BE MATTE ALUMINUM.
2 WARNING RADAR RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM
3. BACKGROUND OF THIS PORTION TO BE RED NO 523M REV.
LOWER PORTION 1. LETTERS OF THIS PORTION TO BE MATTE ALUMINUM.
2 BACKGROUND OF THIS PORTION TO BE BLACK 500M REV.
REVERSE SIDE 1 INSTRUCTIONS FOR INSTALLATION
6"
ALUM LETTERS MATTE FINISH
RED 523M REV BKGD
NAVSHIPS 0967-096-3010
WARNING
RADIO-FREQUENCY RADIATION HAZARD
A HAZARD TO PERSONNEL EXISTS IN THE BEAM OF HIGH POWERED RADARS
RADAR
PERSONNEL HAZARD
FIXED BEAM TO DIST OF FT
MOVING BEAM
BLACK 500M REV BKGD
FOR ADDITIONAL INFORMATION SEE NAVSHIPS 0900-005-8000
TO BE LOCATED ON OR ADJACENT TO RADAR SET CONTROL
TOP PORTION 1. TOP PORTION OF 1.375" TO BE RED NO 523M REV BACKGROUND.
2 RADAR SYMBOL SHALL BE MATTE ALUMINUM
3 WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM.
CENTER PORTION 1 CENTER PORTION OF 1.125" TO BE BLACK NO 500M REV BACKGROUND
2 LETTERS TO BE MATTE ALUMINUM
LOWER PORTION 1 LOWER PORTION OF .375" TO BE ALUMINUM MATTE BACKGROUND
REVERSE SIDE 1 INSTRUCTIONS FOR INSTALLATION
6 7/16"
RED 523M REV BKGD
ALUM-LETTERS MATTE FINISH
WARNING
RADIO-FREQUENCY RADIATION HAZARD
TRANSMITTERS WILL NOT BE OPERATED WHEN HANDLING COMBUSTIBLES WITHIN 25 FEET OF ASSOCIATED ANTENNA. REFER TO "HERO" RESTRICTIONS FOR WEAPONS CONTAINING ELECTRICALLY INITIATED EXPLOSIVE DEVICES.
1/8" BORDER
ALUM-LETTERS MATTE FINISH
BLACK 500M REV BKGD
NAVSHIPS 0967-090-1010
TO BE LOCATED IN RADIO TRANSMITTER ROOM IN SUITABLE LOCATION FOR FULL VIEW OF OPERATION PERSONNEL.
TOP PORTION 1. ANTENNA SYMBOL TO BE MATTE ALUMINUM.
2. R F RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM
3. BACKGROUND OF THIS PORTION TO BE RED 523M REV
LOWER PORTION 1. LETTERS AND FIGURE TO BE MATTE ALUMINUM
2. BACKGROUND OF THIS PORTION TO BE BLACK NO 500M REV
REVERSE SIDE 1 INSTRUCTION FOR INSTALLATION
6 7/16"
RED 523M REV. BKGD
ALUM-LETTERS MATTE FINISH
WARNING
RADIO FREQUENCY RADIATION HAZARD
A RADIO FREQUENCY BURN HAZARD MAY EXIST TO PERSONNEL CONTACTING UNGROUNDED WIRE ROPES, RIGGING, AND UNREP LINES NEAR TRANSMITTING ANTENNAS
1/8" BORDER
ALUM-LETTERS MATTE FINISH
BLACK 500M REV. BKGD.
TO BE LOCATED IN SUITABLE LOCATION IN VIEW OF DECK FORCE PERSONNEL.
TOP PORTION 1. ANTENNA SYMBOL TO BE MATTE ALUMINUM.
2. R F RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM.
3. BACKGROUND OF THIS PORTION TO BE RED 523M REV
LOWER PORTION 1 LETTERS AND FIGURE TO BE MATTE ALUMINUM.
2. BACKGROUND OF THIS PORTION TO BE BLACK NO 500M REV.
REVERSE SIDE 1 INSTRUCTION FOR INSTALLATION

Figure 1-2



NOTES:

1. SCREEN FRAMES SHALL BE FABRICATED FROM ANGLE MATERIAL. TYPE OF ANGLE MATERIAL (STEEL OR ALUM) SHALL CONFORM TO THE MATING MATERIAL: STEEL OR IRON ANGLE FOR TACK WELDING TO STEEL OR IRON STRUCTURES AND ALUMINUM ANGLE FOR WELDING TO ALUMINUM STRUCTURES. FRAMES SHALL BE TACK WELDED IN PLACE AT 18" INTERVALS OR AS REQUIRED FOR PROPER SUPPORT.
2. SCREENS SHALL BE EXPANDED METAL WITH OPENINGS NO GREATER THAN 1/2 INCH AND SHALL BE TACK WELDED TO FRAMES AT INTERVALS NO GREATER THAN 6 INCHES.

FIGURE 1-3 RADIATION HAZARD PERSONNEL SAFETY SCREENS, TYPICAL

SECTION 2

RF-ENERGY BURNS

2-1. INTRODUCTION

The handling of metallic cargo lines while shipboard hf transmitters are radiating can be hazardous to a ship's personnel. RF voltages have been detected on crane hooks and other cargo equipment on numerous occasions. These voltages, which are sometimes of sufficient potential to cause injury, are induced in metallic rigging and other metallic items commonly encountered aboard naval ships by nearby transmitter antennas.

2-2. BIOLOGICAL EFFECT

An RF burn is the result of rf current flowing through the body area in contact with a source of rf voltage. Any damage that occurs is entirely a result of the heat produced by the current flow through the resistance of the skin at the contacted area. Current flow through a resistance produces heat regardless of the nature of the circuit. The effect of the heat on a person ranges from warmth to severely painful burns. The phenomena of rf burns should not be confused with the RF Radiation Hazards (RADHAZ) related to microwave energy. The criteria used for defining electrical shock from power lines are not applicable to the rf burn problem.

The specific level at which contact with rf voltage should be classified as an rf burn hazard is not a distinct one. Hazardous, for the purpose of this instruction, is defined as the rf voltage level that will cause a person pain, visible skin damage, or will cause involuntary reaction. The term "hazard" does not include the lower voltages that cause annoyance, a stinging sensation, or moderate heating of the skin. NAVSEC has established that an open-circuit rf voltage exceeding 140 volts on an item in an rf radiation field is to be considered hazardous.

2-3. INVESTIGATIONS

The Naval Ship Systems Command has been and is continuing to study methods of eliminating the rf burn hazard. One approach has been the use of an insulator link between the crane wire rope and the hook. An insulator link made of filament-wound plastic has been developed, approved and specified under MIL-L-24410. This cargo hook insulator has been tested and shown to be effective in eliminating the possibility of personnel receiving an rf burn when they come in contact with a cargo hook. The rf voltage and potential rf burn hazard above the insulator will, however, remain unaffected. Unfortunately, numerous equipments involved in the rf burn problem do not lend themselves to the use of an insulating link.

Sometimes it is possible to eliminate rf burn problems by relocation of antennas, but this approach is not usually feasible. The locations of shipboard antennas are determined by optimizing the desired radiation patterns within the physical limitations imposed by the ship's structure.

Investigations are being made into the use of nonmetallic materials for applications where the hazard of rf burns is a problem. At the present time there is no suitable nonmetallic substitute for the wire rope used on cargo equipment.

The hazard of personnel receiving rf burns while handling cargo equipment can also be minimized by formulating and observing operating procedures that govern the simultaneous use of the transmitters and cargo equipment. Operating procedures, to be effective, will restrict use of the equipments involved. Therefore, operating procedures must be derived from measurements and tests aboard each affected ship to determine individual conditions relative to hf transmissions and cargo handling operations.

SECTION 3

MICROWAVE COOKING OVENS

3-1. GENERAL

The rapid growth of the use of microwave ovens has created concern for radiation hazards associated with these devices. Microwave ovens having defective shielding or seals can produce a personnel radiation hazard.

There are three reactions to microwave radiation, depending on the frequency of the energy and the molecular structure of the radiated substance: reflection, transmission, or absorption. These can occur individually or collectively in the substances. Cooking by microwave is based on intermolecular friction that results from absorption. The variation in the field causes increased movement of the molecules, thereby resulting in heat.

3-2. HAZARD ANALYSIS

a. The Federal Communications Commission has assigned the frequencies 915 MHz and 2450 MHz for use in microwave cooking ovens. The frequency most commonly used is 2450 MHz.

b. There are three factors which affect the extent of damage to be expected from exposure to microwave radiation by these ovens.

Frequency. The frequencies used for microwave cooking lie in a zone intermediate between the low frequencies which tend to pass through the body without absorption and the higher frequencies which affect only the outer layers of the skin. Energy of the lower frequency will penetrate deeper into the body, while the higher of the two frequencies is the one more likely to cause damage to the eyes. The fact that the tissue below the skin has little temperature sensation increases the hazard since there may be no warning of damage being caused by radiation.

Power Density. Microwave oven door seals may become distorted and radiation leakage may increase with time until power densities outside the oven exceed safe levels. The increase also may be caused by eventual failure of the door interlocks. If leakage does occur, the radiation forms a narrow beam emitted around the periphery of the door. If the interlock completely fails, the emitted radiation with the door open forms a directional but broad beam.

Beginning in 1971 manufacturers were required to meet the following specification on microwave ovens: no more than 1 mW/cm^2 radiation leakage when the ovens are produced; after the ovens are placed in use, the leakage is not to exceed 5mW/cm^2 at any time.

Time of Exposure. Since any biological damage from the microwave radiation is a result of heating of tissue, the cumulative efect over the length of time of exposure is also a factor in the extent of the damage.

3-3. DETERMINING LEAKAGE

a. Place a small container of water in the oven to simulate normal load conditions. Check the seals for rf leakage after opening and closing the door with varying amounts of pressure. Some seals work well if the door is slammed shut but do not seal properly if the door is closed gently.

b. In conducting a microwave hazard survey of a microwave oven, special emphasis should be placed on the door safety interlocks. Check the interlocks to determine if the oven can be activated with the door open or slightly ajar. (While not an endorsement, at the time of publication the Narda Surveyor Model 8100 was the only commercial instrument available specifically intended for microwave oven measurements.)

SECTION 4

BIOLOGICAL RADIATION HAZARD FROM LASER DEVICES

4-1. INTRODUCTION

The acronym "Laser" is derived from the initial letters of the words "light amplification by stimulated emission of radiation". The term "optical maser" was used earlier because the original work was done with microwaves. The effects of laser radiation are essentially the same as light generated by more conventional ultraviolet, infrared, and visible light sources. The unique biological implications attributed to laser radiation are generally those resulting from the very high intensities and monochromaticity of laser light. Such sources differ from conventional light emitters primarily in their ability to attain highly coherent light (in phase). The increased directional intensity of the light generated by a laser results in concentrated light beam intensities at considerable distances.

Recent developments in laser technology have resulted in an increase in the utilization of these devices for military applications, both for research and field use. The widespread use of these systems increases the probability of personnel exposure to injurious intensities of laser radiation. Adequate safeguards must be provided.

4-2. BIOLOGICAL EFFECTS

Laser radiation should not be confused with ionizing radiation (such as x-rays and gamma rays), although very high-power or high-energy densities have been known to produce ionization in air and other materials. The biological effects of the laser beam are essentially those of visible, ultraviolet, or infrared energy upon tissues. However, the intensity of the light is of magnitudes that could previously be approached only by the sun, nuclear weapons, burning magnesium, or arc lights. This magnitude of light intensity is one of the important properties that makes lasers potentially hazardous.

Reactions of a laser beam striking tissue are reflections, transmissions, and/or absorption. The degree to which each of these reactions occurs depends upon various properties of the tissue involved. Absorption is selective, as in the case of visible light; darker material, such as melanin or other pigmented tissue, absorbs more energy.

Skin effects may vary from mild reddening (erythema) to blistering and charring, depending upon the amount of energy transferred.

The effect upon the retina may be a temporary reaction without residual pathologic changes, or it may be more severe with permanent pathologic changes which may heal by fibrosis. The mildest observable reaction may be simple reddening. As the energy is increased, lesions may occur which progress in severity from edema to charring, with hemorrhage and additional tissue reaction around the lesion. Very high energies will cause gases to form, which may disrupt the retina and may alter the physical structure of the eye. Portions of the eye other than the retina may be selectively injured, depending upon the region where the greatest absorption of the specific wavelength of the laser energy occurs and the relative sensitivity of tissue affected.

Infrared light produces heat with its characteristic effect on tissue and the lens of the eye. Some residual energy may reach the retina. Ultraviolet light can produce symptoms similar to those observed in arc welders. It may cause severe acute inflammation of the eye and conjunctiva, and usually does not reach the retina. Light in the far infrared, such as the 10 micron wavelength from the carbon dioxide lasers, is absorbed by the cornea and conjunctiva and may cause severe pain and destructive effects.

4-3. EXPOSURE OF PERSONNEL

Eye exposure. An energy density of 1×10^{-7} joules per square centimeter incident upon the cornea of the eye from a Q-switch laser is considered to be a maximum exposure level not expected to cause detectable bodily injury. An energy density of 10^{-6} joules/cm^2 for a non Q-switched laser (approximately 1 millisecond pulse length) and a power density of 10^{-6} watts/cm^2 for cw lasers are tentative values which may be used pending more complete biological data. Those values apply to the wavelength region between 0.4 micron and 1.4 microns which includes ruby (0.694 micron) neodymium (1.06 microns), helium-neon (0.63 micron), argon (0.49 microns), and gallium-arsenide (0.84 micron). Until additional data is available and uncertainties associated with field measurements are removed, a safety factor of 2 is recommended for use in field evaluation and training activities. For long-term work with lasers, such as in a laboratory, a safety factor of 10 should be used. For the CO_2 cw laser (10.6 micron wavelength) a power density of 100 milliwatts/cm^2 is considered to be the maximum exposure level not expected to cause detectable injury. Use of safety factors are not deemed necessary for the CO_2 cw laser.

Skin Exposure. Exposure of the skin alone should not exceed the recommended energy density levels for the eye by a factor exceeding 10^5 (not applicable to ultra violet), and for the CO_2 cw laser, should not exceed the recommended eye exposure level (100 milliwatts/cm^2).

4-4. GENERAL PRECAUTIONS APPLICABLE TO ALL LASER INSTALLATIONS

a. Avoid aligning the laser with the naked eye to prevent looking along the axis of the beam.

b. Avoid looking into the primary beam and at specular reflections of the beam, including those from lens surfaces.

c. Work with lasers should be done in areas of high general illumination, except where this would severely impair mission accomplishment.

d. The laser beam should be discharged into a background that is nonreflective and fire resistant.

e. An area should be cleared of personnel for a reasonable distance on all sides of the anticipated path of the laser beam.

f. Suitable precautions to avoid electrical shock should be followed in connection with the potentially dangerous electrical circuits (both high-and low-voltage).

g. Safety eyewear of an appropriate optical density should be worn during the firing of a laser when an exposure level exceeding any of those stated in paragraph 4-3 is possible. Safety eyewear, designed to filter out the specific frequencies characteristic of the system, affords adequate protection only if properly designed and utilized. This protective eyewear should be appropriately labelled to indicate the optical density at specific wavelengths and should be inspected periodically to insure physical integrity and proper labelling. There should be assurance that safety eyewear designed for specific lasers are not mistakenly used with lasers of different wavelengths.

SECTION 5

IONIZING RADIATION

5-1. GENERAL

Ionizing radiation is the electromagnetic or particulate emanations produced by radiation sources. These emanations can cause ionization, that is, the ejection of electrons from atoms. Ionization within the cells or tissues of the body can occur as the result of exposure to alpha particles, beta particles (electrons), neutrons, protons, or other atomic or subatomic particles or of exposure to gamma rays, x-rays, or other electromagnetic waves capable of ejecting electrons from atoms.

5-2. UNITS OF MEASUREMENT

a. Rem - An equilibration of the dose of ionizing radiation to the body in terms of its estimated biological effect, relative to an absorbed does of 1 roentgen of high voltage x-rays. The rem shall be the unit of dose for record purposes.

b. Roentgen (r) - That amount of x-or gamma radiation which will produce 2.083 x 10^9 ion pairs in 1 cc of air under standard conditions. For the purpose of these regulations, one roentgen of x-or gamma-radiation is considered to deliver one rad.

c. Rad - The unit of absorbed dose of radiation, equal to 100 ergs of energy absorbed per gram.

5-3. METHODS OF DETECTING IONIZING RADIATION

Ionizing radiation cannot be detected by the senses. It can be detected only by devices which respond to the ionizing properties of radiation. These detecting devies include Geiger counters, scintillation counters, ionization chambers (including pocket dosimeters), phosphors, transformation reaction counters (including photographic emulsions), and free radical counters.

5-4. RADIAC EQUIPMENT

The purpose of radiac equipment is to detect and indicate the amount of radioactivity present in a given area. The type of radioactivity detected (alpha and beta particles, x-ray, gamma radiation, fast and slow neutrons) is determined by the type of radiac equipment used. Radiac equipments vary from small, portable, battery-operated sets to large, integrated, monitoring systems requiring associated electronic equipment. Basically, radiac equipments contain one or a combination of the following:

a. Radiac Detector - A device that is sensitive to radioactivity of free nuclear particles and reacts in a manner that can be interpreted or measured by various means.

b. Radiacmeter - A device that detects the presence of radioactivity and indicates the dose rate or total dose.

c. Computer-Indicator. A device that computes and indicates radiac data received from the radiac detector or detectors.

5-5. HAZARD LEVEL

All personnel working in high-intensity levels of radioactivity must exercise caution to prevent bodily damage. While the radiation from radioactive substances cannot be seen or felt, prolonged or extensive exposure may result in serious damage. One-tenth of a roentgen per week (0.1 r/week or 100 mr/week) is considered to be the maximum permissible exposure.

5-6. PRECAUTIONS

Safety precautions and instructions on handling of radioactive material are contained in NAVMED P-5055, Radiation Health Protection Manual, and various Bureau of Standards Handbooks, particularly No. 23, 42, 49 and 52.

