ORION • SERVICE digest

issue 46 JULY 1988
LOCKHEED AERONAUTICAL SYSTEMS COMPANY

P-3 ORION AIRCRAFT ANTENNAS

ISSUE 46 JULY 1988
LOCKHEED AERONAUTICAL SYSTEMS COMPANY

TABLE OF CONTENTS

editor | **WAYNE CRADDUCK**
art and production by | **ALLEN LUDLOFF**

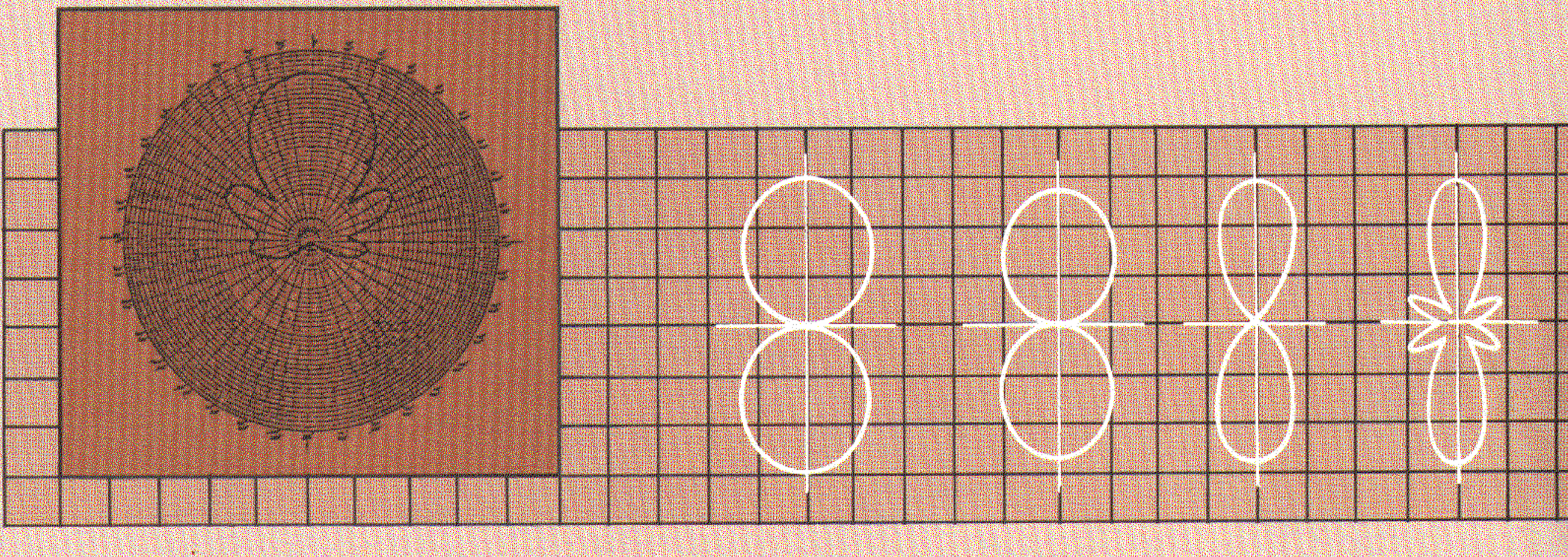
FRONT AND BACK COVERS

Patrol Squadron Sixteen, prominently known as the "War Eagles", is based at NAS Jacksonville, Florida. Its primary mission of anti-submarine warfare (ASW) is to detect, track, and if necessary, destroy hostile submarines. Secondary missions include anti-surface warfare, mine-laying, shipping surveillance, reconnaissance, and search and rescue.

VP-16 was commissioned at NAS Cecil Field, Jacksonville, Florida in May 1946 as Naval Air Reserve Training Squadron VP-ML-56 and equipped with six PBY Catalina amphibians. Redesignated Patrol Squadron 741 in 1949, the squadron continued to operate in reserve status. With the outbreak of hostilities in Korea in 1951, the squadron's Catalina aircraft were replaced with Lockheed P2V-2 Neptune patrol bombers. In February 1953, the squadron was redesignated Patrol Squadron Sixteen and became part of the regular Navy.

During their colorful history, the War Eagles have performed operations on both the east and west coasts, and throughout the world. These activities include Operation Springboard exercises in the Caribbean, and the UNITAS XI, XIII, XX, XXII, and XXVII exercises around South America. In 1961, VP-16 was part of the Project Mercury Space Capsule Recovery Force. A VP-16 Neptune was the first aircraft over LCOL John H. Glenn's "Friendship Seven" capsule after splashdown.

In 1964, VP-16 transitioned from its P-2 Neptunes to the Lockheed P-3A Orion, and in 1973 to the P-3C Orion. The War Eagles were awarded the Battle "E" for readiness and outstanding performance in 1973 and 1974.



In November 1982, during preparation for a split deployment to Lajes, Azores and Rota, Spain, VP-16 won the Top Bloodhound Award for torpedo placement accuracy. VP-16 also set new COMPATWING ELEVEN records with its Operational Readiness Evaluation. It achieved the highest overall ORE grade in Wing history, with individual records in seven of the top ten graded categories.

VP-16 won the COMPATWING ELEVEN Retention Cup for both halves of FY-1982, the COMPATWING ELEVEN Bronze Anchor Award, and the COMNAVAIRLANT Silver Anchor Award. While deployed, the War Eagles won two COMSIXTHFLT "Hook-Em" Awards for ASW excellence in the Mediterranean. The squadron also received the Meritorious Unit Commendation for ASW prosecutions conducted in the Lajes ASW sector, and the Navy Expeditionary Medal for support of U.S. forces in Lebanon.

In June 1983, VP-16 returned to NAS Jacksonville and became the first squadron at that site to transition to the P-3C Update II.5 aircraft. Patrol Squadron Sixteen was nominated by COMPATWING ELEVEN and received the Battle Efficiency "E" for excellence during CY-1983. That year the squadron also won the Golden Wrench Award for Maintenance Excellence, the COMINEWARCOM "Miner of the Year" designation, and the COMPATWING ELEVEN "Top Gun" Award for all facets of weapon loading and delivery excellence.

The War Eagles deployed to Keflavik, Iceland in March 1984, where the squadron earned yet another Meritorious Unit Commendation for ASW excellence. Throughout their Keflavik deployment, and later during the at-home cycle in Jacksonville, the outstanding performance of VP-16's Maintenance Department earned the squadron a second consecutive Golden Wrench Award.

While preparing for their next deployment to Bermuda, the War Eagles led COMPATWING ELEVEN squadrons in every competitive category, scoring the highest overall average on the Operational Readiness Exercises and completing an unparalleled record of 50 successful torpedo exercises (TORPEX). The War Eagles also were first in the Wing in retention during the last two quarters of 1984.

In August 1985, the War Eagles deployed to Bermuda, where they won the Top Bloodhound Award for 1985. Arriving back in Jacksonville in February 1986, VP-16 received an unprecedented third consecutive Golden Wrench Award for Maintenance Excellence. In June 1986, the War Eagles were awarded both the CINCLANTFLT and COMNAVAIRLANT Athletic Excellence Awards for 1985. In October 1986, VP-16 was awarded the Coast Guard Meritorious Unit Commendation for their part in HAT TRICK II operations.

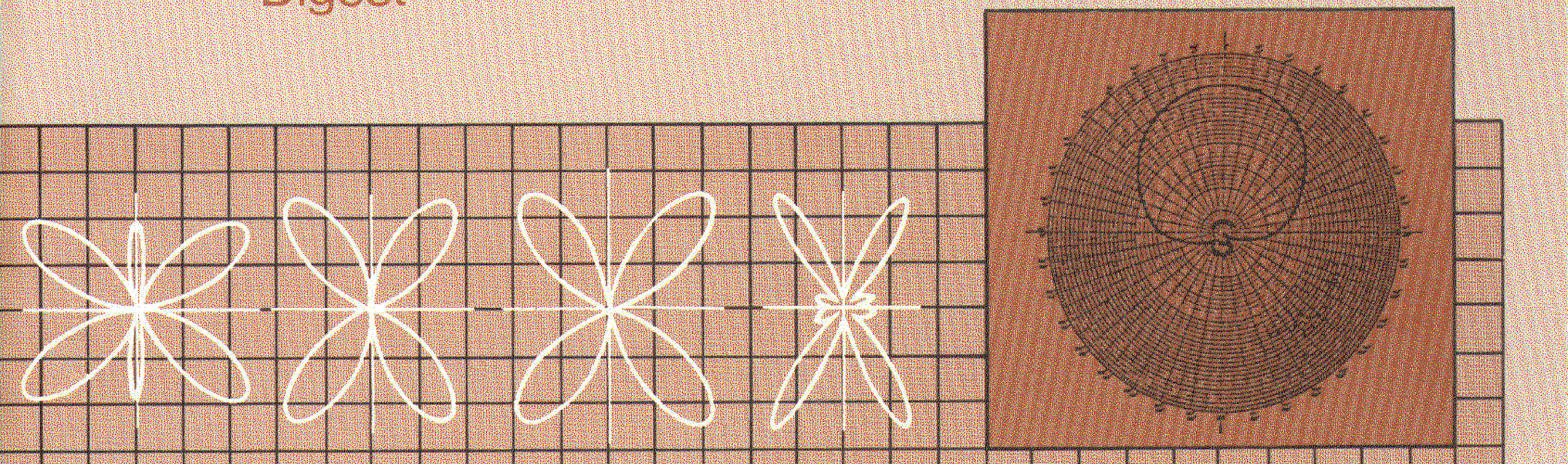
Patrol Squadron Sixteen deployed to Sigonella from January to July 1987, and participated in numerous National and NATO exercises. While supporting three Carrier Battle Groups, the War Eagles logged over 4500 flight hours and received the COMSIXTHFLT "Hook-Em" Award for ASW excellence. Returning home, VP-16 hit the deck running, achieving an outstanding Post-Deployment Corrosion Inspection, a superb AIRLANT NATOPS evaluation, an error-free Navy Technical Proficiency Inspection, and completed over 22 years and 158,000 hours of accident-free flying. VP-16 also received its second Coast Guard Meritorious Unit Commendation for Winter Law Enforcement Operations. With honor and proud tradition, the "War Eagle" Team stands ready to continue dedicated service in defense of our great nation.

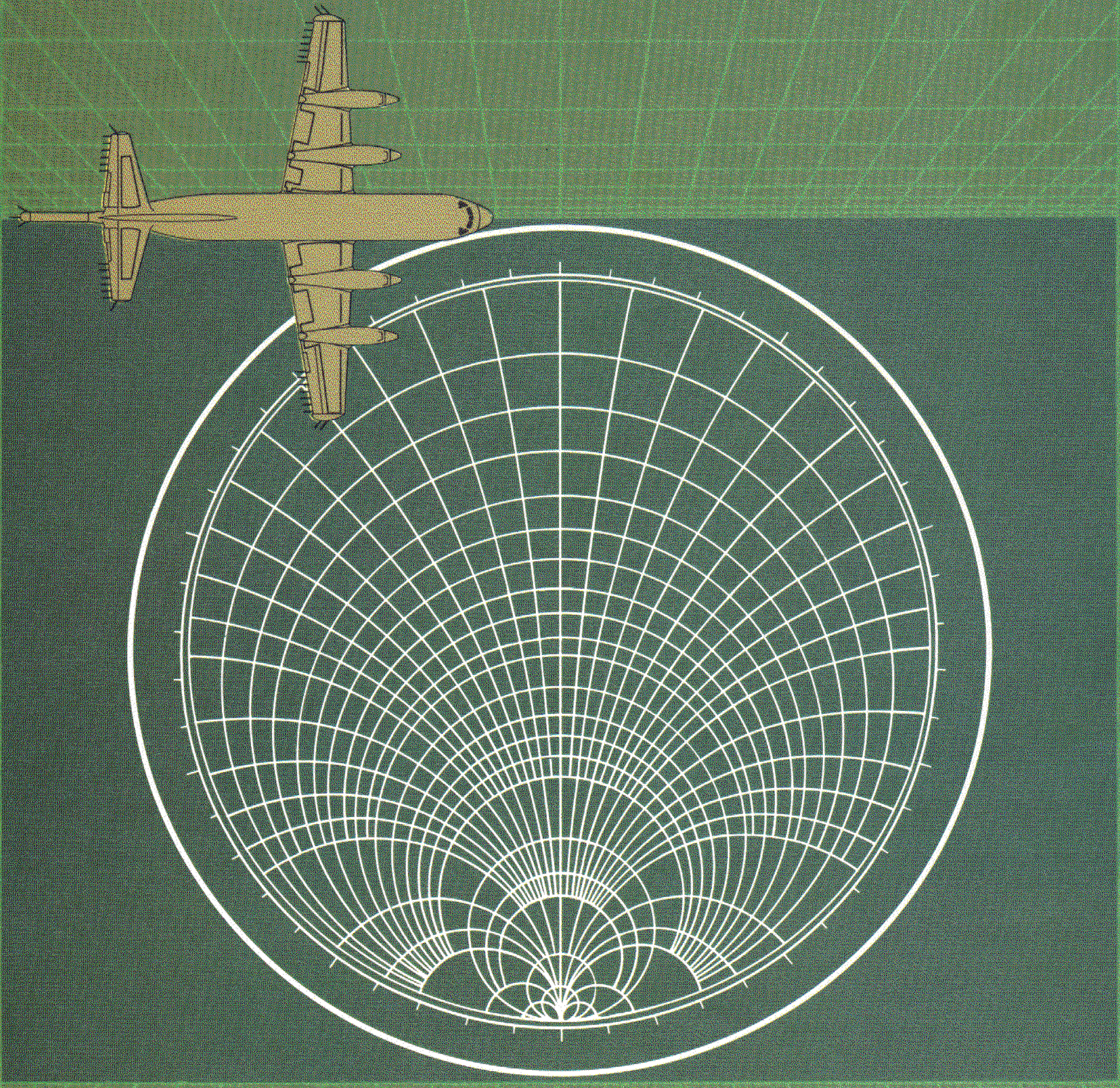
The Lockheed Orion Service Digest is published by Lockheed Aeronautical Systems Company, Burbank, California. Material is not officially approved by the FAA or any of the military services unless specifically noted. Military personnel are advised that direct use of the information in this publication may be restricted by directives in their organization. Material contained herein is not classified, but strictures against unauthorized and indiscriminate dissemination of military information apply. Republication of material is not sanctioned unless written permission is granted by Lockheed Aeronautical Systems Company. Regulations require that republished material conform to the latest information and changes.