Precautions should be taken not to attempt any measurement of ionic radiation while located in an rf electromagnetic field. Radiac detectors are susceptable to electromagnetic fields and will produce an erroneous reading which could be mistaken for ionic radiation. The reverse is also true. Do not attempt to measure rf radiation while in the environment of ionic radiation.

The accumulated dose of radiation to the whole body, head and trunk, active blood-forming organs, gonads or lens of the eye shall not exceed:

(1) 3 rem in any calendar quarter, nor

(2) 5 (N-18) rem total lifetime dose, where N equals the present age in years.

SECTION 6

HAZARDS OF ELECTROMAGNETIC RADIATION TO ORDNANCE (HERO)

6-1. BACKGROUND

This section presents a short synopsis of the HERO problem. The HERO (Hazards of Electromagnetic Radiation to Ordnance) problem has been acute since 1958. The uses of electrically initiated explosive devices are increasing greatly, i.e., for initiating booster rocket igniters and warhead detonators, for stage separation in multistage rockets, for reliable, high-speed operation of switches and valves, and for many other purposes. Some weapons contain more than 75 electroexplosive devices (EED). Continuous development efforts are directed toward reducing weight and space, lowering power requirements, assuring positive response, and increasing reliability and safety. However, these are not always complementary goals.

At the same time, the power of communications and radar transmitting equipment is being constantly increased and the frequency spectrum broadened. The radio frequency spectrum utilized by the Navy now extends from 10 kilohertz to about 20,000 megahertz.

Transmitter power outputs may approach 10 kilowatts at communication frequencies, and peak power outputs extend to approximately 5 megawatts at radar frequencies.

These trends produce incompatible situations. On the one hand, transmitters and their antennas have only one purpose —to radiate electromagnetic energy. On the other hand, the initiating elements of ordnance items need only to be supplied with the proper amount of electrical energy for an explosion to take place. Several shipboard incidents involving ordnance items have been attributed to initiation of their EEDs by electromagnetic radiation from the ship's transmitting equipment. Each incident occurred during shipboard operations while the ordnance item was handled normally. Therefore, with many explosive ordnance items, constraints are required for safety and to ensure reliable performance.

6-2. PRECAUTIONARY INFORMATION

To meet the growing need for new shipboard procedures to reduce the hazard to ordnance equipment from rf radiation, the Naval Ordnance System Command has sponsored tests which, coordinated with studies by other agencies, have enabled the formation of new guidelines and restrictions for handling electrically initiated ordnance equipment. The basic problem in determining an ordnance system's susceptibility to rf radiation lies in the evaluation of the antenna-like couplings that exist between illuminating fields and the various EEDs employed in the system. RF energy may enter a weapon as a wave radiated through a hole or crack in the weapon skin. RF energy may also be conducted into the weapon by the firing leads or other wires that penetrate the weapon enclosure. The precise probabilities of EED actuation are relatively unpredictable, being dependent upon variables of frequency, field strength, geometric orientation, environment, and metallic or personnel contacts with ordnance and aircraft. Actuation of an EED is often undetectable without disassembly of weapons. The most susceptible periods are during assembly, disassembly loading, unloading, or testing in electromagnetic fields. The most likely effects of premature actuation are dudding, reduction of reliability, or propellant ignition. In the very worst environments there is a low, but finite probability of warhead detonation. This manual does not attempt to outline requirements, restrictions, and procedures for the handling of ordnance items. Detailed restrictions and the necessary general and theoretical analysis to enable the reader to make intelligent assessments of the hazard present in tactical use of ordnance may be found in Radio Frequency Hazards Manual, NAVORD OP 3565/NAVAIR 16-1-529.

SECTION 7

HAZARDS OF ELECTROMAGNETIC RADIATION

TO FUEL

7-1. BACKGROUND

The increase in radiated rf energy from high-powered communications and radar equipments installed on ships in recent years has increased the hazard of ignition of volatile fuel-air mixtures by rf energy. Under normal operating conditions such volatile mixtures are present only close to aircraft fuel vents, open fuel inlets during over-the-wing fueling, or close to spilled fuel.

Ignition of fuel vapors in air has been obtained (under laboratory conditions purposely established to favor ignition) at distances as great as one-half wavelength from a transmitting antenna with transmitter powers of 100 watts or less in the frequency range of 2 to 13 MHz. Shipboard tests that employed worst case antenna configurations have also proved ignition possible in the region of 200 MHz. However, considering the efforts required to obtain ignition under test conditions, the probability of ignition during normal refueling procedures is remote.

The problem of fueling in an rf environment has been the subject of extensive study and research. Present efforts are being directed toward eliminating all conditions conducive to arcing while fuel is being handled. These efforts include the development of fueling nozzles and receptacles that prevent metal-to-metal contact with the aircraft being refueled and the use of insulating coatings on areas adjacent to fueling receptacles and vents.

7-2. FUEL HAZARDS

The probability of ignition of fuel vapors by rf-induced arcs is small because the following conditions must occur simultaneously for ignition to take place.

a. A flammable fuel-air mixture must be present within range of the induced arcing.

b. The spark must contain a sufficient amount of energy to cause ignition.

c. The gap across which the spark occurs must be a certain minimum distance.

The limits of flammability of most gasoline (including aviation gasoline) are between 1.25 percent and 7.6 percent by volume of gasoline vapor in air. Handling of aviation gasoline under normal operating conditions does not produce a flammable atmosphere except close to aircraft fuel vents, open fuel inlets during over-the-wing fueling, or close to spilled gasoline. With no ventilation, flammable vapors may travel over an inclined guidance such as that provided by a wing or fuselage before becoming diluted. However, if air movement (wind) is present, the gasoline vapor is diluted rapidly and swept away, reducing the zone of possible ignition.

The presence of an odor of gasoline is not a reliable indicator of flammability since the effect of odorous substances varies among observers. In comparative tests of individual response, it was found that the odor of aviation gasoline was quite perceptible at concentrations of less than 1 percent of the lower flammability limit. At 100 percent a very strong odor existed, and at 125 percent, the gas-air mixture was noticeably irritating to the eyes and nasal passages.

Although tests conducted under laboratory conditions to determine the minimum spark energy necessary to cause ignition have been inconclusive, it is known that the spark energy is a determining factor for ignition of fuel-air mixtures. From actual measurements of voltage and currents on aircraft located on a carrier deck near an energized transmitter antenna, it was found that a volt-ampere product of 50 or more was required to ignite gasoline in an explosive vapor test device.

A minimum spark gap of about 0.02 inch is required for ignition of a proper fuel-air mixture. In terms of shipboard fueling conditions, this requires a metal-to-metal contact and subsequent withdrawal to produce a drawn arc of sufficient length to ignite a proper fuel-air mixture. Sometimes drawn sparks may be noticed in an rf environment where the volt-ampere product is less than the 50 volt-amperes required, but the arc is not of sufficient length to cause ignition in such a case.

7.3 FUEL HANDLING PRECAUTIONS

The following precautions establish criteria for handling fuels in rf fields and they supersede previous fuel handling precautions and restrictions. (RADHAZ to JP-5 fueling operations are not considered to be significant.)

a. AVGAS fueling is considered hazardous only under conditions where an rf arc can be drawn in the presence of a flammable fuel-air mixture. With 10 knots or more wind across flight deck, this mixture is achieved only in the immediate vicinity of fill spouts and vents.

b. The correlation of AVGAS fueling hazards with measured field strength in the near field of antennas is difficult. However, actual hazard conditions can be estimated by testing for drawn arcs between the skin of an aircraft and a fuel nozzle as follows:

(1) Use an aircraft with capped fuel tanks and a dry, purged or dummy fueling hose.

(2) Make tests at night for ease of arc detection.

(3) Position the aircraft in a normal fueling position.

(4) Connect the static ground wire, tie down, and such, in normal fashion.

(5) Attempt to draw arcs from the aircraft skin by making and breaking contact with the fuel nozzle.

(6) Vary transmitter frequency over its normal frequency range and vary the position and orientation of the aircraft.

(7) If an arc is observed, a fueling hazard is present. Otherwise, no hazard exists.

c. If the preceeding tests identify a refueling spark hazard and the transmitter causing the spark voltage cannot be shut down or transferred to a non-hazardous antenna, an insulating sleeve should be installed on over-wing fuel nozzles. The sleeve should be fabricated in accordance with military specifications MIL-N-4180 as follows:

(1) Remove the nozzle spout.

(2) Clean the spout throughly to remove all grease and oil.

(3) File off any burrs or sharp edges found on the end of the spout.

(4) Cut a length of heat-reactive tubing (Scotchtite No. 3024, BB200 or equal) as long as the overall length of the spout. This will be about 10-1/2 inches.

(5) Slide the cut length of tubing over the spout as far as it will go. One end of the tubing should rest against the raised portion of the spout which has the wrench flats on it, while the other end extends about 1 inch beyond the end of the spout.

(6) Using a hot air heat source or infrared heat lamps, apply heat to the spout and tubing to shrink the tubing into place. The tubing will contract to its final size in 20 minutes at 250 degrees F and in 4 to 8 minutes at 275 degrees F. The tubing should be shrunk sufficiently to fit the metal spout tightly. Avoid excessive shrinking of the tubing that extends beyond the end of the nozzle so as not to restrict fuel flow. Trim the tubing to extend 1/2 inch beyond the spout. (The tubing it not to be tucked back into the nozzle as was formerly required.) Do not overshrink the portion of the tubing that covers the larger diameter, cast portion of the spout.

(7) After the heat-reactive tubing has been shrunk into place, reassemble the spout and strainer to the nozzle body. Wrap the wrench portion of the spout with a fuel-resistant tape (Scotchbrand No. 99 or equal). The fuel-resistant tape should completely cover the wrench portion of the spout with a least two wraps and should be led down over the previously applied heat-reactive tubing for a distance of 1 to 1-1/2 inches.

(8) Visual inspection. The heat reactive tubing and fuel-resistant tape should be inspected visually prior to each fueling operation. It should be replaced when it is either damaged or worn in such a way that the metal spout is exposed. In no case should a damaged area be repaired by the addition of fuel-resistant tape.

The heat-reactive tubing is available in 100-foot lengths from the Minnesota Mining and Manufacturing Company. The fuel-resistant tape 3/4-inch wide is also available from the above company.

APPENDIX A

BIOLOGICAL EFFECTS OF RF RADIATION

A-1. FUNDAMENTAL PHYSICAL RELATIONSHIPS

The energy impinging on a person in an electromagnetic field may be scattered, transmitted, or absorbed. The energy absorbed into the body depends upon the dimensions of the body, the electrical properties of the tissues, and the wavelength of the rf radiation. Thus, the wavelength of the energy and its relationship to a person's dimensions are important factors bearing on the biological effects produced by rf radiation.

It has been determined that, for any significant effect to occur, the physical size of a person, or part of a person, must be the equivalent of at least a tenth of a wavelength at the frequency of radiation. If a man is considered to be a vertical receiving antenna, his electrical length (height) depends upon the frequency of radiation. As the frequency of radiation increases, the wavelength decreases, and the man's height represents an increasingly greater number of electrical wavelengths. As the frequency is decreased, the wavelength increases, and the man becomes a less significant object in the radiation field. Thus, the likelihood of the occurrence of biological effects increases with an increase in radiation frequency. Also, as the radiation frequency is increased and the wavelength becomes progressively shorter, the dimensions of parts and appendages of the body in themselves become increasingly significant in terms of the number of equivalent electrical wavelengths.

When a man stands erect in an rf field he is comparable to a broadband receiving antenna. When his body is oriented so that any of his major body dimensions are parallel to the plane of polarization of the rf energy, the effects produced are likely to be more pronounced than when his body is oriented in other positions.

A-2. RADIATION AND THE HUMAN BODY

The cross section of the body mass can be considered to consist of two distinct layers and an interior central mass, each of which have different electrical characteristics. The materials of the body that are of primary interest are the skin tissues forming the outer surface of the body, the layer of fat tissue lying immediately underneath the skin, a central mass of deeper tissues, and bone formations. Within the deeper tissues are two general types of tissues: those with high water content and those relatively free of water. The muscular tissues and internal organs (heart, liver, lungs, and such) have high water content, while the bone structures and deep fat tissues have low water content. The deep tissues with high water content exhibit much higher values of dielectric constant and conductivity, since water itself has a high dielectric constant. The presence of moisture, perspiration, or high humidity increases the conductivity, and usually affects insulation resistance.

A-3. THERMAL EFFECTS

The depth of penetration and coincident heating effects of energy on the human body are dependent on frequency, the region of transition being between 1 and 3 GHz. Below 1 GHz, the rf energy penetrates to the deep body tissues; above 3 GHz, the heating effect occurs on or near the surface and may be compared to infrared radiation or direct sunlight. The body thus has an inherent warning system in the sensory elements located in the skin at the higher frequencies. At frequencies between 1 and 3 GHz the thermal effects are subject to varying degrees of penetration, the percentage of energy absorbed ranging from 20 to 100 percent. It is interesting to note that the two microwave cooking oven frequencies fall close to this range. The lower frequency, 915 MHz, produces a deeper heating effect on roasts and is not as effective for surface cooking (browning) as the higher 2450 MHz.

Dielectric heating of tissues by rf energy can also be induced by other than direct radiation. Diathermy treatments have been used for many years in the medical field to raise internal body temperatures. Low frequencies are used (13-40 MHz) to obtain deep penetration. To obtain sufficient coupling or energy transfer at these frequencies the portion the body being treated is used as the "dielectric" between the two plates of a capacitor.

The heat produced by rf radiation may adversely affect live tissue. If the organism cannot dissipate this heat energy as fast as it is produced, the internal temperature of the body will rise. This may result in damage to the tissue and, if the rise is sufficiently high, in destruction of the organism.

A-4. THE BODY'S ABILITY TO DISSIPATE HEAT

The body's ability to dissipate heat successfully depends upon many related factors, such as environmental air circulation rate, clothing, power density of the radiation field, amount of energy absorbed, and duration of exposure (time). Temperature regulation in the human body is accomplished primarily through the action of sweat glands (cooling through evaporation) and by heat exchange resulting from peripheral circulation of blood. The temperature regulation process is extremely complex, and the adverse effects produced when high temperatures are induced in the body may result in a decrease in the efficiency of the system. Since the body has a limited ability to lose heat through sweating and by blood circulation, it can tolerate only a moderate increase above normal body temperature. If only a portion of the body is exposed to energy, the internal temperature of the portion irradiated may rise considerably above normal. However, if the exposure is not prolonged and the areas exposed have adequate blood circulation, the measured oral and rectal temperatures may remain completely normal. Where areas of the body are cooled by an adequate flow of blood through the vascular system, there is less likelihood of tissue damage resulting from abnormal temperature; however, in areas in which relatively little blood circulates, the temperature will rise considerably since there is little means for the interchange of heat. Consequently, tissue damage is more likely to occur in those areas where proportionately greater rises in temperature can occur.

A-5. GEOMETRIC AND OTHER CONSIDERATIONS

When the body is irradiated by energy in the form of a beam originating from a point source, the total body surface is usually not exposed. Only the portion facing the source is exposed, provided that no reflections of energy occur from nearby reflecting surfaces to cause complete irradiation of the body. The temperature elevation produced by the exposure obviously depends on the ratio of the body surface irradiated to the total body surface. The larger the area exposed, the higher the temperature rise, and the greater the hazard. The increase in body temperature to the tolerance threshold (the point at which biological effects begin to occur) may possibly be delayed if the exposure occurs in an environment of low ambient temperature and adequate air circulation.

It is interesting to note that sedatives and tranquilizers interfere with the body's ability to regulate temperature and lose heat. The body's reaction to an abnormally high fever (hyperpyrexia) is essentially the same regardless of how the fever is produced, whether it is the result of hot baths, steam cabinets, heatstroke, diathermy, or absorbed microwave energy. Hyperpyrexia causes anoxia, which is the absence of oxygen in blood, cells, or tissues, and causes anoxemia, which is an abnormal condition caused by insufficient aeration of the blood. Hyperpyrexia also affects the rate of blood coagulation, increasing the clotting time. This effect can be serious in the event of hemorrhage. The limited ability of the body to dissipate heat when its temperature is elevated above normal is complicated by the fact that the basal metabolic rate increases for every degree of temperature rise above normal. This increase in the basal metabolic rate demands an increase in the blood circulation and respiration, as an increase in the supply of oxygen to the tissue, to maintain cellular activity. The problem is aggravated by the reduced capability of hemoglobin to combine with oxygen and by the increased blood circulation rate, which reduces the time available for oxygen transfer in the lungs. The increase in temperature also causes abnormally rapid breathing, or fever hyperpnea. The lack of oxygen available in the blood for release to cells or tissues results in hemorrhages and damage to the brain cells, the central nervous system, and certain internal organs; it may also result in muscular irritability and sometimes convulsions. If these conditions persist, the results are usually coma and eventual death. However, administration of oxygen may keep the oxygen saturation at normal levels and thus help to prevent lethal effects.

A-6. SUSCEPTIBILITY OF CERTAIN ORGANS

Certain organs of the body are considered to be more susceptible than others to the effects or rf radiation. Organs such as the lungs, the eyes, the testicles, the gall bladder, the urinary bladder, and portions of the gastrointestinal tract are not cooled by an abundant flow of blood through the vascular system. Therefore these organs are more likely to be damaged by heat resulting from excessive exposure to radiation. Of the organs just mentioned, presently available information and experience indicate that the eyes and testicles are the most vulnerable to microwave radiation.

EYE. - The transparent lens of the eye appears to be easily damaged by radiated energy, whether ionizing, infrared, or radiofrequency, which causes the development of cataracts or opacities in the eyes. The eye appears to be very susceptible to thermal damage, since it has an inefficient vascular system to circulate blood and exchange heat to the surrounding tissues. Temperature elevation within the eye alters certain complex organic substances, causing impaired functioning and perhaps some tissue destruction. Unlike other cells of the body, the transparent lens cells of the eye cannot be replaced by regrowth. When the cells making up the lens become damaged or die, a cataract may be formed. The damaged cells may lose their transparency slowly and, as a result, depending upon the extent of damage, the individual suffers impaired vision. Apparently, the presence of even a relatively few damaged cells is believed to act upon other lens cells, either by releasing toxic substances or by preventing normal chemical transformations to take place within other cells. The fact that the lens of the eye is transparent makes it possible to employ visual examination techniques to detect early changes in lens structure. Lens opacities or other changes can be identified promptly and their development investigated without need for anesthesia by use of the slit lamp. The slit lamp is an instrument which projects a narrow beam of light into the eye and provides sufficient magnification to enable the visual study of the various layers comprising the eye lens.

TESTICLE. - Testicular reaction to heat injury resulting from rf radiation appears to be the same as the reaction to high fever associated with many illnesses. Although a condition of temporary sterility and damage to seminiferous tubules may occur, the condition does not appear to be of a permanent nature and will ultimately correct itself. For that matter, temporary partial sterility can frequently be caused by tight-fitting underwear which does not permit freedom of movement and adequate air circulation for the dissipation of heat.

A-7. NON-THERMAL EFFECTS

The results of laboratory experiments involving animals have indicated that nonthermal (or athermal) effects may be associated with electromagnetic radiation. It is difficult to establish a relationship between the nonthermal effects and the thermal effects, because temperatures are never constant in the rather poor regulating system of an animal and thus rise when the animal is exposed to microwave energy. However, the results obtained provide evidence that nonthermal effects do exist, in that the clotting time of blood increases when an animal is exposed at near-normal body temperatures. The relationship of physical size to wavelength already discussed established that certain dimensional resonances can cause heating in tissues of the human body; this heating is a thermal effect of microwave energy. Another resonance, which is not dimensional, depends primarily upon the material irradiated and its molecular structure. The electrons orbiting about the nucleus can resonate; also, the nucleus itself can resonate and orient itself with respect to the energy field. These molecular resonances could result in movement of the constituents of molecules in such a manner as to stretch and strain the bonds between them. It is therefore conceivable that breakage of the molecular bonds could occur if placed under extreme stress, as when exposed to pulsed energy at high peak power, and yet not be accompanied by sufficient rise in temperature to be considered a thermal effect. Thus, the molecule could be modified and broken up to form different molecules and result in denaturation of living tissues. Considerable work remains to be done before the full biological significance will be understood.

APPENDIX B

CHARACTERISTICS OF ELECTROMAGNETIC RADIATION

B-1. ELECTROMAGNETIC ENVIRONMENT

Electromagnetic radiation is not visible nor is it detected reliably by any biological response. Its intensity must be measured by instruments or approximated by theoretical calculations. This section presents a method for calculating the on-axis power density radiated from large-aperture antennas and includes procedures for making power density measurements.

The regions of radiation associated with a large-aperture antenna are the Fresnel Region (near field) and the Fraunhofer Region (far field). The Fresnel Region is that portion of the radiation field lying between a wavelength (λ) from the antenna and a distance given by two times the square of the largest linear dimension (L) of the aperture divided by the wavelength (from λ to $2L^2/\lambda$). This is the region in which the beam is being formed, and both the antenna gain and beamwidth vary depending on the type of antenna illumination and the distance from the antenna. Beyond the Fresnel Region is the Fraunhofer Region where the secondary pattern characteristics are well defined and the on-axis power density is given by the Friis free-space transmission formula.

$$P.D. = \frac{PG}{4\pi (d)^2}$$

Where

$P.D.$ = power density

P = power transmitted

G = far field gain (power ratio)

d = distance from the antenna

If the antenna gain is not known, it can be approximated by the formula:

$$G = \frac{4\pi A_e}{\lambda^2}$$

Where

λ = wavelength (see table C-1 for conversion from frequency)

A_e = effective area of the antenna (area of beam-forming surface)

Because the antenna gain and beamwidth are both degraded in the Fresnel Region, the power density in this region is given by:

$$P.D. = \left(\frac{PG}{4\pi (d)^2}\right)(N)$$

Where

N is the near field correction factor, and other symbols are as previously defined.

The near-field correction factor depends on the type of antenna illumination and the distance from the antenna. If the antenna illumination is unknown, it can be estimated by the formula:

$$R = 1.78 \times 10^{-5} (f) (BW) (L)$$

Where

R = constant for estimating illumination

f = frequency in MHz

BW = beamwidth (horizontal or vertical) at 3 dB points

L = horizontal or vertical dimension of antenna in feet

NOTE: A power density calculation using the near-field gain correction factor N is shown in paragraph B-5.

After calculating R, the illumination can be estimated from tables B-1 and B-2. Illuminations above $\cos^4$ or $(1 - r^2)^4$ are purposely omitted since the gain reduction in the Fresnel Region would be almost negligible. When the constant (R) is found to be borderline between two orders of illumination, the higher order should be tried first, since the power density in the Fresnel Region will be greater and therefore more hazardous to personnel. If the choice of the higher order illumination causes the efficiency to be too high, then the next lower order can be tried. The antenna efficiency can be checked by the following equation:

$$K = \frac{G(\lambda)^2}{4\pi (A)F}$$

Where

K = antenna efficiency

A = antenna aperture area

F = factor depending on antenna illumination

The numerical factor (F is tabulated in tables B-1 and B-2 adjacent to the type of antenna illumination. An efficiency (K) within the limits of 0.4 to 0.9 is reasonable.

B-2. CALCULATION OF THE ON-AXIS POWER DENSITY FROM LARGE-APERTURE RECTANGULAR ANTENNAS IN THE FRESNEL REGION

After the illumination has been determined, the Fresnel gain correction factors for both the horizontal and vertical planes can be found. Graphic curves of gain versus distance have been provided for finding the gain correction factors within the Fresnel Region of antennas, depending on the type of illumination of the antenna. Graphs showing uniform, cos, $\cos^2$, $\cos^3$, and $\cos^4$ illumination are given by figures B-1 through B-5 at the end of this appendix. On each of these graphs, the abscissa is the distance from the antenna in wavelengths, and the ordinate is the gain reduction in decibels within the Fresnel Region. The aperture dimension, L, on the graphs is in wavelengths.

TABLE B-1. RECTANGULAR APERTURES

LIMITS OF R	ESTIMATED ILLUMINATION
0.88 to 1.2	uniform
1.2 to 1.45	cos
1.45 to 1.66	$\cos^2$
1.66 to 1.93	$\cos^3$
1.93 to 2.03	$\cos^4$
ILLUMINATION	**F_h or F_v**
uniform	1.000
cos	0.810
$\cos^2$	0.667
$\cos^3$	0.575
$\cos^4$	0.515

NOTE: $F = F_h \times F_v$

TABLE B-2. CIRCULAR APERTURES with $(1-r^2)^p$ Illumination

LIMITS OF R	ESTIMATED ILLUMINATION
1.02 to 1.27	uniform
1.27 to 1.47	$(1 - r^2)$ Taper
1.47 to 1.65	$(1 - r^2)^2$ Taper
1.65 to 1.81	$(1 - r^2)^3$ Taper
greater than 1.81	$(1 - r^2)^4$ Taper
ILLUMINATION	**F**
uniform	1.00
$(1 - r^2)$ Taper	0.75
$(1 - r^2)^2$ Taper	0.56
$(1 - r^2)^3$ Taper	0.44
$(1 - r^2)^4$ Taper	0.36

NOTE: $F = F_h \times F_v$

$r = \frac{e}{A}$, where e = a point on the antenna
A = radius of aperture

The Fresnel gain is always less than the far field gain and is determined by subtracting the appropriate gain reduction for both horizontal and vertical planes from the far field gain. Therefore, by the use of this reduced gain in the far field equation, the power density in the Fresnel Region can be calculated.

B-3. CALCULATION OF THE ON-AXIS POWER DENSITY FROM LARGE-APERTURE CIRCULAR ANTENNAS IN THE FRESNEL REGION

After the illumination has been determined, the Fresnel Region power density can be determined by calculating the far field distance ($d = 2L^2/\lambda$), the power density at this point by the Friis free-space transmission formula ($Pd = PG/4\pi d^2$), and multiplying this power density by the gain correction factor given in figure B-6 for the desired distance and antenna illumination.

B-4. CALCULATION OF POWER DENSITY OF SIDELOBES

Under certain circumstances it may be necessary to calculate the radio frequency power density at a location to the side of a radar antenna main beam. If the antenna in question does not have its aperture distribution defined in its fundamental characteristics, the aperture distribution parameters can be established by using tables B-3 and B-4. Table B-3 defines the directivity patterns for circular aperture from $(1-r^2)^\circ$ through $(1-r^2)^2$ illumination while table B-4 defines the directivity patterns of rectangular aperture from uniform through cosine^2 illumination. Because the sidelobe is less than the main beam, the power density is given as:

$$P.D. = \frac{PG}{4\pi (d)^2} SL$$

Where:

SL = gain degradation of the first sidelobes. The angular displacement in degrees of the first sidelobes are also listed in tables B-3 and B-4.

TABLE B-3

CIRCULAR APERTURE DISTRIBUTION				
Type of Illumination	Half-Power Beamwidth in degrees	Angular Distance to First Zero	Intensity of 1st Sidelobe dB below Max	Angular Distance to 1st Sidelobe
$(1 - r^2)^{\circ}$	$58.9 \frac{\lambda}{D}$	$69.8 \frac{\lambda}{D}$	17.6	$97.4 \frac{\lambda}{D}$
$(1 - r^2)^1$	$72.7 \frac{\lambda}{D}$	$93.6 \frac{\lambda}{D}$	24.6	$119.8 \frac{\lambda}{D}$
$(1 - r^2)^2$	$84.3 \frac{\lambda}{D}$	$116.2 \frac{\lambda}{D}$	30.6	$139.3 \frac{\lambda}{D}$

Where: D = Aperture Diameter

TABLE B-4

RECTANGULAR APERTURE DISTRIBUTION				
Type of Illumination	Half Power Beamwidth in Degrees	Angular Distance to First Zero	Intensity of 1st Sidelobe dB Below Max	Angular Distance to 1st Sidelobe
Uniform	$50.8 \frac{\lambda}{L}$	$57.3 \frac{\lambda}{L}$	13.2	$83.8 \frac{\lambda}{L}$
Cosine	$68.8 \frac{\lambda}{L}$	$85.9 \frac{\lambda}{L}$	23	$113.5 \frac{\lambda}{L}$
Cosine Squared	$83.2 \frac{\lambda}{L}$	$114.6 \frac{\lambda}{L}$	32	$137.3 \frac{\lambda}{L}$

Where: L = Vertical or Horizontal Length of Aperture

B-5. SAMPLE ON-AXIS POWER DENSITY COMPUTATION

The above procedures are illustrated by the following calculation of near-field power density of the AN/BPS-15 radar.

The near-field gain correction factor (N) is the sum of the vertical and horizontal gain correction factors in dB. These factors are derived from the graphs of Figure B-1 thru B-5 which show the near-field gain correction in dB as a function of the antenna dimension (either vertical or horizontal) in wavelengths and the distance d from the antenna in wavelengths.

The pertinent characteristics of the AN/BPS-15 antennas are as follows:

antenna width = 3.33 ft = 30 λ

antenna height = 0.58 ft = 5.2 λ

Gain (far-field) = 29.3 dB = 851

Center frequency 8,825 MHz

$$\lambda = \frac{984}{8825} = 0.1115 \text{ ft}$$

$$\text{Far-field} = 2\frac{L^2}{\lambda}$$ where L is the longer dimension of antenna

$$= \frac{2\,(3.33)^2}{0.1115} = 199 \text{ ft}$$

R, the constant for estimating illumination, is found by:

$$R = 1.78 \times 10^5 \text{ (F) (BW) (L)}$$

Where

F = frequency in MHz

BW= beamwidth is degrees (horizontal or vertical) at 3 dB points.

L = horizontal or vertical dimension in feet.

1. Horizontal illuminations

$$R = 1.78 \times 10^5 \text{ (8825) (2.6) (3.33)}$$

R = 1.36 = cosine (from Table B-1)

2. Vertical illuminations

$$R = 1.78 \times 10^5 \text{ (8825) (12) (.58)}$$

R = 1.07 = uniform (from Table B-1)

N, is the sum of the horizontal and vertical correction factors obtained from figure B-1 for uniform and figure B-2, for cosine illumination.

At 3 feet (27λ) the horizontal gain reduction is approximately - 11.3 dB; the vertical gain reduction at 3 feet is 0.1 dB.

$$\text{Therefore } N = (-11.3 \text{ dB}) + (-0.1 \text{ dB})$$

$$= -11.4 \text{ dB}$$

$$N = \frac{1}{13.8}$$

$$\text{P.D. at 3 ft.} = \frac{PG}{4(d)^2}(N)$$

$$= \frac{13.1 \times 851}{12.56 \times 8340} \quad \frac{1}{13.8}$$

$$P = 13.1 \text{ watts (average power at 0.5 us. pulse width)}$$

$$= .0078 \text{ w/cm}^2$$

$$\text{P.D. at 3 ft.} = 7.8 \text{ mW/cm}^2$$

B-6. INSTRUMENTATION FOR POWER MEASUREMENTS

Radio-frequency power is usually measured by either of two methods. The first method represents an application of the calorimeter principle. A mass is heated by the absorption of the rf power to be measured, and the amount of dc or audio frequency power required to heat an exactly equal mass to an exactly equal temperature is taken as a measurement of the rf power. The second method employs a bolometer element which converts rf energy into heat energy to produce a change in the bolometer resistance. The bolometer is operated in a bridge circuit and the amount of dc or audio-frequency power that is required to rebalance the bridge and keep the bolometer resistance constant is taken as a measurement of the rf power. One type of bolometer is the barretter, which uses a short length of resistive wire; another type is the thermistor, which uses a small mass of resistive material. Power meters cannot measure power density in the radiation field; they can only measure the rf power delivered to the bolometer element. However, when the power that is delivered to the bolometer has been extracted from a radiation field by a precisely calibrated probe antenna, the power reading of the meter can be interpreted as an indication of the power density in the radiation field by the application of a conversion factor which is determined by the properties of the probe. Shipboard power density measurements are made with thermistor type power meters, usually the Hewlett-Packard 431 series or the AN/USM-177 Power Meters are used. Following is the general method of operation:

a. Determine the frequencies at which the measurements are to be made. Select the proper horn antenna or dipole antenna elements and directional coupler or attenuator according to frequency band designation. To avoid damage to the meter, use an attenuator or directional coupler having maximum attenuation for initial measurement.

b. Connect equipment as shown in figure B-7.

NOTE: Last connection should be from directional coupler to thermistor, watching for overload on power meter.

c. Orient the pickup antenna for a maximum reading on the power meter.

d. Take readings as required.

B-7. EXAMPLE POWER MEASUREMENT

Assume the following data:

Radar Frequency	-	3250 MHz
Pickup Antenna	-	Waveline Horn Model 299
Connecting Cables	-	10 feet of RG-9A/U
Directional Coupler	-	Narda Model 3003-20
Power Meter	-	Hewlett Packard Model 431C
Meter Reading	-	1.5 milliwatts

From the proper charts and curves, the following data were obtained.

Effective area of pickup antenna at 3250 MHz - 213 cm^2
(obtained from graph of Waveline horn model 299)

Directional coupler attenuation at 3250 MHz - 20 dB
(obtained from table for Narda Directional coupler 3003-20)

Cable attenuation at 3250 MHz - 1.8 dB (obtained from graph for RG-9A/U cable)

Total attenuation = Cable Attenuation + Directional Coupler Attenuation = 20 dB + 1.8 dB = 21.8 dB.

From table D-3, 21.8 dB = a power ratio of 151.4

$$\text{Power Density} = \frac{\text{Power Ratio x Meter Reading (mW)}}{\text{Effective Area of Pickup Antenna}}$$

$$= \frac{151.4 \times 1.5 \text{ mW}}{213 \text{ cm}^2}$$

$$= 1.06 \text{ mW/cm}^2$$

B-8. POWER DENSITY AND FIELD STRENGTH RELATIONSHIP

On certain occasions it becomes necessary to convert field strength measurements in V/m to power density units in W/m^2 or to convert power density measurements to field strength units. These occasions may arise under the following circumstances:

a. A thermistor-type power meter is unavailable, but a field strength meter having the required frequency range is available.

b. Field strength measurements obtained to establish electromagnetic interference levels are also used as the basis for determining power density levels.

The conversion of V/m to W/m^2 under free space conditions is shown in the following equation:

$$\text{P.D.} = \frac{E^2}{377} \text{ power density in W/m}^2$$

Where:

E = field strength in V/m

377 = impedance of free space in ohms

Where field strength measurements are made closer to the antenna than $\lambda/2\pi$, the free space impedance will not equal 377 ohms, and the above correlation will not hold true.

B-9. ON-AXIS POWER DENSITY COMPUTER PROGRAM

This program calculates the on-axis power density in the Fresnel and Fraunhofer region of large aperture antennas from the antenna parameters and transmitter power.

This program is intended to provide design engineers with power density data which may be used to predict radio frequency hazards areas.

NAVSHIPS 0900-006-5240, Ship Design Computer Program provides the method by which the on-axis power density in the Fresnel and Fraunhofer regions of large-aperture circular antennas may be computed. NAVSHIPS 0900-006-5250, Ship Design Computer Program provides the method by which the on-axis power density in the Fresnel and Fraunofer regions of large-aperture rectangular antennas may be computed.

The On-Axis Power Density Computer Program is available from the Naval Ships Engineering Center, 6179C.04, Radiation Hazard Section.

Table B-5 is representative of a computer readout of the On-Axis Power Density.