COPIES REQUIRED OR CHANGE OF ADDRESS – Please send your name; present address; occupation; your organization's name; and, if applicable, your old address as imprinted on a Digest envelope to:

YOUR LOCAL LOCKHEED AERONAUTICAL SYSTEMS COMPANY – HEADQUARTERS OPERATIONS SERVICE REPRESENTATIVE, OR LOCKHEED ORION SERVICE DIGEST, DEPT. 64-38, BURBANK, CALIFORNIA 91520-6438.

Lockheed
ORION
Service
Digest





P-3 ORION

AIRCRAFT ANTENNAS

by E. Rockwell James
Communications Design Specialist
with Nadathur S. Jayaraman, Group Engineer
and David A. Lopez, Design Engineer

INTRODUCTION

Every decade more electronic equipment is installed on modern aircraft. By necessity, aircraft have been equipped with a proliferation of antennas to connect these devices to the outside world. This has resulted in a gradually decreasing amount of space available on the aircraft exterior for future installation of antennas. The P-3 Orion aircraft has been subject to this electronic evolution, since it is engaged in many varied missions that use these new equipments.

When a new communication or radio navigation system is installed in an aircraft, the designer must find some place on the aircraft exterior to install an antenna for that system. In fact, in a recent Communications ECP installation on the P-3 Orion, it was necessary to use a multifunction antenna that combines three bandwidths (VHF, UHF, and L-band) and two entirely different functions. Use of a multifunction antenna was necessary because there was no more useable space on the aircraft skin available for the additional antenna required to perform those particular functions. In the future, P-3 Orion aircraft will be equipped with the Global Positioning System (GPS) and Satellite Communications (SATCOM). These new systems will require specialized antennas that will again occupy more of the aircraft's diminishing "real estate." Consequently, system engineers, operators and maintenance personnel must make every effort to get the maximum performance from every antenna on today's aircraft.

This article begins with a discussion of basic antenna theory, followed by a discussion of the various types of antennas. Next is a section that describes the types of antennas that are installed on the P-3 Orion aircraft, followed by sections that discuss antenna location on aircraft, antenna cable design, electromagnetic considerations, antenna scale modeling, the care of antenna systems, and an examination of antenna problems and suggested remedies. The article concludes with a brief look at antennas of the future.

Discussions on antenna maintenance have been included in this article, and in some instances maintenance suggestions and tips have been offered. The reader is cautioned that these discussions and suggestions are presented solely to help the reader understand the reasons for proper antenna maintenance. It must be emphasized that maintenance personnel must strictly observe the procedures and requirements presented in the applicable NAVAIR maintenance publications.

ANTENNA THEORY

This article was prepared to help the reader understand why certain antennas have been selected for P-3 Orion avionics systems, and the reasons for installation specifications and maintenance. It discusses the basic properties of antennas and certain related phenomena. A few basic formulas have been included to give the reader a working understanding of antennas and their operation. An in-depth discussion of antenna theory is beyond the scope of this article, but several good textbooks are generally available for those who wish to pursue the subject.

RADIO WAVES, PROPAGATION, AND POLARIZATION

The reader must have a basic understanding of radio waves, signal propagation, and signal polarization to understand how antennas function. The phenomenon of wave propagation makes it possible to transmit information from one location to another via the medium of air. Several theories of wave propagation have been proposed over the past two centuries. James C. Maxwell proposed the most popular theory in 1865. He stated that all waves traveled through a substance that he called *ether.* According to Maxwell, ether permeated all space and matter, and it was this medium that made possible the transmission of radio and light waves. For over a century, scientists have tried to prove the existence of ether, but without success. The past decade has seen the term "ether" virtually vanish from scientific journals. Recently, H. C. Dudley, working at the University of Illinois, developed a theory that states that all space and matter are permeated by a substance defined as the *neutrino,* the existence of which can be demonstrated by experiment. Dudley's

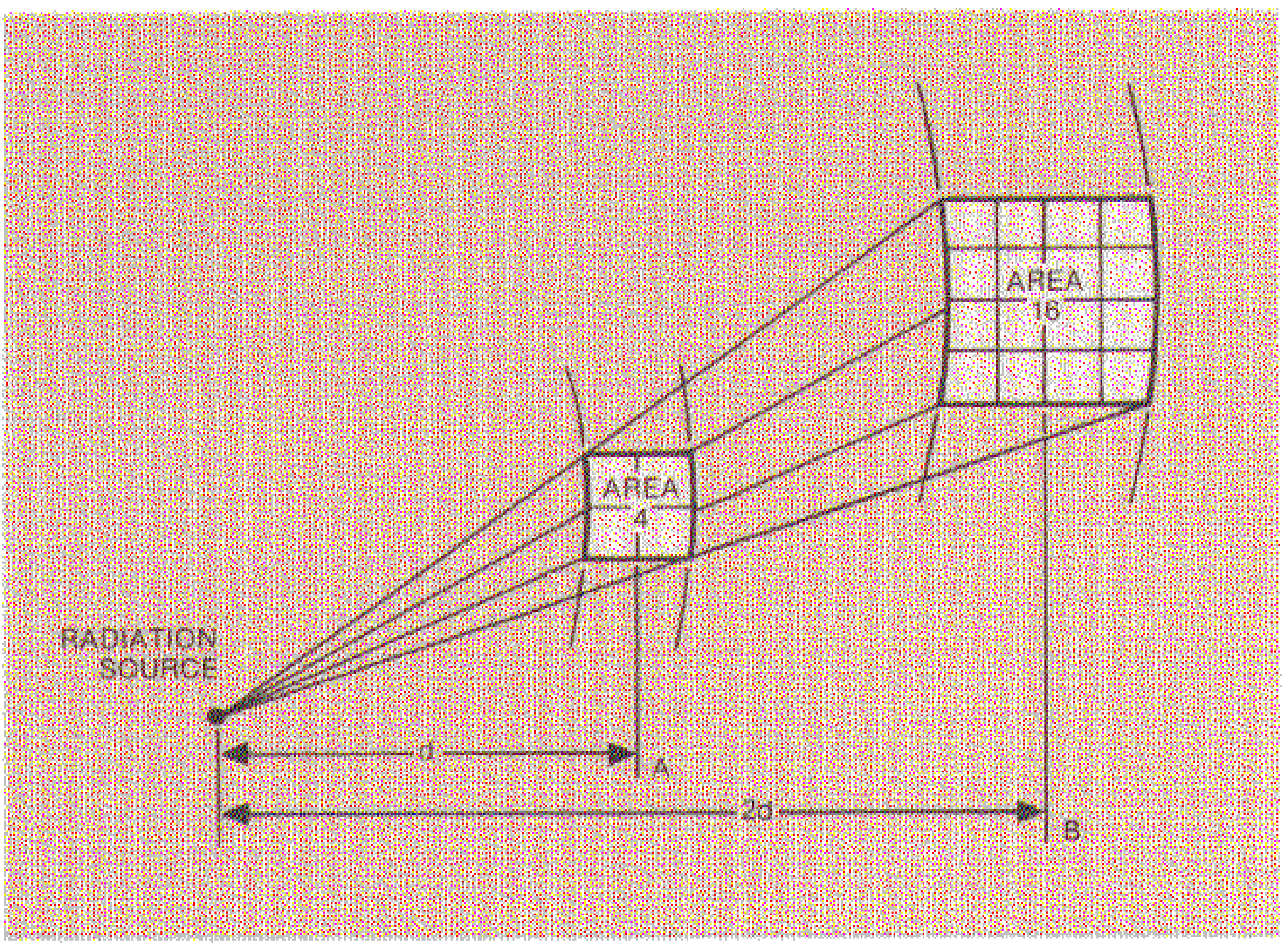


Figure 1. Radiated Energy Strength Decreases with Distance

theory seems to have merit, and scientists are now looking to the neutrino as a possible answer to the riddle of how radio waves are passed through the atmosphere.

Radio Waves Radio waves can be shown to transmit energy by the relation of the Square Law, or $E_p = E_s/d^2$. In this formula, E_p is the radiated voltage at the point of measurement, E_s is the radiated voltage at the source or at the previous point against which the measurement is to be compared, and d is the distance between the two points. This is illustrated in Figure 1, which shows that as energy is radiated from a point, it expands to cover an area that is four times greater each time the distance is doubled from the point of previous measurement. For example, 1 volt of radiated voltage at a specific point is reduced to 0.25 volt at any point that is twice as far away. This explains why receivers with greater sensitivity are required to detect the weaker signals of radio waves transmitted from a distant point, and why antenna system performance must be maintained at the highest possible level.

A radio wave is composed of E (electrical) and H (magnetic) fields as shown in Figure 2. They are at right angles to each other, and coexist as the wave is propagated from the transmitting antenna. James C. Maxwell developed equations to mathematically expand the relationship between the E and H fields. The mathematics of this relationship is complex and not within the scope of this article. However, it is this relationship that leads the designer to select a particular type of antenna for a specific job. What the reader *should* observe is that the radio wave is composed of a field that can be resolved into "E" and "H" components. Therefore, when an antenna is labeled an "E-field antenna", one knows that it is designed to maximize reception of the E-field component of the radio wave. Conversely, an H-field antenna is designed to maximize reception of the H-field component. Omega navigation systems, for example, can be designed to operate with either type of radio wave component, but are mainly H-field systems. Antennas designed to operate with the E-field component are more susceptible to the interference from precipitation static (P-static) noise, since P-static is a form of voltage interference.

Propagation Radar and radio communication are at the mercy of the atmosphere, since that is the medium used to link the transmitting station and the receiver. The atmosphere is an uncontrollable medium that cannot be precisely defined. Its characteristics vary with time-of-day, season, sunspot cycle, and with geographic location. However, these variations are reasonably predictable. Fortunately, the science of radio communication is so mature, that much data has been accumulated about atmospheric conditions. This data has enabled engineers to optimize communication for improved connectivity.