B-10. DETERMINING THE HAZARD FROM A ROTATING BEAM

Although the on-axis power density of a radar beam may exceed 10 mW/cm^2, there may be no hazard if the beam is being rotated or scanned. Duration of exposure, as well as power density, is a factor in determining the hazard of exposure to radio-frequency radiation. The time factor is recognized by specifying the permissible exposure limits in two ways: 10 mW/cm^2 for continuous exposure, and 300 millijoules/cm^2 in any given 30-second interval. Since one millijoule equals one milliwatt-second, one can see that these limits are identical for the case of continuous exposure. That is,

$$\frac{300 \text{ mj/cm}^2}{30 \text{ sec}} \times \frac{(\text{mw}) \quad (\text{sec})}{\text{mj}} = 10 \text{ mW/cm}^2$$

The latter limit, though, expresses the fact that higher power densities are permissible for intermittent exposure. To illustrate the use of this criterion for a rotating antenna, assume the following radiation characteristics:

Maximum power density on axis	100 mW/cm^2
Beamwidth	10 degrees
Rotation speed	6 rpm

The permissible exposure time in a power density of 100 mW/cm^2 is:

$$\frac{300 \text{ mW-sec/cm}^2}{100 \text{ mW/cm}^2 \times 30 \text{ sec}} = 3 \text{ sec/30 sec (3 seconds per 30-second interval)}$$

At 6 rpm the antenna will make one revolution each 10 seconds, and the 10° beam will scan a given point in 10/360ths of this period, or 0.278 seconds. In 30 seconds there will be 3 revolutions, so a given point will be scanned for 3 x 0.278 = 0.834 seconds out of each 30 seconds. Since this is well below the 3 seconds permissible, the radar is not hazardous as long as it is rotating, even though the on-axis power density exceeds the safe limit for continuous exposure.

B-11. DETERMINING THE HAZARD FROM A SCANNING BEAM

As a rule of thumb, the safe distance from a scanning antenna is determined by reducing the fixed-beam safe distance by a factor of two times the 3dB beamwidth divided by the angle scanned. For example, assume a scanning angenna with the following characteristics:

Scan Angle	30°
Beamwidth (3dB)	1.5°
Fixed-beam safe distance	1000 ft.

Then, applying the rule of thumb, the safe distance with the antenna scanning is:

$$\frac{2 \times 1.5}{30} \times 1000 = 100 \text{ ft.}$$

TABLE B-5 ON-AXIS POWER DENSITY IN FRESNEL AND FRAUNHOFER REGIONS OF LARGE APERTURE CIRCULAR ANTENNAS

MK 39 MOD 3

FREQUENCY (GC)

PULSE CHARACTERISTICS
AVG POWER (KW) .032

ANTENNA CHARACTERISTICS
BEAMWIDTH (DEG) 5.000
DIAMETER (FT)
GAIN (RATIO) 2240.000
(1-R**2) **4 TAPER

FAR FIELD STARTS AT Z= 114.375 FEET

DISTANCE (FT)	POWER DENSITY (MW/SQ CM)	ANT GAIN (RATIO)	BEAMWIDTH (DEG)
10.0	41.862	1527.817	6.054
15.0	22.908	1881.155	5.456
20.0	13.897	2028.780	5.253
25.0	9.214	2101.914	5.161
30.0	6.524	2142.985	5.111
35.0	4.849	2168.215	5.082
40.0	3.741	2184.770	5.062
45.0	2.971	2196.220	5.049
50.0	2.416	2204.449	5.040
55.0	2.002	2210.559	5.033
60.0	1.686	2215.208	5.027
65.0	1.438	2218.673	5.023
70.0	1.242	2221.774	5.020
75.0	1.083	2223.928	5.018
80.0	.953	2226.152	5.015
85.0	.844	2227.585	5.013
90.0	.754	2228.992	5.012
95.0	.676	2229.862	5.011
100.0	.611	2230.616	5.010
120.0	.426	2240.000	5.000
140.0	.313	2240.000	5.000
160.0	.239	2240.000	5.000
180.0	.189	2240.000	5.000
200.0	.153	2240.000	5.000
220.0	.126	2240.000	5.000
240.0	.106	2240.000	5.000
260.0	.090	2240.000	5.000
280.0	.078	2240.000	5.000
300.0	.068	2240.000	5.000
320.0	.059	2240.000	5.000
340.0	.053	2240.000	5.000
360.0	.047	2240.000	5.000
380.0	.042	2240.000	5.000
400.0	.038	2240.000	5.000