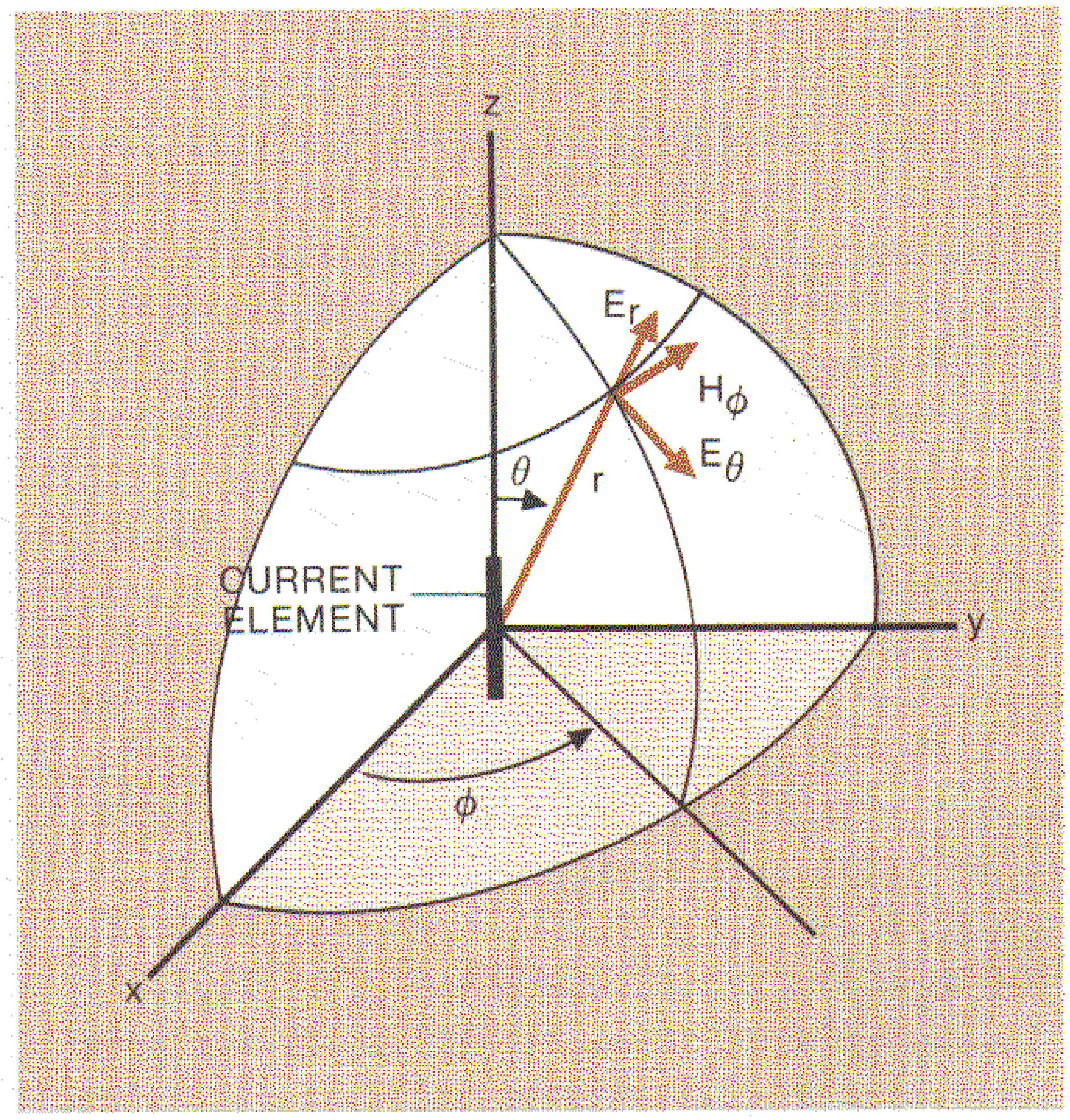


Figure 2. Electrical (E) and Magnetic (H) Fields

The atmosphere affects radio waves in different ways, depending on their frequency (see Figure 3). Very low frequency (VLF) radio waves tend to hug the earth's surface, and they can even be transmitted to other locations on the ground or at sea by using the earth's surface as the medium. Currently, very high frequency (VHF) waves are used for line-of-sight communication and for meteor burst communication. During meteor burst communication, VHF waves are reflected off the ionized trails that meteors produce when they enter the atmosphere. Ultra high frequency (UHF) communication is strictly line-of-sight, so it is used for close communication or with satellites. Radio waves do not readily pass through large solid objects or metallic surfaces, but lower frequency radio waves can be bent or bounced off reflective media. These latter phenomena are used in many forms of electronic transmission to achieve extended-range communication.

The lower frequency radio waves, primarily in the band of from 2 MHz to 70 MHz, are most influenced by atmospheric conditions and solar activity. These two phenomena subject high frequency (HF) communications to considerable noise and interference. Unpredictable performance has encouraged operators to replace HF communication with SATCOM for reliable long-range communication. However, HF radio is being restored as a dependable long-range communications tool by the application of Programmable Optimum Atmospheric Path Selection. Specialized equipment and operator training are required to take advantage of these new HF radio communication techniques. The National Bureau of Standards broadcasts a summary of solar activity every hour on radio station WWV.

Polarization The polarization of a radio wave is determined by the orientation of its E-field, as shown in Figure 2. The electrical field vector is factored into its x and y components, and the orientation of these components determines the radio wave polarization. Polarization may be horizontal, vertical, circular, or elliptical. The basic form is elliptical, with the others being a derivative form of elliptical. Horizontal and vertical polarization are linear forms of polarization, and occur when the E_x and E_y components of the E-field are superimposed. This linear field is propagated in-line with either the surface plane of the earth (horizontal) or perpendicular to it (vertical). Circular polarization occurs when the E_x and E_y components are 90 degrees out of phase. Most communication radio transmissions use linear polarization, although satellite communications use circular polarization to minimize the effect of undesired signals reflected off the earth and other

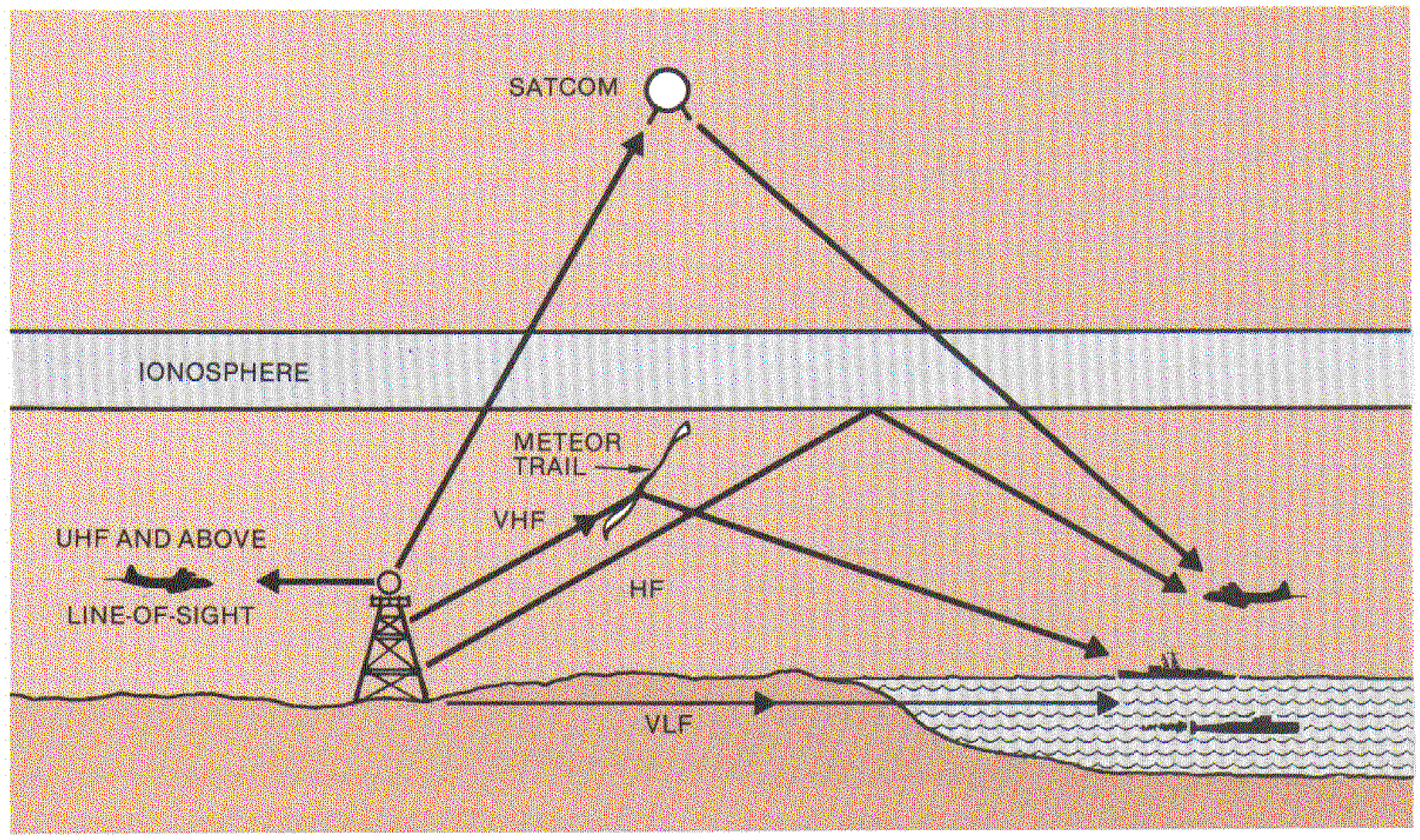


Figure 3. The Relationship of Frequency to Radio Wave Propagation

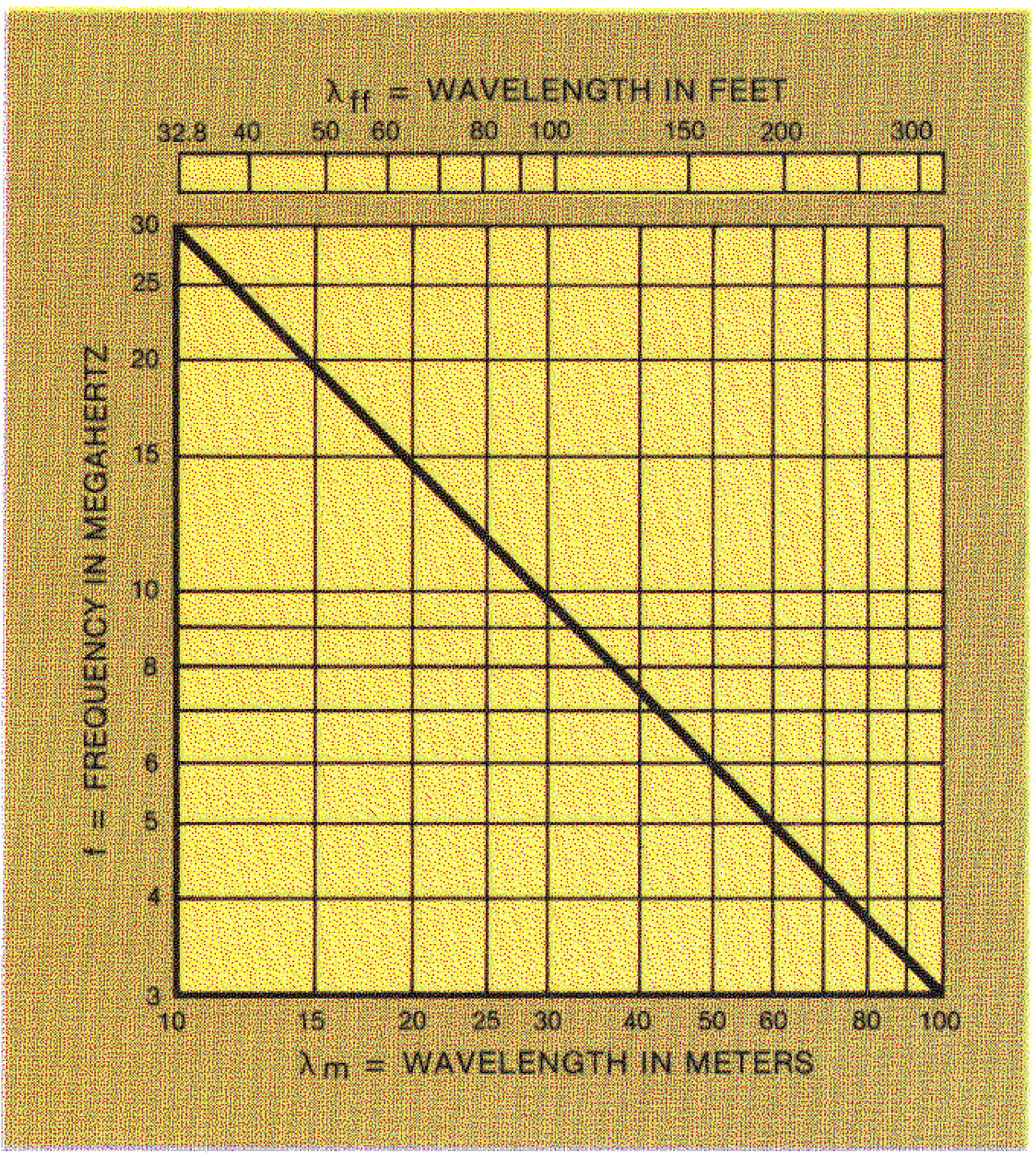


Figure 4. Frequency Versus Wavelength Nomograph

surfaces. A circularly-polarized antenna can be either right-hand or left-hand polarized, with good rejection of reverse-sense polarized signals.

Polarization is important, because the receiving antenna must have the same polarization as the transmitting antenna in order for the system to obtain a maximum transfer of radiated energy. A polarization mismatch will produce a power transfer loss, which can be defined as the polarization loss factor (PLF). Theoretically, if the PLF is 0, no power will be transferred; if the PLF is 1, maximum power will be transferred. A PLF of 1 occurs when identical polarization exists, while a PLF of 0 results when there is total polarization mismatch. In practical radio transmission, totality never exists and some polarization mismatch is inevitable. The antenna designer must minimize polarization losses by careful consideration of those factors that influence polarization shift in the transmitted signal. Among these factors are antenna mount stability, atmospheric effects, and interfering reflective obstacles between the receiving and transmitting antennas.

WAVELENGTH AND FREQUENCY The foundation of antenna design is the basic formula:

$$\lambda = c/f$$

This formula simply states that the wavelength (λ) of any radio wave is equal to the speed of light (c) divided by the frequency (f). A nomograph of frequency versus wavelength is shown in Figure 4. This relationship explains why the antenna gets smaller as the radio frequency increases. It also explains why more complex antennas can be used at the higher radio frequencies, since less space is required for the multi-element antenna configurations.

FREQUENCY ALLOCATION The radio frequency spectrum is divided into segments called bands for easier frequency identification. These basic frequency band designations are listed in Table I, while Table II lists the microwave or radar letter-bands and sub-bands that are used to distinguish the higher frequencies. The P-3 aircraft uses a significant portion of the frequency spectrum, with equipment operating from 10 kHz to 10 GHz. Table III lists P-3 aircraft avionics equipment, the antennas designed for these systems, and their operational frequency bands.

GROUND PLANE The scientific model of an antenna suspended in free space is used only for theoretical analysis. In real-life applications, the antenna requires a surface or plane from which the radiated signal is reflected. This surface is called the *ground plane.* The earth's surface is the primary ground plane for antennas located close to the earth. For aircraft antenna analysis, the airframe itself must be considered as the ground plane when the length of the aircraft is a significant percentage of the radio signal wavelength.[1] Certain antennas, such as the vertical monopole, require a ground plane to achieve optimum performance. In these cases, a high-quality ground plane is essential. To be effective, a ground plane should be at least 5 wavelengths in diameter (or if square, 5 wavelengths on a side).

Some antennas actually have a "built-in" ground plane. This type of antenna operates with a much smaller ground plane, because it is a functional part of the antenna. The turnstile antenna is one

---

[1] This is true for all frequency bands except the HF band.

Table I. Frequency Band Designations

BAND NO.	FREQUENCY RANGE	METRIC SUBDIVISION	ADJECTIVAL DESIGNATION
2	30 to 300 Hz	Megametric waves	ELF — Extremely low frequency
3	300 to 3000 Hz	———	VF — Voice frequency
4	3 to 30 kHz	Myriametric waves	VLF — Very-low frequency
5	30 to 300 kHz	Kilometric waves	LF — Low frequency
6	300 to 3000 kHz	Hectometric waves	MF — Middle frequency
7	3 to 30 MHz	Decametric waves	HF — High frequency
8	30 to 300 MHz	Metric waves	VHF — Very-high frequency
9	300 to 3000 MHz	Decimetric waves	UHF — Ultra-high frequency
10	3 to 30 GHz	Centimetric waves	SHF — Super-high frequency
11	30 to 300 GHz	Millimetric waves	EHF — Extremely-high frequency
12	300 to 3000 GHz (or 3 THz)	Decimillimetric waves	———