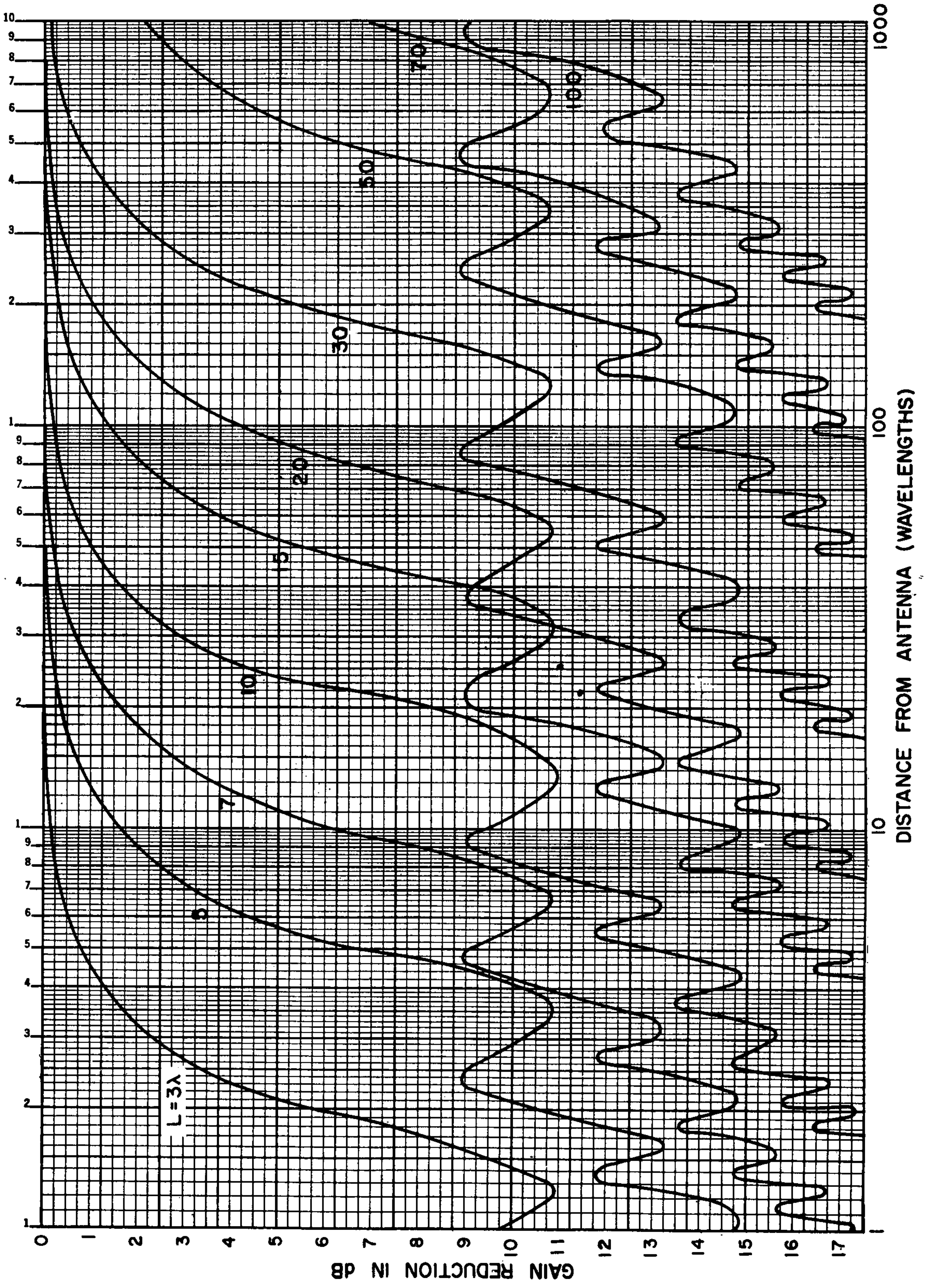


Figure B-1. Fresnel Region Gain Correction for Uniform Illumination

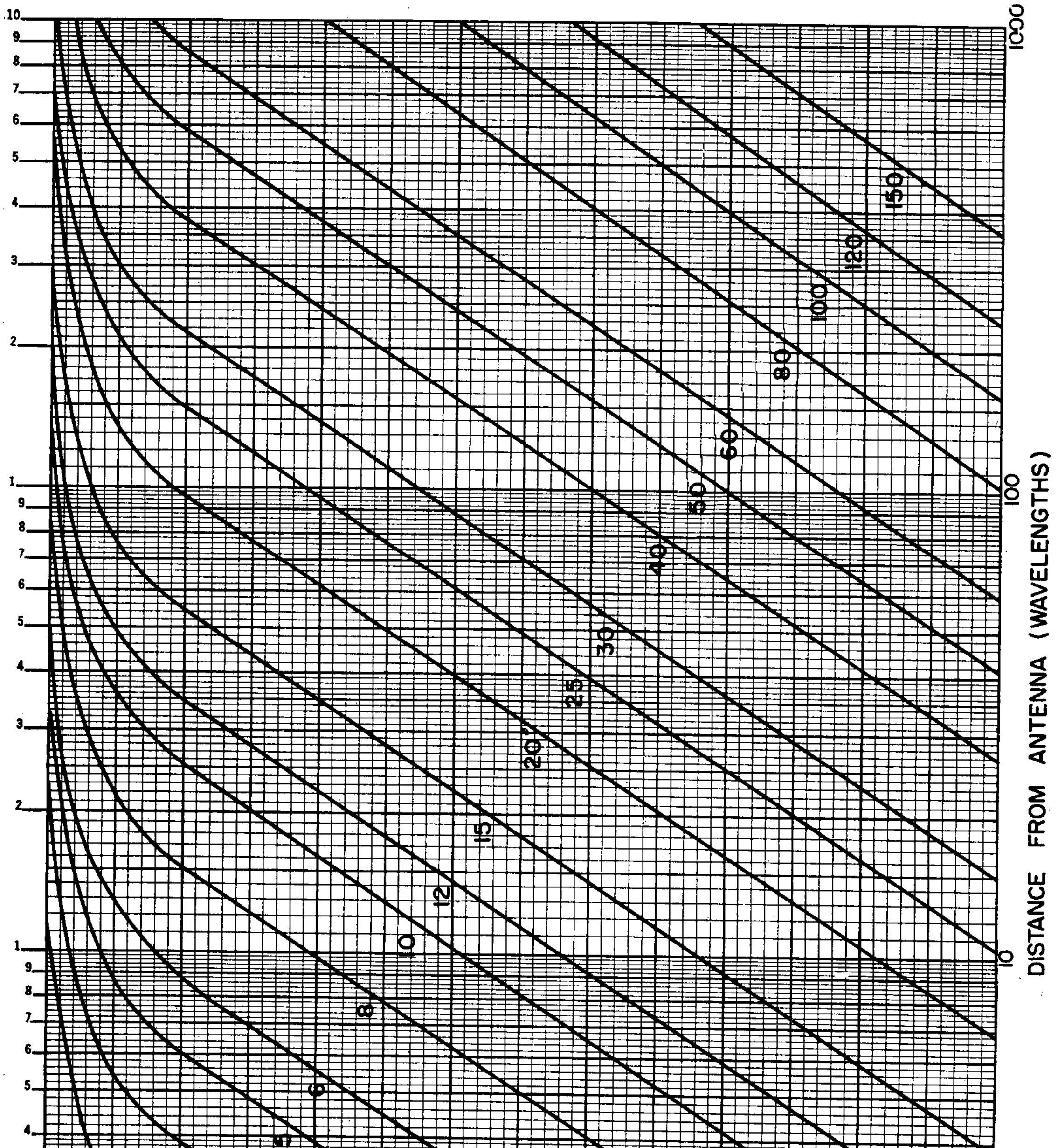


Figure B-2. Fresnel Region Gain Correction for Cosine Illumination

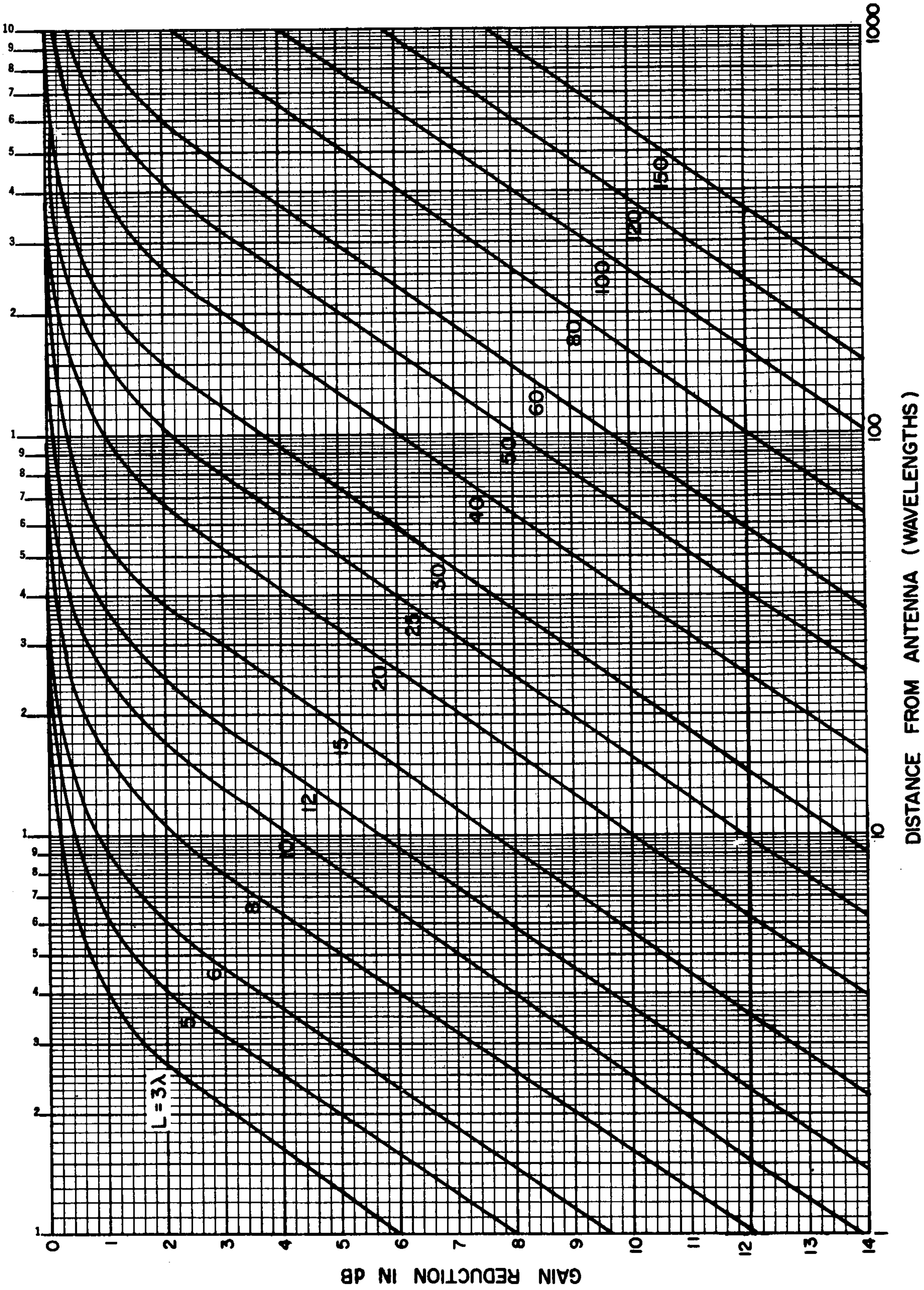


Figure B-3. Fresnel Region Gain Correction for Cosine Square Illumination

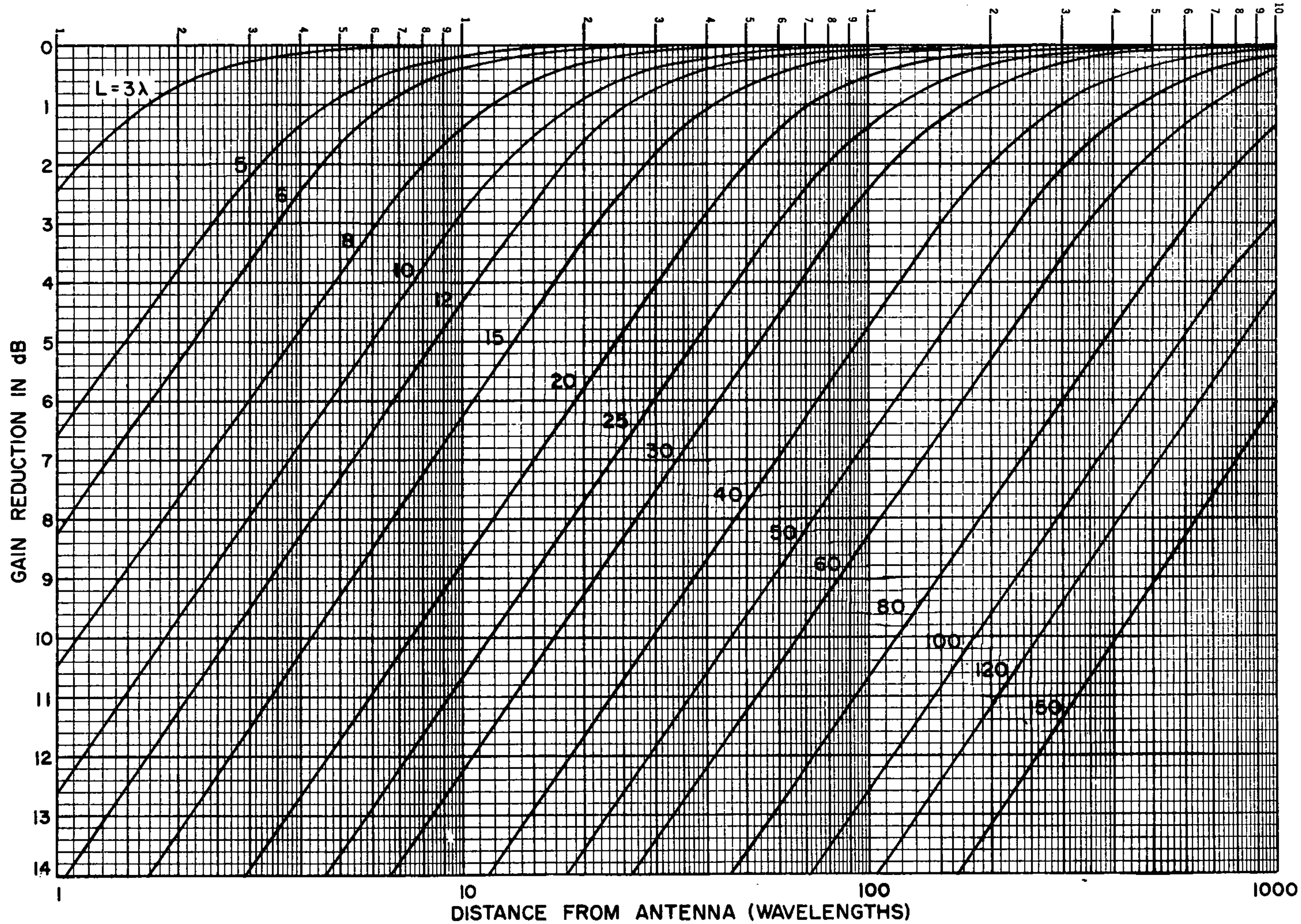


Figure B-4. Fresnel Region Gain Correction for Cosine Cubed Illumination

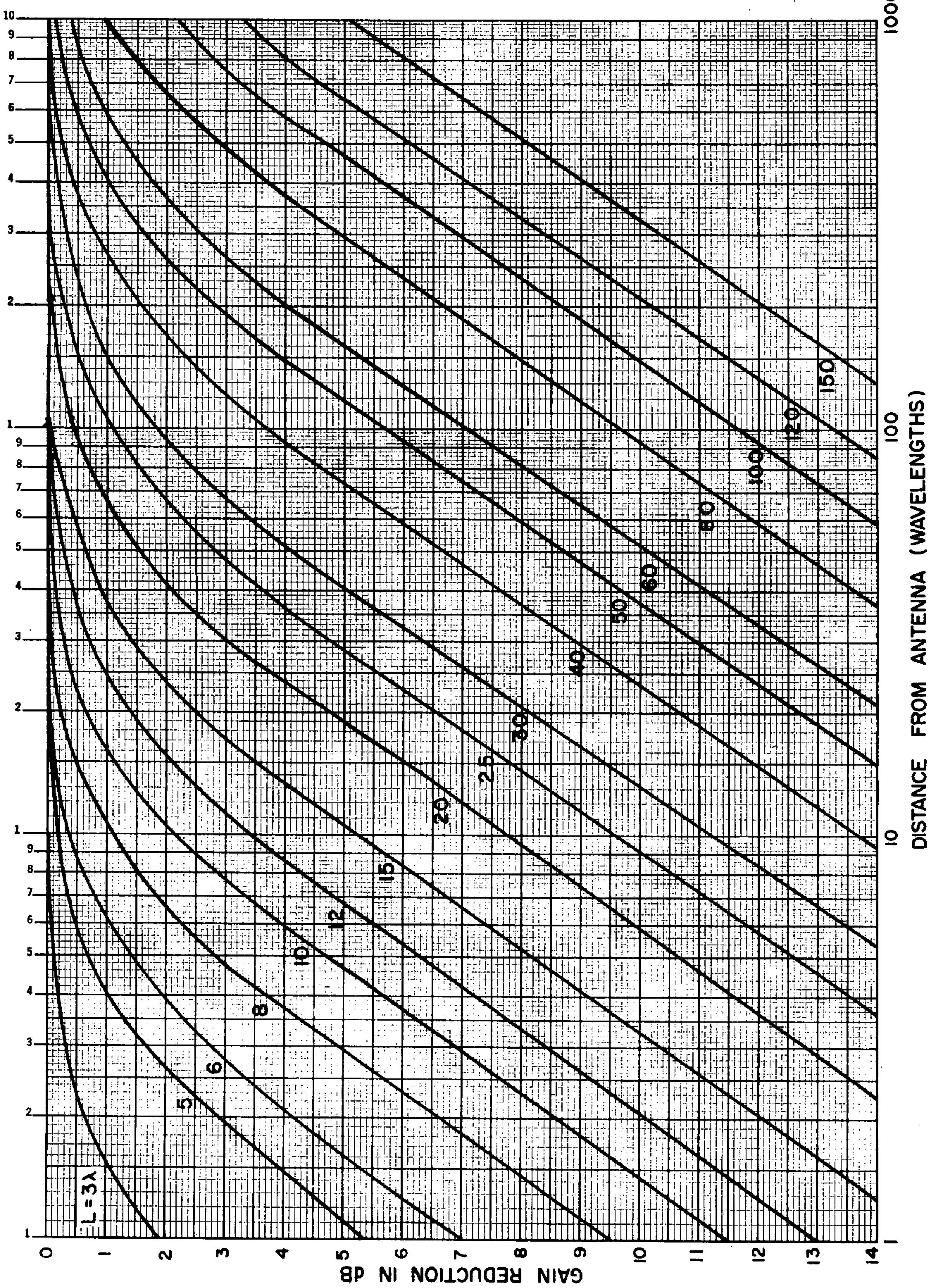


Figure B-5. Fresnel Region Gain Correction for Cosine Fourth Illumination

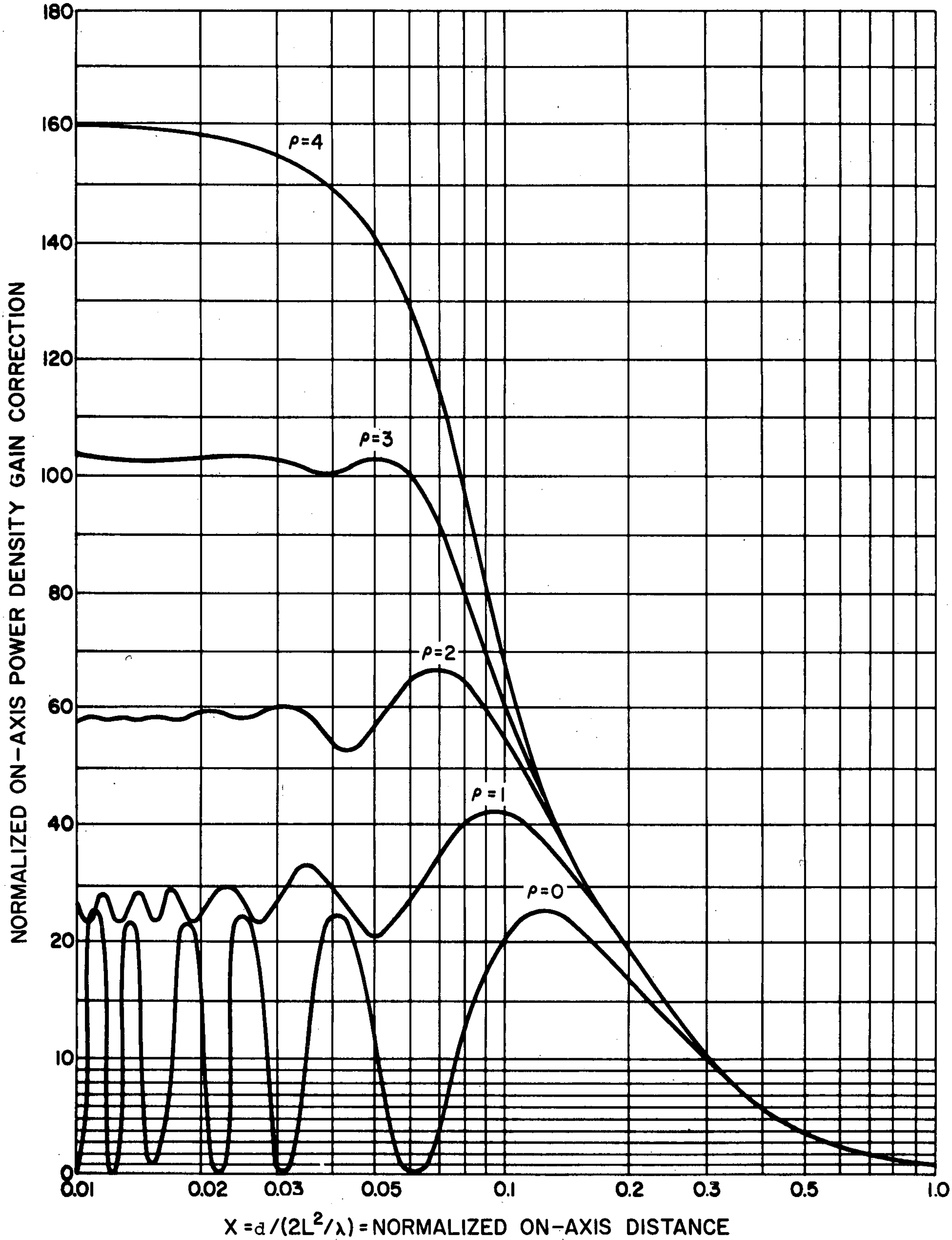


Figure B-6. Normalized On-Axis Power Density Curves for Circular Aperture $(1-r^2)^p$ Tapers

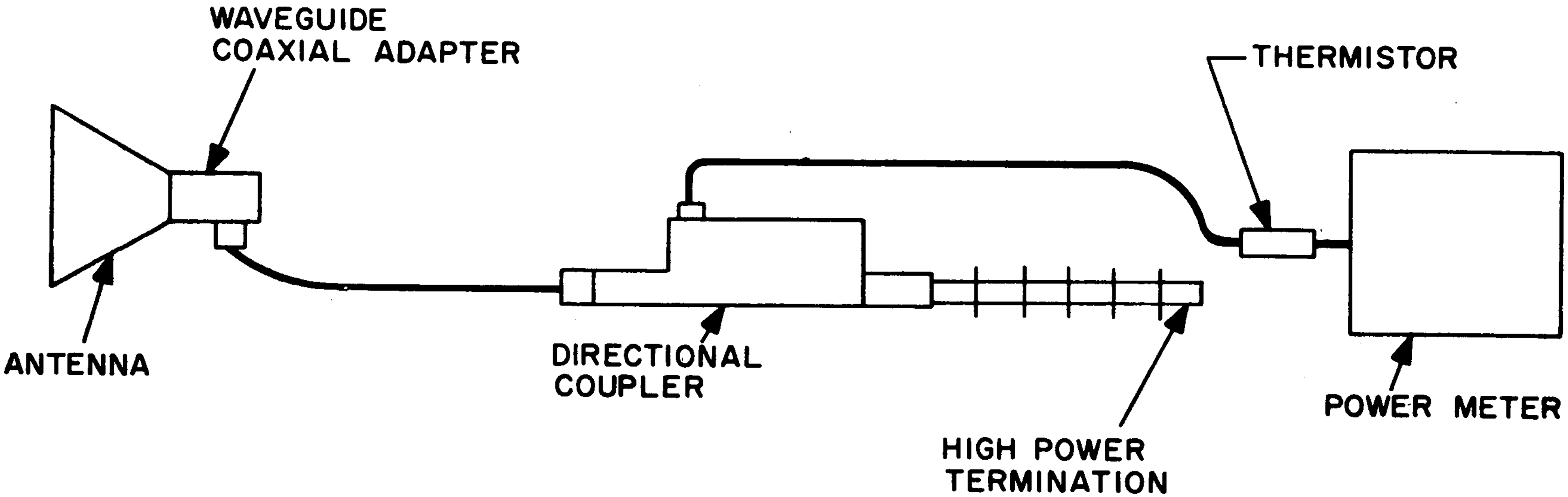


Figure B-7. Typical Microwave Test Configuration

APPENDIX C

DEFINITIONS OF TERMS RELATED TO RADIO-FREQUENCY RADIATION HAZARDS AND USEFUL ENGINEERING AIDS

C-1 INTRODUCTION

a. This appendix contains definitions of terms related to the radio-frequency radiation hazards to personnel, volatile flammable liquids, and ordnance. In recent years, interest in these hazards has spread to many technical fields, including physics, electrical engineering, biology, and chemistry. The problem of communication is acute where a team of specialists representing a wide variety of fields is working together. This glossary is the result of an endeavor to supply an aid to such communication.

b. Formulation of the glossary was aided by reference to definitions and explanations in various technical dictionaries and technical papers, and definitions prepared by various professional societies and military groups.

c. A list of abbreviations is included following the glossary.

C-2 DEFINITIONS

<u>Antenna</u>

A device for radiating or receiving radio waves.

<u>Antenna Array</u>

A system of antennas coupled together for the purpose of obtaining directional effects.

<u>Antenna, Dipole</u>

A straight radiator, usually fed in the center, and producing a maximum of radiation in the plane normal to its axis. The length specified is the overall length.

NOTE: Common usage considers a dipole antenna to be a metal radiating structure which supports a line current distribution similar to that of a thin straight wire a half wavelength long, so energized that the current has two nodes, one at each of the far ends.

<u>Antenna Directivity</u>

The ratio of the maximum radiation intensity to the average radiation intensity produced at a given distance from a given transmitting antenna.

NOTE: By the principle of reciprocity, the directivity of an antenna is the same when that antenna is used as a receiving antenna as when it is used as a transmitting antenna.

<u>Antenna Gain, Relative</u>

The ratio of the power gain of an antenna referred (relative) to a standard antenna. The relative gain may be in dB or it may be a numeric. The standard antenna is usually a half wave dipole or an isotropic antenna. The latter is preferred even though such an antenna does not exist.

<u>Antenna Regions</u>

The regions of small radiators, of the order of one wavelength or less (current elements and small linear radiators), are the electrostatic field region, the induction field region, and the radiation field region.

The regions of large radiators or aperture antennas, larger than one wavelength, are the "near field region" and the "radiation field region." The term induction field as defined for small antennas is not meaningful, but important vector field terms decaying inversely as higher powers of the distance than the first are usually called near field terms.

Arc

An electrical discharge of relatively long duration which may be brought about by separating current carrying electrodes or may result from a spark discharge between initially separated electrodes, provided that the energy source is sufficient to maintain the arc.

Athermal Effect (Non-Thermal Effect)

Any effect of electromagnetic radiation absorption, exclusive of the production of heat.

Attenuation

A general term used to denote a decrease in magnitude in transmission from one point to another. It may be expressed as a ratio or, by extension of the term, in decibels.

Attenuator

A device for reducing the amplitude of electromagnetic energy without introducing appreciable distortion.

Average Power ($\overline{W}$)

The time-average rate of energy transfer:

$$\overline{W} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} W(t)\, dt.$$

For radar calculations:

Average Power ($\overline{W}$) = Peak Power x Pulse Width x PRF.

Average Power Output of an Amplitude-Modulated Transmitter

The average power output of an amplitude-modulated transmitter is the radio-frequency power delivered to the transmitter output terminals, averaged over a modulation cycle.

Bandwidth

The width of the frequency response curve of a circuit between points at a specified output level.

NOTE: Bandwidth is usually measured between frequencies at which power output is one-half of the maximum. (3 dB down).

Beam

A flow of electromagnetic radiation or of particles that is essentially unidirectional.

Beamwidth

The angular width between half-power points on the major lobe of an antenna radiation pattern for a specified plane.

Bolometer

A device capable of absorbing energy, using the heat so developed to change its electrical resistance, thus serving as an indication of the magnitude of power flow.

Breakdown Voltage

When a sufficiently high potential is established between separated electrodes, the gases in the gap become ionized and form a path for a spark discharge. The minimum potential necessary to produce this discharge is termed the breakdown voltage.

Decibel (dB)

A unit of transmission giving the ratio of two powers. Onetenth of a bel. See Paragraph C-6.

dBm: dBW

A decibel ratio related to a specific reference power is often used to define the level of a new quantity. The reference quantity used in expressing the level may be indicated by means of a suffix associated with dB.

Thus the level of power referred to 1 milliwatt may be shown as dBm.

The level of power referred to 1 watt may be shown as dBW.

Deflagration

Combustion proceeding at a very rapid, but subsonic, rate in a material.

Depth of Penetration

The distance from the surface of a material, measured in the direction of propagation, within that material, at which the field intensity is reduced to 1/e times its value at the surface.

Effective Area

The effective area of an antenna in any specified direction is equal to the square of the wavelength multipled by the power gain (or directive gain) in that direction and divided by 4π.

$$A = \frac{G\lambda^2}{4\pi}$$

NOTE: When power gain is used, the effective area is that for power reception; when directive gain is used, the effective area is that for directivity.

Electric Field (E)

A state of the medium in which stationary electrified bodies are subject to force by virtue of their electrifications.

Electric Field Strength

The magnitude of the electric field vector.

Electric Field Vector (E)

A quantity equal in magnitude and direction to the force exerted by an electric field on a stationary unit positive charge.

Electroexplosive Device (EED)

Any single discrete unit, device, or subassembly whose actuation is caused by the application of electric energy which, in turn, initiates an explosive, propellant, or pyrotechnic material contained therein. The term electroexplosive device does not include complete assemblies which have electric initiators as subassemblies, but includes only subassemblies themselves. Synonymous with electric initiator.

Electromagnetic Energy

The energy in an electromagnetic wave or field.

Electromagnetic Radiation

Emission of energy in the form of electromagnetic waves.

Electromagnetic Wave (EMW)

A wave characterized by variations of electric and magnetic fields.

NOTE: Electromagnetic waves are known as radio waves, heat rays, light rays, and the like, depending on the frequency at which the field varies.

Erythema

Redness of the skin caused by congestion of underlying capillaries.

E-Vector

Electric field vector.

Fire Point

The lowest temperature at which a liquid in an open container gives off enough vapors to continue to burn when ignited. This temperature is generally slightly above the flash point.

Flammable

A relative term applied to liquids, gases, and solids indicating that they are easily ignited in air.

Flammable Limits (Flammability Limits Preferred)

The minimum and maximum concentration of a vaporized material in air which will propagate flame if ignited. The difference between the upper and lower flammability limit is known as the flammable or explosive range. The limits are usually expressed in terms of percentage of vapor by volume in air.

Flash Point

The lowest temperature at which a substance will give off enough vapors to form an ignitable mixture with air near the surface of the substance.

Fraunhofer Region

That portion of the radiation field for which antenna patterns are independent of the distance r from the aperture. The field decays as 1/d and, for all practical purposes, one may speak of it as a plane wave field. For large aperture antennas, the boundary between the Fresnel and Fraunhofer Regions occurs for $d > kL^2/\lambda$ (see Fresnel Region) where L is the largest linear dimension of the aperture. For current elements, the boundary is given by $d > \lambda$.

Fresnel Region

That portion of the radiation field, for large aperture antennas, lying between a wavelength from the antenna and a distance d defined by: $d < kL^2/\lambda$ where L is the largest linear dimension of the aperture and k is a constant (usually 1 or 2) whose value depends on the error one is willing to tolerate in assuming that a plane wave exists at the maximum distance given above.

In the Fresnel Region, the antenna pattern is dependent of distance from the aperture and most of the energy is contained within a cylinder swept out by the aperture of the antenna for d greater than λ and less than kL^2/λ.

HERO, Hero

"Hazards of Electromagnetic Radiation to Ordnance."

H-Vector

Magnetic field vector.

Horn Antenna

An antenna having the shape of a tube whose cross-sectional area increases toward the open end, and through which radio waves pass.

Hyperpyrexia

A high degree of fever; hyperthermic condition.

Hyperthermia

Abnormally high body temperature.

Hypothermia

Abnormally low body temperature.

Igniter

An electrical, chemical, explosive, or mechanical device used to initiate combustion.

Ignition Temperature

The minimum temperature to which a solid, liquid, or gaseous substance must be heated to initiate or cause self-sustained combustion independently of the heating element. In the case of solids, the ignition temperature may vary with particle size.

Isotropic Antenna

A hypothetical antenna radiating or receiving equally in all directions.

NOTE: In the case of electromagnetic waves, isotropic antennas do not exist physically but represent convenient reference antennas for expressing directional properties of actual antennas.

Joule

The work done by a force of 1 newton acting through a distance of 1 meter. One joule is equivalent to 1 watt-second.

Main Beam of Radar

The "main beam" as used herein refers to the solid angular arc describing the maximum radiation lobe of the radar, outside of which the power level is at least 20 db below the maximum power level radiated. (It should be noted that this definition is in contrast to the definition which describes beamwidth as that within the half-power (3 dB) points.)

Minimum Ignition Energy

The minimum threshold energy required to ignite a flammable vapor mixture by a spark discharge for a given mixture and electrode shape and spacing.

Microwaves

The term microwaves is used rather loosely to signify radio waves in the frequency range from 300 MHz to 300,000 MHz.

Non-Thermal Effect

See Athermal Effect.

Peak Power Output

In a modulated carrier system, the peak power output is the output power, averaged over a carrier cycle, at the maximum amplitude which can occur with any combination of signals to be transmitted.

Peak Pulse Power

The power at the maximum of a pulse of power, excluding spikes.

Radar

A system which radiates electromagnetic waves and utilizes the reflection of such waves from distant objects to determine their existence or position. The name is derived from the initial letters of the expression Radio Direction and Ranging.

Radiation Field

That portion of the total electromagnetic field produced by a current-carrying conductor or aperture, the magnitude of whose electric or magnetic vector varies inversely as the distance from the conductor, and the energy of which is propagated away from the conductor. This region is made up of two distinct parts: the Fresnel Region and the Fraunhofer or Far-Zone Region.

The distinction between Fresnel and Far Regions has no practical meaning for small radiators but is extremely important for large antennas.

NOTE: The radiation field constitutes the major portion of the total field at distances much greater than $\lambda/2$ from the source. For this reason, it is sometimes called the "Far Field."

Radiation Hazards (RADHAZ)

Radio-frequency electromagnetic fields of sufficient intensity to produce harmful biological effects in humans, cause spark ignition of volatile combustibles, or actuate electroexplosive devices.

Radio Frequency

A frequency useful for radio transmission. The present practicable limits of radio frequency are roughly 10 kilohertz to 100,000 megahertz.

Repetition Frequency

The number of times a repetitive phenomenon occurs per unit time. Example: pulse repetition frequency equals the number of pulses generated or emitted per unit time.

Secondary Heat of Radiation

Heat produced indirectly by the absorption of electromagnetic energy.

Shield

A housing, screen, or other object, usually conducting, which substantially reduces the effect of electric or magnetic fields on one side thereof, upon devices or circuits on the other side.

Shielding Effectiveness

The insertion loss to electromagnetic waves at a point in space which results from the presence of a shield surrounding the point.

Spark

An electrical discharge of relatively short duration between initially separate electrodes; the discharge may be repetitive.

Spontaneous Ignition Temperature

The lowest temperature at which a flammable material can be ignited in a specified atmosphere and at a specified pressure without the use of a flame, spark discharge, or any other energy source.

Static Field

That portion of the total electromagnetic field produced by a current-carrying conductor, the magnitude of which varies inversely as the cube of the distance from the conductor and the energy of which returns to the conductor when the current ceases.

Survey Instrument

A portable instrument used for detecting or measuring radiation rate or intensity under varied physical conditions.

Susceptibility

As used herein, refers to the actual induction of measurable rf energy into an EED of a weapon. The degree of susceptibility is dependent upon the amount of induced energy, the characteristics of the EED, and the environment (such as field strength, orientation of weapon system, weapon configuration, and such).

Threshold Energy

The minimum energy required to ignite a flammable vapor mixture by a spark discharge for a given mixture, electrode shape, and electrode spacing.

Volatile

A relative term which indicates the tendency of a liquid or solid to assume the vapor state (evaporate).

Wavelength

The distance between two successive points of a periodic wave in the direction of propagation, in which the oscillation has the same phase.

Whole Body Irradiation

Pertains to the case in which the entire body is exposed to the incident electromagnetic energy or that the cross-section of the body is smaller than the cross-section of the incident radiation beam.

C-3. ABBREVIATIONS

ac	alternating current
af	audio frequency
AM	amplitude modulation
CRO	cathode-ray oscilloscope
CRT	cathode-ray tube
cw	continuous wave
dB	decibel
dBm	decibel referred to 1 milliwatt
dBV	decibel referred to 1 volt
dBW	decibel referred to 1 watt
EED	electroexplosive device
ehf	extremely-high frequency
elf	extremely-low frequency
EM	electromagnetic
EMR	electromagnetic radiation
EMW	electromagnetic wave
fm	frequency modulation

GHz	gigahertz, kilomegahertz
GCI	ground controlled interception (radar)
HERO	hazards of electromagnetic radiation to ordnance
hf	high frequency
kHz	kilohertz
kW	kilowatt
lf	low frequency
mA	milliamphere
MHz	megahertz
mf	medium frequency
MW	megawatt
mW	milliwatt
PRF	pulse-repetition frequency
PRR	pulse-repetition rate
Radar	radio direction and ranging
RADHAZ	radiation hazards
rf	radio frequency
shf	super-high frequency
SPARKS	hazards of electromagnetic radiation to volatile liquids
uhf	ultra-high frequency
vhf	very-high frequency
vlf	very-low frequency
VSWR	voltage standing-wave ratio
Vpm	volt per meter
W	watt

C-4 USEFUL TABLES

This section contains two mathematical tables, conversion tables, and graphs, which will be found to be of assistance in the calculation or prediction of rf radiation hazards. Explanations regarding the use of the various tables are presented immediately preceding the table, where such explanations are deemed necessary.

Table C-1 lists frequencies in 25-megahertz steps between the values of 200 and 10,000 megahertz, and the equivalent values of wavelength in meters and centimeters. For intermediate values interpolation should be used. The fourth column in the table lists the value of the square of the centimeter equivalent of wavelength, taken from the third column, for convenience in calculations.

Table C-1. FREQUENCY-WAVELENGTH CONVERSION TABLE

FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2
200	1.500	150.0	22500.
225	1.333	133.3	17769.
250	1.200	120.0	14400.
275	1.091	109.1	11903.
300	1.000	100.0	10000.
325	.9231	92.31	8521.
350	.8571	85.71	7346.
375	.8000	80.00	6400.
400	.7500	75.00	5625.
425	.7059	70.59	4983.
450	.6667	66.67	4445.
475	.6316	63.16	3989.

FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2
850	.3529	35.29	1245.
875	.3429	34.29	1176.
900	.3333	33.33	1111.
925	.3243	32.43	1052.
950	.3158	31.58	997.3
975	.3077	30.77	946.8
1000	.3000	30.00	900.0
1025	.2927	29.27	856.7
1050	.2857	28.57	816.2
1075	.2791	27.91	779.0
1100	.2727	27.27	743.7
1125	.2667	26.67	711.3

Table C-1. FREQUENCY-WAVELENGTH CONVERSION TABLE—Cont'd

FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2	FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2
500	.6000	60.00	3600.	1150	.2609	26.09	680.7
525	.5714	57.14	3265.	1175	.2553	25.53	651.8
550	.5455	54.55	2976.	1200	.2500	25.00	625.0
575	.5217	52.17	2722.	1225	.2449	24.49	599.8
600	.5000	50.00	2500.	1250	.2400	24.00	576.0
625	.4800	48.00	2304.	1275	.2353	23.53	553.7
650	.4615	46.15	2130.	1300	.2308	23.08	532.7
675	.4444	44.44	1975.	1325	.2264	22.64	512.6
700	.4286	42.86	1837.	1350	.2222	22.22	493.7
725	.4138	41.38	1712.	1375	.2182	21.82	476.1
750	.4000	40.00	1600.	1400	.2143	21.43	459.2
775	.3871	38.71	1498.	1425	.2105	21.05	443.1
800	.3750	37.50	1406.	1450	.2069	20.69	428.1
825	.3636	36.36	1322.	1475	.2034	20.34	413.7
1500	.2000	20.00	400.0	3025	.0992	9.92	98.41
1525	.1967	19.67	386.9	3050	.0984	9.84	96.83
1550	.1935	19.35	374.4	3075	.0976	9.76	95.26
1575	.1905	19.05	362.9	3100	.0968	9.68	93.70
1600	.1875	18.75	351.6	3125	.0960	9.60	92.16
1625	.1846	18.46	340.8	3150	.0952	9.52	90.63
1650	.1818	18.18	330.5	3175	.0945	9.45	89.30
1675	.1791	17.91	320.8	3200	.0938	9.38	87.98
1700	.1765	17.65	311.5	3225	.0930	9.30	86.49
1725	.1739	17.39	302.4	3250	.0923	9.23	85.19
1750	.1714	17.14	293.8	3275	.0916	9.16	83.91
1775	.1690	16.90	285.6	3300	.0909	9.09	82.63
1800	.1667	16.67	277.9	3325	.0902	9.02	81.36
1825	.1644	16.44	270.3	3350	.0896	8.96	80.28
1850	.1622	16.22	263.1	3375	.0889	8.89	79.03
1875	.1600	16.00	256.0	3400	.0882	8.82	76.79
1900	.1579	15.79	249.3	3425	.0876	8.76	76.74
1925	.1558	15.58	242.7	3450	.0870	8.70	75.69
1950	.1538	15.38	236.5	3475	.0863	8.63	74.48
1975	.1519	15.19	230.7	3500	.0857	8.57	73.44
2000	.1500	15.00	225.0	3525	.0851	8.51	72.42
2025	.1481	14.81	219.3	3550	.0845	8.45	71.40
2050	.1463	14.63	214.0	3575	.0839	8.39	70.39
2075	.1446	14.46	209.1	3600	.0833	8.33	69.39
2100	.1429	14.29	204.2	3625	.0828	8.28	68.56
2125	.1412	14.12	199.4	3650	.0822	8.22	67.57
2150	.1395	13.95	194.6	3675	.0816	8.16	66.59
2175	.1379	13.79	190.2	3700	.0811	8.11	65.77
2200	.1364	13.64	186.0	3725	.0805	8.05	64.80
2225	.1348	13.48	181.7	3750	.0800	8.00	64.00
2250	.1333	13.33	177.7	3775	.0795	7.95	63.20
2275	.1319	13.19	174.0	3800	.0789	7.89	62.25
2300	.1304	13.04	170.0	3825	.0784	7.84	61.47
2325	.1290	12.90	166.4	3850	.0779	7.79	60.68
2350	.1277	12.77	163.1	3875	.0774	7.74	59.91
2375	.1263	12.63	159.5	3900	.0769	7.69	59.14
2400	.1250	12.50	156.2	3925	.0764	7.64	58.37

Table C-1 FREQUENCY-WAVELENGTH CONVERSION TABLE—Cont'd

FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2	FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2
2425	.1237	12.37	153.0	3950	.0759	7.59	57.61
2450	.1224	12.24	149.8	3975	.0755	7.55	57.00
2475	.1212	12.12	146.9	4000	.0750	7.50	56.25
2500	.1200	12.00	144.0	4025	.0745	7.45	55.50
2525	.1188	11.88	141.1	4050	.0741	7.41	54.91
2550	.1176	11.76	138.3	4075	.0736	7.36	54.17
2575	.1165	11.65	135.7	4100	.0732	7.32	53.58
2600	.1154	11.54	133.2	4125	.0727	7.27	52.85
2625	.1143	11.43	130.6	4150	.0723	7.23	52.27
2650	.1132	11.32	128.1	4175	.0719	7.19	51.70
2675	.1121	11.21	125.7	4200	.0714	7.14	50.98
2700	.1111	11.11	123.4	4225	.0710	7.10	50.41
2725	.1101	11.01	121.2	4250	.0706	7.06	49.84
2750	.1091	10.91	119.0	4275	.0702	7.02	49.28
2775	.1081	10.81	116.9	4300	.0698	6.98	48.72
2800	.1071	10.71	114.7	4325	.0694	6.94	48.16
2825	.1062	10.62	112.8	4350	.0690	6.90	47.61
2850	.1053	10.53	110.9	4375	.0686	6.86	47.06
2875	.1043	10.43	108.8	4400	.0682	6.82	46.51
2900	.1034	10.34	106.9	4425	.0678	6.78	45.97
2925	.1026	10.26	105.3	4450	.0674	6.74	45.43
2950	.1017	10.17	103.4	4475	.0670	6.70	44.89
2975	.1008	10.08	101.6	4500	.0667	6.67	44.49
3000	.1000	10.00	100.0	4525	.0663	6.63	43.96
4550	.0659	6.59	43.43	6075	.0494	4.94	24.40
4575	.0656	6.56	43.03	6100	.0492	4.92	24.21
4600	.0652	6.52	42.51	6125	.0490	4.90	24.01
4625	.0649	6.49	42.12	6150	.0488	4.88	23.81
4650	.0645	6.45	41.60	6175	.0486	4.86	23.62
4675	.0642	6.42	41.22	6200	.0484	4.84	23.43
4700	.0638	6.38	40.70	6226	.0482	4.82	23.23
4725	.0635	6.35	40.32	6250	.0480	4.80	23.04
4750	.0632	6.32	39.94	6275	.0478	4.78	22.85
4775	.0628	6.28	39.44	6300	.0476	4.76	22.66
4800	.0625	6.25	39.06	6325	.0474	4.74	22.47
4825	.0622	6.22	38.69	6350	.0472	4.72	22.28
4850	.0619	6.19	38.32	6375	.0471	4.71	22.18
4875	.0615	6.15	37.82	6400	.0469	4.69	22.00
4900	.0612	6.12	37.45	6425	.0467	4.67	21.81
4925	.0609	6.09	37.09	6450	.0465	4.65	21.62
4950	.0606	6.06	36.72	6475	.0463	4.63	21.44
4975	.0603	6.03	36.36	6500	.0462	4.62	21.34
5000	.0600	6.00	36.00	6525	.0460	4.60	21.16
5025	.0597	5.97	35.64	6550	.0458	4.58	20.98
5050	.0594	5.94	35.28	6575	.0456	4.56	20.79
5075	.0591	5.91	34.93	6600	.0455	4.55	20.70
5100	.0588	5.88	34.57	6625	.0453	4.53	20.52
5125	.0585	5.85	34.22	6650	.0451	4.51	20.34
5150	.0583	5.83	33.99	6675	.0449	4.49	20.16
5175	.0580	5.80	33.64	6700	.0448	4.48	20.07
5200	.0577	5.77	33.29	6725	.0446	4.46	19.89