Table II. Letter Designations for Microwave Bands

Sub-band	Frequency in GHz	Wavelength in cm
P-BAND		
	0.225	133.3
	to	
	0.390	76.9
L-BAND		
	0.390	76.9
P	to	
	0.465	64.5
c	to	
	0.510	58.8
l	to	
	0.725	41.4
y	to	
	0.780	38.4
t	to	
	0.900	33.3
s	to	
	0.950	31.6
x	to	
	1.150	26.1
k	to	
	1.350	22.2
f	to	
	1.450	20.7
z	to	
	1.550	19.3
S-BAND		
	1.55	19.3
e	to	
	1.65	18.3
f	to	
	1.85	16.2
t	to	
	2.00	15.0
S-BAND (Continued)		
	2.00	15.0
c	to	
	2.40	12.5
q	to	
	2.60	11.5
y	to	
	2.70	11.1
g	to	
	2.90	10.3
s	to	
	3.10	9.68
a	to	
	3.40	8.83
w	to	
	3.70	8.11
h	to	
	3.90	7.69
z*—	to	
	4.20	7.15
d	to	
	5.20	5.77
C-BAND		
X-BAND		
	5.20	5.77
a	to	
	5.50	5.45
q	to	
	5.75	5.22
y*—	to	
	6.20	4.84
d	to	
	6.25	4.80
b	to	
	6.90	4.35
r	to	
	7.00	4.29
X-BAND (Continued)		
	7.00	4.29
c	to	
	8.50	3.53
l	to	
	9.00	3.33
s	to	
	9.60	3.13
x	to	
	10.00	3.00
f	to	
	10.25	2.93
k	to	
	10.90	2.75
K-BAND		
	10.90	2.75
p	to	
	12.25	2.45
s	to	
	13.25	2.26
e	to	
	14.25	2.10
c	to	
	15.35	1.95
u#	to	
	17.25	1.74
t	to	
	20.50	1.46
q#	to	
	24.50	1.22
r	to	
	26.50	1.13
m	to	
	28.50	1.05
n	to	
	30.70	0.977
l	to	
	33.00	0.909
K-BAND (Continued)		
	33.00	0.909
a	to	
	36.00	0.834
Q-BAND		
	36.0	0.834
a	to	
	38.0	0.790
b	to	
	40.0	0.750
c	to	
	42.0	0.715
d	to	
	44.0	0.682
e	to	
	46.0	0.652
V-BAND		
	46.0	0.652
a	to	
	48.0	0.625
b	to	
	50.0	0.600
c	to	
	52.0	0.577
d	to	
	54.0	0.556
e	to	
	56.0	0.536
W-BAND		
	56.0	0.536
	to	
	100.0	0.300

*C-Band includes S_z through X_y (3.90 - 6.20 Hz)

#K-Band includes K_u through K_q (15.35 - 24.50 GHz)

Table III. P –3 Avionics Systems and Antennas, and Their Operational Frequency Bands

P-3 COMMUNICATION SYSTEMS

SYSTEM	CONFIGURATION	ANTENNA	FREQUENCY	MANUFACTURER	ANTENNA TYPE	COMMENTS
HF COMMUNICATION SYSTEMS						
AN/ARC-94	P-3A/B	NO. 1: LAC P/N 939149-105	HF RANGE	LOCKHEED	LONGWIRE	
		NO. 2: LAC P/N 939149-103				
AN/ARR-41	P-3A/B	SEE ARC-94		SEE ARC-94		CURRENT WITH ARC-94
AN/ARC-142	P-3C PRE-U/D III	LAC P/N 941238-101	HF RANGE	LOCKHEED	LONGWIRE	
AN/ARC-142	P-3C U/D II	NO. 1: LAC P/N 941238-103	HF RANGE	LOCKHEED	LONGWIRE	
		NO. 2: LAC P/N 941238-105				
AN/ARC-161	P-3C U/D III					
VHF COMMUNCATION SYSTEMS						
AN/ARC-84	P-3A/B	LAC P/N 808312-5	VHF RANGE	LOCKHEED	SLOT	
AN/ARC-101	YP-3C	LAC P/N 808312-101	VHF RANGE	LOCKHEED	SLOT	
AN/ARC-101	P-3C PRE-U/D III	LAC P/N 949880-101	VHF RANGE	LOCKHEED	SLOT	TAILCAP
AN/ARC-197	P-3C U/D II.5-III	LAC P/N 949880-101	VHF RANGE	LOCKHEED	SLOT	TAILCAP
UHF COMMUNICATION SYSTEMS						
AN/ARC-52	P-3A/B	AT-256/ARC	UHF RANGE		BLADE	TOP AND BOTTOM
AN/ARC-143	P-3C PRE-U/D III	NO. 1: AT-879/ARC	UHF RANGE	TRANSCO	BLADE	TOP
		NO. 2: LAC P/N 740692-101			BLADE	BOTTOM
AN/ARC-143B	P-3C U/D III	AT-879/ARC	UHF RANGE	TRANSCO	BLADE	BOTTOM
		NO. 1.: AT 879/ARC				TOP
		NO. 2.: LAC P/N 740692-101				TAILCAP
AN/ARC-182	P-3A/B	AS-3191/A GFE	UHF/VHF	DAYTON GRANGER	BLADE	BOTTOM
	P-3C	AS-3775/A		DORNE & MARGOLIN		
AN/ARC-187	P-3C		UHF RANGE	TRANSCO	BLADE	TOP/BOTTOM

P-3 NAVIGATION SYSTEMS

SYSTEM	CONFIGURATION	ANTENNA	FREQUENCY	MANUFACTURER	ANTENNA TYPE	COMMENTS
TACAN SYSTEMS						
AN/ARN-21A	P-3A/B	AT-741/A	XMIT: 1025-1150 MHz	GFE	BLADE	
			RCV: 962-1213 MHz			
AN/ARN-52(V)	P-3C PRE-U/D III	AT-741/A	XMIT: 1025-1150 MHz	GFE	BLADE	
			RCV: 962-1213 MHz			
AN/ARN-84	P-3C S/N 5633, 5640 & UP	M25708/A-01	XMIT: 1025-1150 MHz		BLADE	TOP
			RCV: 962-1213 MHz			
		AT-741/A	XMIT: 1025-1150 MHz	GFE	BLADE	BOTTOM
			RCV: 962-1213 MHz			
AN/ARN-118	P-3C U/D III	SAME AS AN/ARN-84				

Table III. P–3 Avionics Systems and Antennas, and Their Operational Frequency Bands (Cont'd)