Table C-1 FREQUENCY-WAVELENGTH CONVERSION TABLE—Cont'd

FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2	FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2
5225	.0574	5.74	32.95	6750	.0444	4.44	19.71
5250	.0571	5.71	32.60	6775	.0443	4.43	19.62
5275	.0569	5.69	32.38	6800	.0441	4.41	19.45
5300	.0566	5.66	32.04	6825	.0440	4.40	19.36
5325	.0563	5.63	31.70	6850	.0438	4.38	19.18
5350	.0561	5.61	31.47	6875	.0436	4.36	19.00
5375	.0558	5.58	31.14	6900	.0435	4.35	18.92
5400	.0556	5.56	30.91	6925	.0433	4.33	18.75
5425	.0553	5.53	30.58	6950	.0432	4.32	18.66
5450	.0550	5.50	30.25	6975	.0430	4.30	18.49
5475	.0548	5.48	30.03	7000	.0429	4.29	18.40
5500	.0545	5.45	29.70	7025	.0427	4.27	18.23
5525	.0543	5.43	29.48	7050	.0426	4.26	18.15
5550	.0541	5.41	29.27	7075	.0424	4.24	17.98
5575	.0538	5.38	28.94	7100	.0423	4.23	17.89
5600	.0536	5.36	28.73	7125	.0421	4.21	17.72
5625	.0533	5.33	28.41	7150	.0420	4.20	17.64
5650	.0531	5.31	28.20	7175	.0418	4.18	17.47
5675	.0529	5.29	27.98	7200	.0417	4.17	17.39
5700	.0526	5.26	27.67	7225	.0415	4.15	17.22
5725	.0524	5.24	27.46	7250	.0414	4.14	17.14
5750	.0522	5.22	27.25	7275	.0412	4.12	16.97
5775	.0519	5.19	26.94	7300	.0411	4.11	16.89
5800	.0517	5.17	26.73	7325	.0410	4.10	16.81
5825	.0515	5.15	26.52	7350	.0408	4.08	16.65
5850	.0513	5.13	26.32	7375	.0407	4.07	16.56
5875	.0511	5.11	26.11	7400	.0405	4.05	16.40
5900	.0508	5.08	25.81	7425	.0404	4.04	16.32
5925	.0506	5.06	25.60	7450	.0403	4.03	16.24
5950	.0504	5.04	25.40	7475	.0402	4.02	16.16
5975	.0502	5.02	25.20	7500	.0400	4.00	16.00
6000	.0500	5.00	25.00	7525	.0399	3.99	15.92
6025	.0498	4.98	24.80	7550	.0397	3.97	15.76
6050	.0496	4.96	24.60	7575	.0396	3.96	15.68
7600	.0395	3.95	15.60	8825	.0340	3.40	11.56
7625	.0393	3.93	15.44	8850	.0339	3.39	11.49
7650	.0392	3.92	15.37	8875	.0338	3.38	11.42
7675	.0391	3.91	15.29	8900	.0337	3.37	11.36
7700	.0390	3.90	15.21	8925	.0336	3.36	11.29
7725	.0388	3.88	15.05	8950	.0335	3.35	11.22
7750	.0387	3.87	14.98	8975	.0334	3.34	11.16
7775	.0386	3.86	14.90	9000	.0333	3.33	11.09
7800	.0385	3.85	14.82	9025	.0332	3.32	11.02
7825	.0383	3.83	14.67	9050	.0331	3.31	10.96
7850	.0382	3.82	14.59	9075	.0331	3.31	10.96
7875	.0381	3.81	14.52	9100	.0330	3.30	10.89
7900	.0380	3.80	14.44	9125	.0329	3.29	10.82
7925	.0379	3.79	14.36	9150	.0328	3.28	10.76
7950	.0377	3.77	14.21	9175	.0327	3.27	10.69
7975	.0376	3.76	14.14	9200	.0326	3.26	10.63
8000	.0375	3.75	14.06	9225	.0325	3.25	10.56

Table C-1 FREQUENCY-WAVELENGTH CONVERSION TABLE—Cont'd

FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2	FREQUENCY (MHz)	METERS	CENTI-METERS	cm^2
8025	.0374	3.74	13.99	9250	.0324	3.24	10.50
8050	.0373	3.73	13.91	9275	.0323	3.23	10.43
8075	.0372	3.72	13.84	9300	.0323	3.23	10.43
8100	.0370	3.70	13.69	9325	.0322	3.22	10.37
8125	.0369	3.69	13.62	9350	.0321	3.21	10.30
8150	.0368	3.68	13.54	9375	.0320	3.20	10.24
8175	.0367	3.67	13.47	9400	.0319	3.19	10.18
8200	.0366	3.66	13.40	9425	.0318	3.18	10.11
8225	.0365	3.65	13.32	9450	.0317	3.17	10.05
8250	.0364	3.64	13.25	9475	.0317	3.17	10.05
8275	.0363	3.63	13.18	9500	.0316	3.16	9.986
8300	.0361	3.61	13.03	9525	.0315	3.15	9.923
8325	.0360	3.60	12.96	9550	.0314	3.14	9.860
8350	.0359	3.59	12.89	9575	.0313	3.13	9.797
8375	.0358	3.58	12.82	9600	.0313	3.13	9.797
8400	.0357	3.57	12.74	9625	.0312	3.12	9.734
8425	.0356	3.56	12.67	9650	.0311	3.11	9.672
8450	.0355	3.55	12.60	9675	.0310	3.10	9.610
8475	.0354	3.54	12.53	9700	.0309	3.09	9.548
8500	.0353	3.53	12.46	9725	.0308	3.08	9.486
8525	.0352	3.52	12.39	9750	.0308	3.08	9.486
8550	.0351	3.51	12.32	9775	.0307	3.07	9.425
8575	.0350	3.50	12.25	9800	.0306	3.06	9.364
8600	.0349	3.49	12.18	9825	.0305	3.05	9.302
8625	.0348	3.48	12.11	9850	.0305	3.05	9.302
8650	.0347	3.47	12.04	9875	.0304	3.04	9.242
8675	.0346	3.46	11.97	9900	.0303	3.03	9.181
8700	.0345	3.45	11.90	9925	.0302	3.02	9.120
8725	.0344	3.44	11.83	9950	.0302	3.02	9.120
8750	.0343	3.43	11.76	9975	.0301	3.01	9.060
8775	.0342	3.42	11.70	10,000	.0300	3.00	9.000
8800	.0341	3.41	11.63				

Table C-2 gives the natural sines, cosines, and tangents for angles of 0 degrees to 89 degrees inclusive, by degrees.

Table C-2 NATURAL SINES, COSINES, AND TANGENTS

ANGLE	SIN	COS	TAN	ANGLE	SIN	COS	TAN
0	.0000	1.0000	.0000	45	.7071	.7071	1.0000
1	.0175	.9998	.0175	46	.7193	.6947	1.0355
2	.0349	.9994	.0349	47	.7314	.6820	1.0724
3	.0523	.9986	.0524	48	.7431	.6691	1.1106
4	.0698	.9976	.0699	49	.7547	.6561	1.1504
5	.0872	.9962	.0875	50	.7660	.6428	1.1918
6	.1045	.9945	.1051	51	.7771	.6293	1.2349
7	.1219	.9925	.1228	52	.7880	.6157	1.2799
8	.1392	.9903	.1405	53	.7986	.6018	1.3270
9	.1564	.9877	.1584	54	.8090	.5878	1.3764
10	.1736	.9848	.1763	55	.8192	.5736	1.4281
11	.1908	.9816	.1944	56	.8290	.5592	1.4826
12	.2079	.9781	.2126	57	.8387	.5446	1.5399
13	.2250	.9744	.2309	58	.8480	.5299	1.6003
14	.2419	.9703	.2493	59	.8572	.5150	1.6643
15	.2588	.9659	.2679	60	.8660	.5000	1.7321
16	.2756	.9613	.2867	61	.8746	.4848	1.8040
17	.2924	.9563	.3057	62	.8829	.4695	1.8807
18	.3090	.9511	.3249	63	.8910	.4540	1.9626
19	.3256	.9455	.3443	64	.8988	.4384	2.0503
20	.3420	.9397	.3640	65	.9063	.4226	2.1445
21	.3584	.9336	.3839	66	.9135	.4067	2.2460
22	.3746	.9272	.4040	67	.9205	.3907	2.3559
23	.3907	.9205	.4245	68	.9272	.3746	2.4751
24	.4067	.9135	.4452	69	.9336	.3584	2.6051
25	.4226	.9063	.4663	70	.9397	.3420	2.7475
26	.4384	.8988	.4877	71	.9455	.3256	2.9042
27	.4540	.8910	.5095	72	.9511	.3090	3.0777
28	.4695	.8829	.5317	73	.9563	.2924	3.2709
29	.4848	.8746	.5543	74	.9613	.2756	3.4874
30	.5000	.8660	.5774	75	.9659	.2588	3.7321
31	.5150	.8572	.6009	76	.9703	.2419	4.0108
32	.5299	.8480	.6249	77	.9744	.2250	4.3315
33	.5446	.8387	.6494	78	.9781	.2079	4.7046
34	.5592	.8290	.6745	79	.9816	.1908	5.1446
35	.5736	.8192	.7002	80	.9848	.1736	5.6713
36	.5878	.8090	.7265	81	.9877	.1564	6.3138
37	.6018	.7986	.7536	82	.9903	.1392	7.1154
38	.6157	.7880	.7813	83	.9925	.1219	8.1443
39	.6293	.7771	.8098	84	.9945	.1045	9.5144
40	.6428	.7660	.8391	85	.9962	.0872	11.4300
41	.6561	.7547	.8693	86	.9976	.0698	14.3000
42	.6691	.7431	.9004	87	.9986	.0523	19.0810
43	.6820	.7314	.9325	88	.9994	.0349	28.6360
44	.6947	.7193	.9657	89	.9998	.0175	57.2900

C-5 RIGHT TRIANGLES

An triangle is a figure having three sides and three angles; the sum of the angles is equal to 180 degrees. A right triangle is a triangle in which one of the angles is a right angle, or 90°; therefore the sum of the other two angles is 90°. The longer of the three sides, which in the case of the right triangle is the side opposite the right angle, is called the hypotenuse.

In the right triangle shown in figure C-1, functions of the angle A will be discussed. When the triangle is in the position as shown in figure C-1, it is said to be in the standard position. The side a, which is opposite the angle A, is called the altitude. Side b, which is opposite the angle B, is called the base. Side c, the hypotenuse, is opposite the right angle.

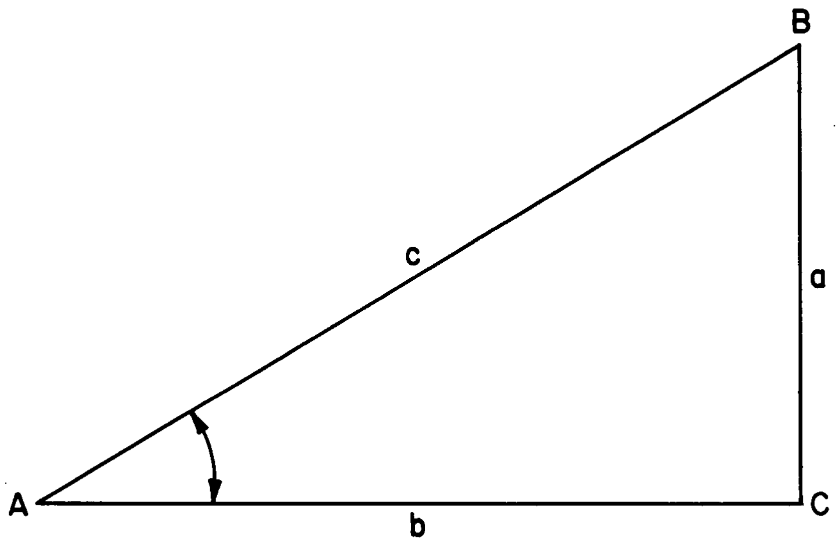


Figure C-1. Functions of a Right Triangle

TRIGONOMETRIC FUNCTIONS OF A RIGHT TRIANGLE

In the right triangle shown in figure C-1, the trigonometric functions of angle A are defined as follows:

$\frac{a}{c}$ is the sine of angle A, and is written sin A.

$\frac{b}{c}$ is the cosine of angle A, and is written cos A.

$\frac{a}{b}$ is the tangent of angle A, and is written tan A.

To illustrate the use of the above functions, consider a right triangle having an altitude of 3 units and a hypotenuse of 6 units. For these values, the sine of the angle A is:

$$\sin A = \frac{a}{c} = \frac{3}{6} = 0.5$$

By reference to table C-2, the angle whose sine is 0.5 is found to be 30°.

Now consider a right triangle having a base of 3 units and a hypotenuse of 8 units. The cosine of angle A is:

$$\cos A = \frac{b}{c} = \frac{3}{8} = 0.375$$

By reference to table C-2, the angle whose cosine is 0.375 is found to be 68° (approximately).

Finally, consider a right triangle having an altitude of 5 units and a base of 8 units. The tangent of angle A is:

$$\tan A = \frac{a}{b} = \frac{5}{8} = 0.625$$

Referring to the tangent column of table C-2, the angle whose tangent is 0.625 is found to be approximately 32°.

USE OF TRIGONOMETRIC FUNCTIONS IN SOLVING PROBLEMS

To illustrate the use of trigonometric functions in solving problems, consider the following example:

Given: A radar set in which the antenna has a radiation pattern that covers a vertical angle of 60 degrees, with the beam center elevated = 20 degrees from the horizontal plane. The center of the antenna is 6 feet above the base of a pedestal, which is mounted on a 15-foot tower. See figure C-2.

To find: Whether any part of the main beam will illuminate a person who is 6 feet tall, and who is on the ground at a distance of 100 feet.

Solution: Lower edge of beam $= +20 - (1/2 \times 60)$
$= -10$ degrees

$$\tan 10° = \frac{a}{b}$$

$$a = b \tan 10° = 100 \times 0.1763 = 17.63 \text{ feet}$$

The center of the beam above ground (tower + pedestal) is 15 feet + 6 feet, or 21 feet, and the clearance of the beam above ground at 100 feet is 21 feet -17.63 feet, or 3.37 feet; therefore, a 6-foot person would have 6 feet - 3.37 feet, or 2.63 feet of his body illuminated by the radar beam.

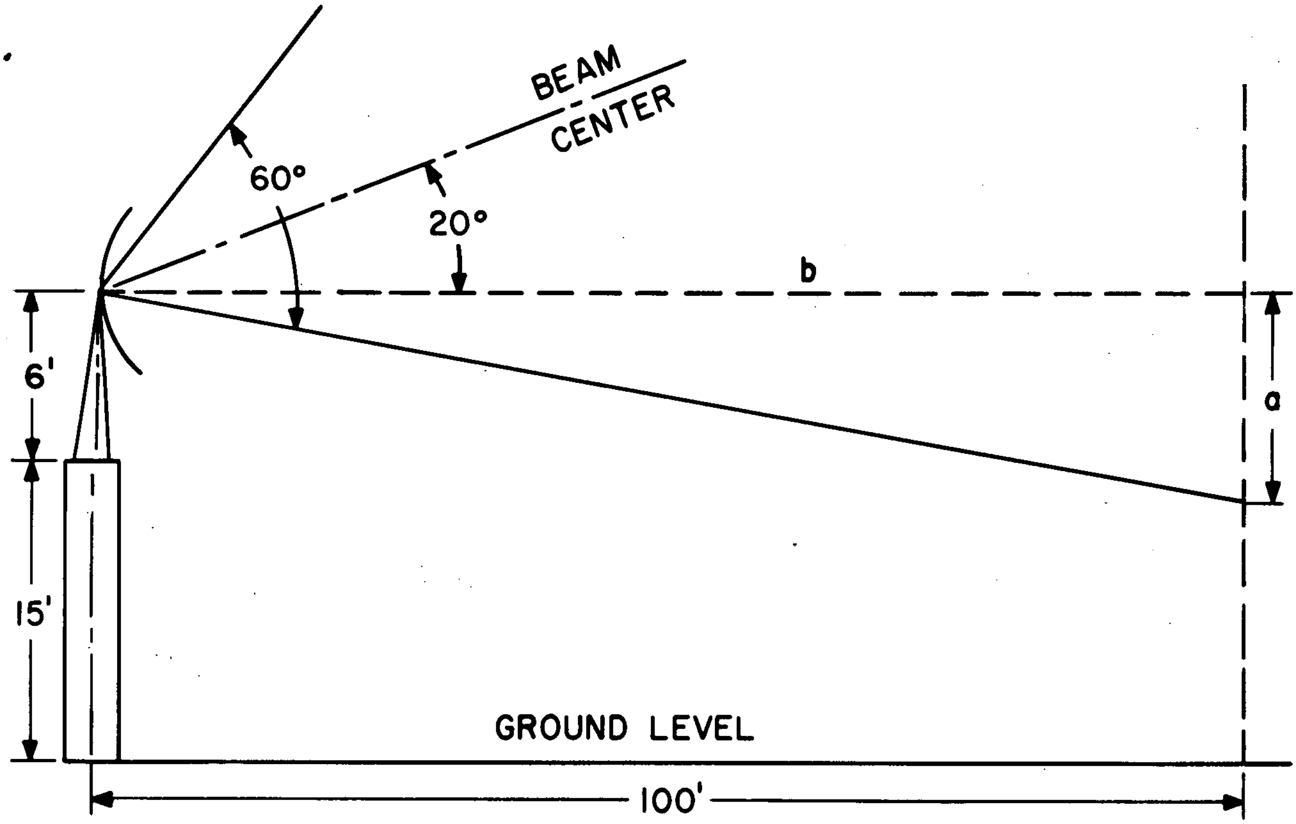


Figure C-2 Calculation of Beam Clearance above Ground at a Given Distance from Antenna

C-6 THE DECIBEL

The decibel is part of at larger unit called the bel. As originally used, the bel represented a power ratio of 10 to 1 between the strength of two sounds. To gain a better understanding of the bel, consider three sounds of unequal power intensity. If the power intensity of the second sound is 10 times the power intensity of the first, its power level is said to be 1 bel above that of the first. If the third sound has a power intensity which is 10 times that of the second, its level is 1 bel above that of the second. But, since the third sound is 100 times as intense as the first, its level is 3 bels above that of the first.

Thus a power ratio of 100 to 1 is represented by 2 bels; a power ratio of 1000 to 1, by 3 bels; a power ratio of 10,000 to 1, by 4 bels; etc. It is readily seen, therefore, that the concept of bels represents a logarithmic relationship, since the logarithm of 100 to the base 10 equals 2 (corresponding to 2 bels), the logarithm of 1000 equals 3 (corresponding to 2 bels), the logarithm of 1000 equals 3 (corresponding to 3 bels), etc. The exact relationship is given by the formula:

$$\text{Bels} = \log \frac{P_2}{P_1}$$

where $\frac{P_2}{P_1}$ represents the power ratio

This logarithmic characteristic of the bel makes it a very convenient means for expressing power ratios. Since the bel is a rather large unit, however, it use may prove inconvenient. Usually, therefore, a smaller unit, the decibel, is used. Ten decibels equals 1 bel. A 10-to-1 power ratio, which is represented by 1 bel, is also represented by 10 decibels (10 dB), a 100-to-1 ratio (2 bels) is represented by 20 dB, a 1000-to-1 ratio (3 bels) is represented by 30 dB, etc. The formula for bels may be rewritten to give a result in decibels merely by multiplying by 10. Thus, the formula becomes:

$$\text{Decibels (dB)} = 10 \log \frac{P2}{P_1}$$

For example, assume that it is necessary to find the attenuation ratio of an r-f attenuator which is to be used to measure transmitter power output. On test, it is found that 60,000 watts of r-f input to the attenuator produces an output of 6 milliwatts. To find the attenuation ratio, use the equation:

$$\text{Attenuation ratio} = \frac{P_2}{P_1} = \frac{60,000}{.006} = 10,000,000$$

This ratio can be expressed much more conveniently in terms of decibels.

$$\text{Decibels (dB)} = 10 \log \frac{P_2}{P_1} = 10 \log \frac{60,000}{.006}$$

$$= 10 \log 10,000,000 = 70 \text{ decibels}$$

In this case, the attenuation ratio is 70 decibels. In other words, P_2 is said to be 70 decibels up with respect to P_1. In all instances where P_2 is numerically greater than P_1, as in the above example, the final result is expressed as a positive quantity. When P2 is smaller that P_1, the numerical result is the same, but it is expressed as a negative quantity in dB. If, for example, P_2 is .006 watt and P_1 is 60,000 watts, then:

$$\text{Decibels (dB)} = 10 \log \frac{P_2}{P_1} = 10 \log \frac{.006}{60,000}$$

$$= 10 \log 0.0000001 = -70 \text{ decibels}$$

In this case, P_2 is said to be 70 decibels <u>down</u> with respect to P_1.

Voltage and current ratios may also be expressed in terms of decibels, provided that the resistance (or impedance) remains constant. For equal resistances, the formulas are:

$$\text{dB} = 20 \log \frac{E_2}{E_1}$$

$$\text{dB} = 20 \log \frac{I_2}{I_1}$$

The difference in the multiplying factor in these formulas (20 rather than 10, as in the case of power ratios) arises from the fact that power is proportional to voltage or current <u>squared</u>, and when a number is squared, the logarithm of that number is doubled. For power ratios, the dB value is 10 times the logarithm of the ratio. For voltage or current ratios, the dB value is 20 times the logarithm of the ratio.

Conversions from voltage, current, or power ratios to decibels may be readily made by referring to table C-3. Conversions may also be made by means of the graph shown in figure C-3.

Table C-3. DECIBEL TABLE: VOLTAGE, CURRENT, AND POWER RATIOS

MINUS ←		dB	→ PLUS	
VOLTAGE OR CURRENT RATIO (EQUAL IMPEDANCE)	POWER RATIO		VOLTAGE OR CURRENT RATIO (EQUAL IMPEDANCE)	POWER RATIO
1.000	1.000	0	1.000	1.000
0.989	0.977	0.1	1.012	1.023
0.977	0.955	0.2	1.023	1.047
0.966	0.933	0.3	1.035	1.072
0.955	0.912	0.4	1.047	1.096
0.944	0.891	0.5	1.059	1.122
0.933	0.871	0.6	1.072	1.148
0.923	0.851	0.7	1.084	1.175
0.912	0.832	0.8	1.096	1.202
0.902	0.813	0.9	1.109	1.230
0.891	0.794	1.0	1.122	1.259
0.841	0.708	1.5	1.189	1.413
0.794	0.631	2.0	1.259	1.585
0.750	0.562	2.5	1.334	1.778
0.708	0.501	3.0	1.413	1.995
0.668	0.447	3.5	1.496	2.239
0.631	0.398	4.0	1.585	2.512
0.596	0.355	4.5	1.679	2.818
0.562	0.316	5.0	1.778	3.162
0.531	0.282	5.5	1.884	3.548
0.501	0.251	6.0	1.995	3.981
0.473	0.224	6.5	2.113	4.467
0.447	0.200	7.0	2.239	5.012
0.422	0.178	7.5	2.371	5.623
0.398	0.159	8.0	2.512	6.310
0.376	0.141	8.5	2.661	7.079
0.355	0.126	9.0	2.818	7.943
0.335	0.112	9.5	2.985	8.913
0.316	0.100	10	3.162	10.00
0.282	0.0794	11	3.55	12.6
0.251	0.0631	12	3.98	15.9
0.224	0.501	13	4.47	20.0
0.200	0.0398	14	5.01	25.1
0.178	0.0316	15	5.62	31.6
0.159	0.0251	16	6.31	39.8
0.141	0.0200	17	7.08	50.1
0.126	0.0159	18	7.94	63.1
0.112	0.0126	19	8.91	79.4
0.100	0.0100	20	10.00	100.0
3.16×10^{-2}	10^{-3}	30	3.16×10^{1}	10^{3}
10^{-2}	10^{-4}	40	10^{2}	10^{4}
3.16×10^{-3}	10^{-5}	50	3.16×10^{2}	10^{5}

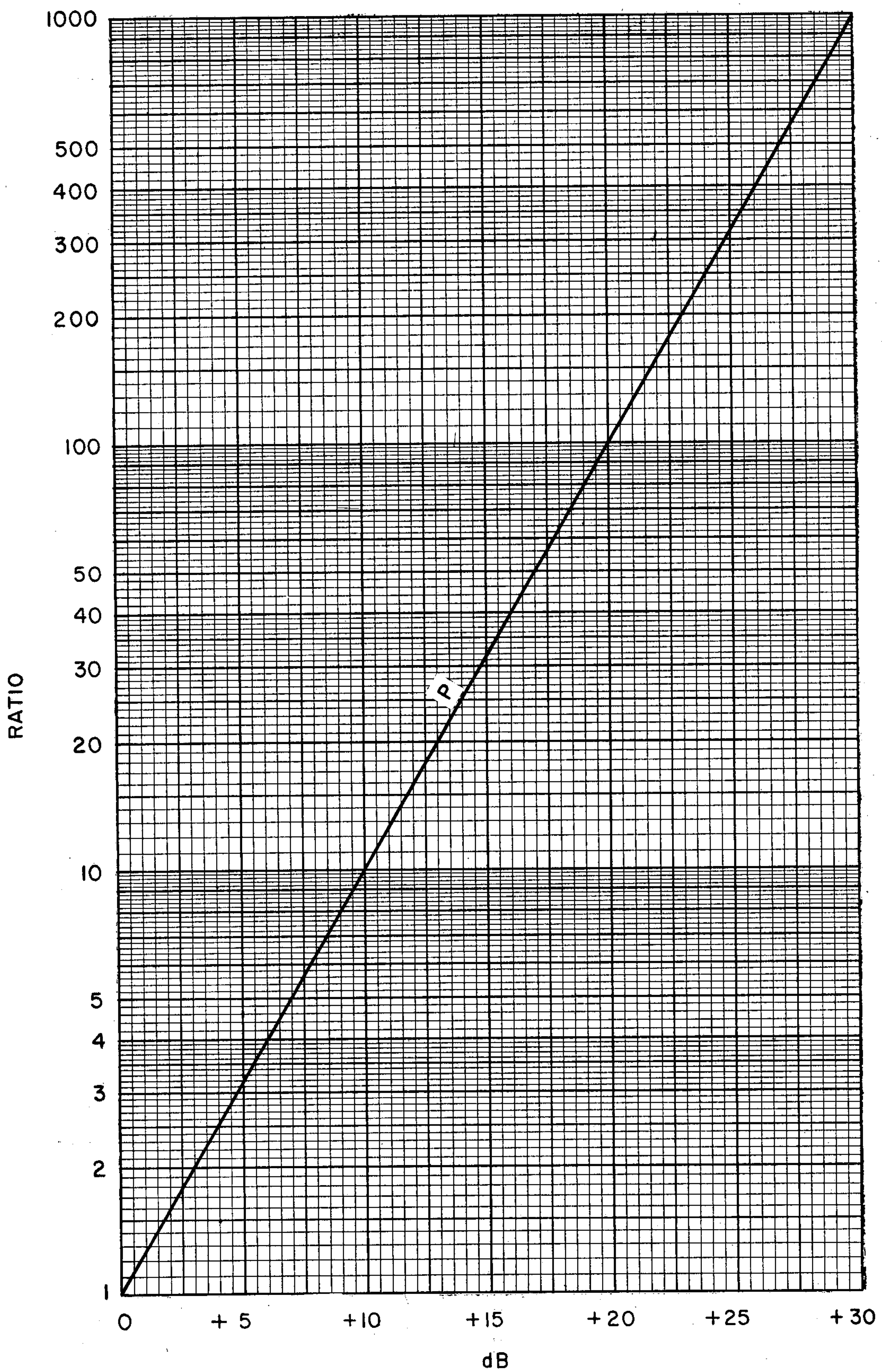


Figure C-3. Power Gain Ratio Versus Decibel Gain

C-7. THE dBm

It should be clearly understood that the term decibel does not, in itself, indicate power, but rather a ratio of, or comparison between, two power values. It is very often desirable, however, to express a single level or quantity of power, voltage, or current in decibels, as for example in transmissionline work, or in connection with the input or output of an amplifier. This can be done by using a fixed power level as a reference. The original standard reference level was 6 milliwatts (0.006 watt), but to simplify calculations a 1-milliwatt standard has been adopted and will be used hereafter as the reference level. (A few equipments use 1 watt as a standard.)

When 1 milliwatt is used as a reference level, the ratio is expressed in dBm's. The abbreviation dBm indicates decibels relative to a 1-milliwatt standard. Thus a pulsed radar transmitter having an average power output of 100 watts is said to have an average power output of 50 dBm. The conversion from power to dBm can be made as follows:

$$\text{Average power (dBm)} = 10 \log \frac{P_2}{P_1}$$

(Where P_1 is the reference value of .001 watt)

$$= 10 \log \frac{100}{.001}$$

$$= 10 \log 100{,}000 = 50 \text{ dBm}$$

Conversions from power to dBm can be made more readily by means of the graph shown in figure C-4. Reasonable care should be exercised in reading the graph, using the appropriate dBm scale for power in either milliwatts, watts, kilowatts, or megawatts.

C-8 CONVERSION OF POWER OR dBm TO MICROVOLTS ACROSS 50, 72, OR 600 OHMS

Both the decibel and the dBm are power ratios; their adaptation to voltage or current ratios are meaningful only if the impedance is the same for both values of voltage (or current) in the ratio. For example, in the formula for the ratio, expressed in decibels, of two voltages E_2 and E_1:

$$\text{dB} = 20 \log \frac{E_2}{E_1}$$

It would not be possible to obtain correct information on the gain of a given amplifier if the input impedance differed from that of the output. Hence, in circuits where the impedances differ, the expression for the decibel equivalents of the voltage ratios becomes:

$$\text{dB} = 20 \log \frac{E_2}{E_1} + 10 \log \frac{Z_1}{Z_2}$$

Where E_1 = input voltage
E_2 = output voltage
Z_1 = input impedance
Z_2 = output impedance

In calculations involving power in transmission lines, it is often required to convert extremely small amounts of power to dBm, or to convert either of these values to voltage, in microvolts, which would appear across a load impedance of 50, 72, or 600 ohms. Conversions from dBm or power in micromicrowatts to microvolts across 50, 72, or 600 ohms, or vice versa, may be made directly by means of table C-4.

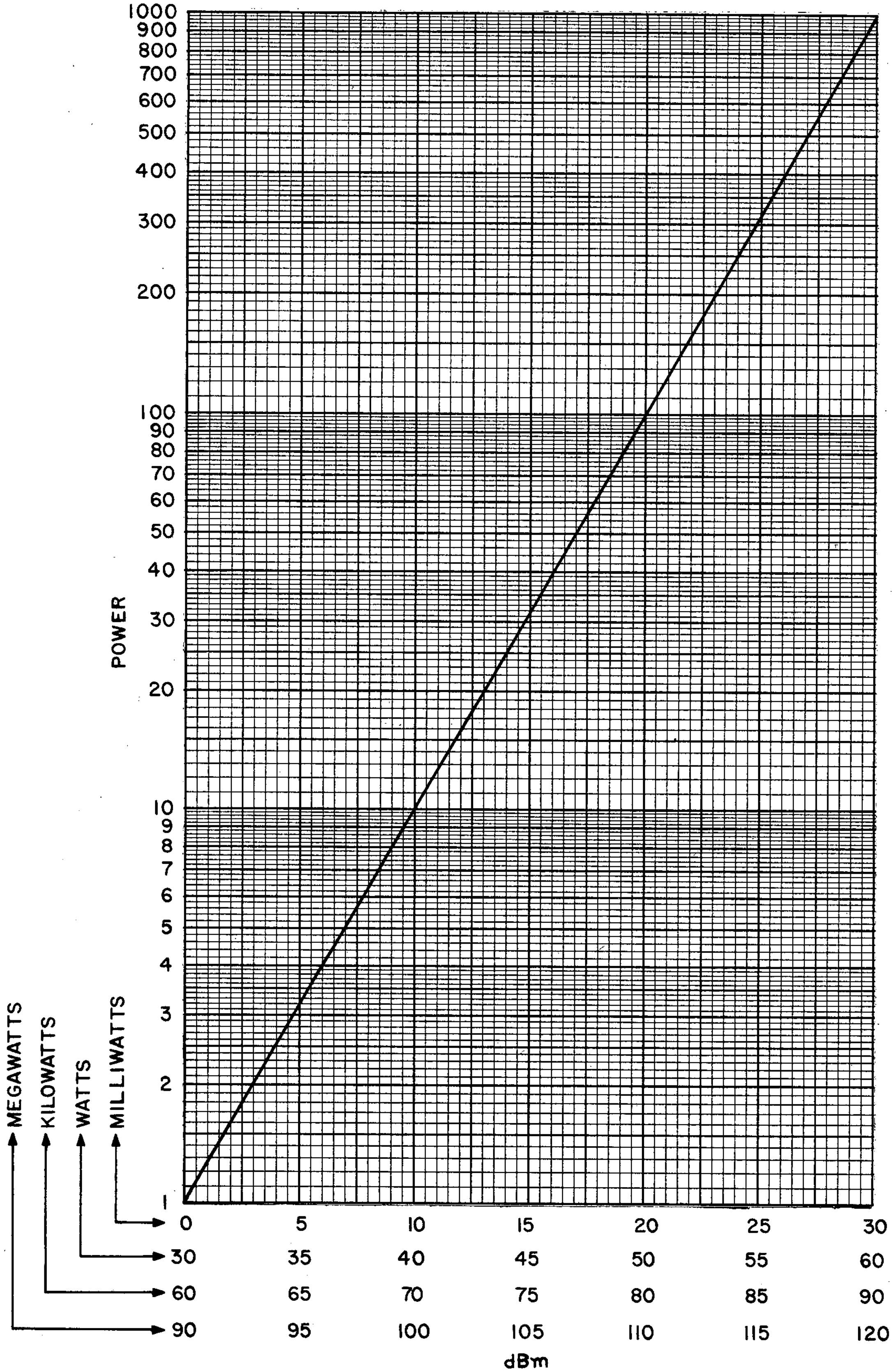


Figure C-4. Power Gain Ratio Versus dBm

Table C-4. dBm CONVERSION TABLE

dBm	MICROVOLTS ACROSS 50 OHMS	MICROVOLTS ACROSS 72 OHMS	MICROVOLTS ACROSS 600 OHMS	MICROMICROWATTS
0	223,607.0	268,328.0	774,596.7	1,000,000,000.0
-3	158,314.0	189,976.0	548,379.4	501,200,000.0
-6	112,094.0	134,513.0	388,265.4	251,250,000.0
-9	79,358.0	95,230.0	274,845.4	125,900,000.0
-12	56,192.0	67,431.0	194,576.5	63,100,000.0
-15	39,780.0	47,736.0	137,738.9	31,620,000.0
-18	28,174.0	33,809.0	97,519.2	15,850,000.0
-21	19,932.0	23,919.0	69,034.8	7,943,000.0
-24	14,112.0	16,934.0	48,873.3	3,981,000.0
-27	9,990.0	11,988.0	34,597.7	1,995,000.0
-30	7,073.0	8,487.0	24,494.9	1,000,000.0
-33	5,009.0	6,011.0	17,341.3	501,200.0
-36	3,546.0	4,256.0	12,276.8	251,200.0
-39	2,511.0	3,013.0	8,691.4	125,900.0
-42	1,776.0	2,132.0	6,153.0	63,100.0
-45	1,258.0	1,509.0	4,355.7	31,620.0
-48	890.0	1,068.0	3,083.8	15,850.0
-51	630.0	756.0	2,183.1	7,943.0
-54	446.0	536.0	1,545.5	3,981.0
-57	316.0	379.0	1,094.0	1,995.0
-60	223.607	268.328	774.597	1,000.0
-63	158.314	189.976	548.379	501.2
-66	112.094	134.513	388.265	251.25
-69	79.358	95.230	274.845	125.9
-72	56.192	67.431	194.576	63.1
-75	39.780	47.736	137.739	31.62
-78	28.174	33.809	97.519	15.85
-81	19.932	23.919	69.035	7.943
-84	14.112	16.934	48.873	3.981
-87	9.990	11.988	34.598	1.995
-90	7.073	8.487	24.495	1.0
-93	5.009	6.011	17.341	0.5012
-96	3.546	4.256	12.277	0.2512
-99	2.511	3.013	8.691	0.1259
-102	1.776	2.132	6.153	0.0631
-105	1.257	1.509	4.356	0.03162
-107	0.999	1.199	3.460	0.01995

APPENDIX D

REFERENCES

1. Control of Hazards to Health from Laser Radiation, TB MED 279 NAVMED P-5052-35, Department of the Army and the Navy, Washington, D.C.

2. Radiation Health Protection Manual, NAVMED P-5055

3. Laser and Microwave Hazards Course Manual, U.S. Army Environment Hygiene Agency

4. Methods of Reduction of Shipboard RF Burn Hazards, NAVSHIPS 0967-317-7010