P-3 NAVIGATION SYSTEMS

SYSTEM	CONFIGURATION	ANTENNA	FREQUENCY	MANUFACTURER	ANTENNA TYPE	COMMENTS
UHF DIRECTION FINDING SYSTEMS						
AN/ARA-25A	P-3A/B; P-3C S/N 5501-5507, & 5509-5524	AS-578B/ARA-25	UHF RANGE	GFE	FOLDED DIPOLE	
AN/ARA-50	P-3C S/N 5508, 5525 & UP	AS-909/ARA-48	UHF RANGE	COLLINS	FOLDED DIPOLE	
ADF LOOP SYSTEMS						
DF-202	P-3A/B	LAC P/N 616211-13	190-1750 kHz	COLLINS	LOOP	
AN/ARN-83	P-3C - ALL U/D	AS-1863/ARN-83	190-1750 kHz	COLLINS	LOOP	
ADF SENSE SYSTEMS						
DF-202	P-3A/B	LAC P/N 616211-13	225-400 MHz	COLLINS	SENSE	
AN/ARN-83	P-3C - ALL U/D	AS-2611/APN-201	225-400 MHz	HOFFMAN ELECTRONICS	SENSE	
LORAN SYSTEMS						
AN/APN-70	P-3A/B	SEE HF-1 & HF-2	1050, 1850, 1900 kHz	SEE HF-1 & HF-2	LONGWIRE	REPLACED BY OMEGA
AN/ARN-81	P-3C S/N 5501-5619	AS-2611/APN-201	1050, 1850, 1900 kHz	HOFFMAN ELECTRONICS	SENSE	
OMEGA NAVIGATION SYSTEM						
AN/ARN-99(V)	P-3C - ALL U/D	AS-2623/ARN-99	10.2, 11.33, 13.6 kHz	NORTHROP	LOOP	
LTN-211	P-3A/B & P-3C NUD	ANTENNA/ COUPLER UNIT	10.2, 11.05, 11.33 & 13.6 kHz	LITTON AERO PRODUCTS	LOOP	RETROFIT
MARKER BEACON SYSTEMS						
AN/ARN-32	P-3A/B & P-3C PRE-U/D III	AT-536/ARN	75 MHz	GFE	CAVITY	
VIR-31A	P-3C U/D III					
RADAR ALTIMETER SYSTEMS						
AN/APN-141(V)	P-3A/B & P-3C PRE-U/D III	AS-1233/APN-141	4200 - 4400 MHz	GFE	CAVITY-FED SLOT	
AN/APN-194	P-3C U/D III					
VOR SYSTEMS						
NVA-22A	P-3A/B	RA-21A/NVA-22A	108.0 - 117.95 MHz		BALANCED LOOP	
AN/ARN-87	P-3C NUD, U/D I, & U/D II	AS-1342A		DORNE & MARGOLIN		
		LAC P/N 949880-101		LOCKHEED		
VIR-31A	P-3C U/D II.5 & U/D III	SEE AN/ARN-87		SEE AN/ARN-87		
DOPPLER RADAR SYSTEMS						
AN/APN-153	P-3A/B	AS-1350/APN-153	13.275 - 13.375 GHz	SINGER & LORAL	PLATFORM	
AN/APN-187	P-3C S/N 5501 & UP	RT-890/APN-187		SINGER	PHASED ARRAY	LAC P/N 671341-101
AN/APN-227	P-3C PRE-U/D III	RT-1358/ARN-227		CANADIAN MARCONI		LAC P/N 673957-101
AN/APN-187	P-3C U/D III					
GLIDESLOPE SYSTEMS						
GLIDESLOPE	P-3 C PRE-U/D III	LAC P/N 615785	329.5 - 335.0 MHz	COLLINGS RADIO	DIPOLE	
ARINC-404	P-3C U/D III					

Table III. P–3 Avionics Systems and Antennas, and Their Operational Frequency Bands (Cont'd)

P-3 DETECTION AND ATTACK SYSTEMS

SYSTEM	CONFIGURATION	ANTENNA	FREQUENCY	MANUFACTURER	ANTENNA TYPE	COMMENTS
OTPI SYSTEMS						
R-1047A/A	P-3A/B; P-3C S/N 5501-5507 & 5509-5524	AS-5780/ARA-25	162.250-173.125 MHz	GFE	FOLDED DIPOLE	
	P-3C S/N 5508, 5525-5531, 5533-5547, 5653 & UP	AS-909/ARA-48		COLLINS		
R-1651	P-3C U/D III					
RADAR SYSTEMS						
AN/APS-80	P-3A/B	AM4711/APS-60		TEXAS INSTRUMENTS	HORN-FED PARABOLA	NOSE AND TAIL
AN/APS-115	P-3C	AN-2146/APS-115	9.5-9.6 GHz			
IFF SYSTEMS						
AN/APX-7	P-3A/B	AM4711/APS-80	1010 - 1030 MHz	TEXAS INSTRUMENTS	BLADE	NOSE AND TAIL
AN/APX-76	P-3C PRE-U/D III	AN-2146/APS-115	1030 MHz			LAC P/N 671377-101
AN/APX-72	P-3C U/D III	AS-2628A/A	1090 MHz	TRANSCO; DORNE & MARGOLIN		DUAL CASS/IFF
IFF TRANSPONDER SYSTEMS						
AN/APX-68	P-3A/B	AT-741/A	RCV: 1030 MHz	GFE	BLADE	
			XMIT: 1090 MHz			
AN/APX-72	P-3C PRE-U/D III		1090 MHz			
	P-3C U/D II.5 & III	AS-2628A/A		TRANSCO; DORNE & MARGOLIN		LAC P/N 741280-103
ECM SYSTEMS						
AN/ALD-2	P-3A/B	AS-1352	CLASSIFIED	DORNE & MARGOLIN	HORNS	
		AS-1353				
		AS-1354				
		AS-1355		AMERICAN ELECTRONICS LABS		
AN/ALR-66	P-3 A/C WITH AFC-407/AVC-2517	AS-3100		GENERAL INSTRUMENTS	CAVITY-BACKED SPIRALS	
		AS-3537				
AN/ALQ-78	P-3C - ALL U/D	AS/2563/ALQ-78		LORAL ELECTRONICS	SPIRAL ARRAY	
ECM TEST SYSTEM						
AN/ALQ-78	P-3C - ALL U/D	AS-2564/ALQ-78	CLASSIFIED	LORAL ELECTRONICS	DIPOLE	LAC P/N 672329-101
SONOBUOY RECEIVER SYSTEMS						
AN/ARR-52	P-3A/B	AT-1014A	CLASSIFIED	TRANSCO	ROD	
AN/ARR-72	P-3C PRE-U/D III	AS-2273			BLADE	LAC P/N 740578-101, RCVR/TEST
AN/ARR-78(V)	P-3C U/D III	AS-3153		HAZELTINE	BLADE CLUSTER	
SONOBUOY REFERENCE SYSTEMS						
AN/ARS-3	P-3C - ALL U/D	AS-3103/ARS-3	CLASSIFIED	CUBIC	BLADE	
AN/ARS-5	P-3C U/D III					
SONOBUOY COMMAND SYSTEMS						
AN/ASA-76	P-3A/B	AT-256A	CLASSIFIED	GFE	BLADE	
AN/ASA-76	P-3C PRE-U/D III	AT-879/ARC		TRANSCO		
BULLPUP SYSTEMS						
BULLPUP	P-3A/B	AGM-12B	CLASSIFIED	DORNE & MARGOLIN	BLADE	
AN/ARW-77	P-3C PRE-U/D III	LAC P/N 740537-101				
ACPA COUNTERMEASURES SYSTEM						
AN/ALQ-150	P-3C U/D III	AS-3153/ALQ-158	CLASSIFIED	GFE	BLADE	

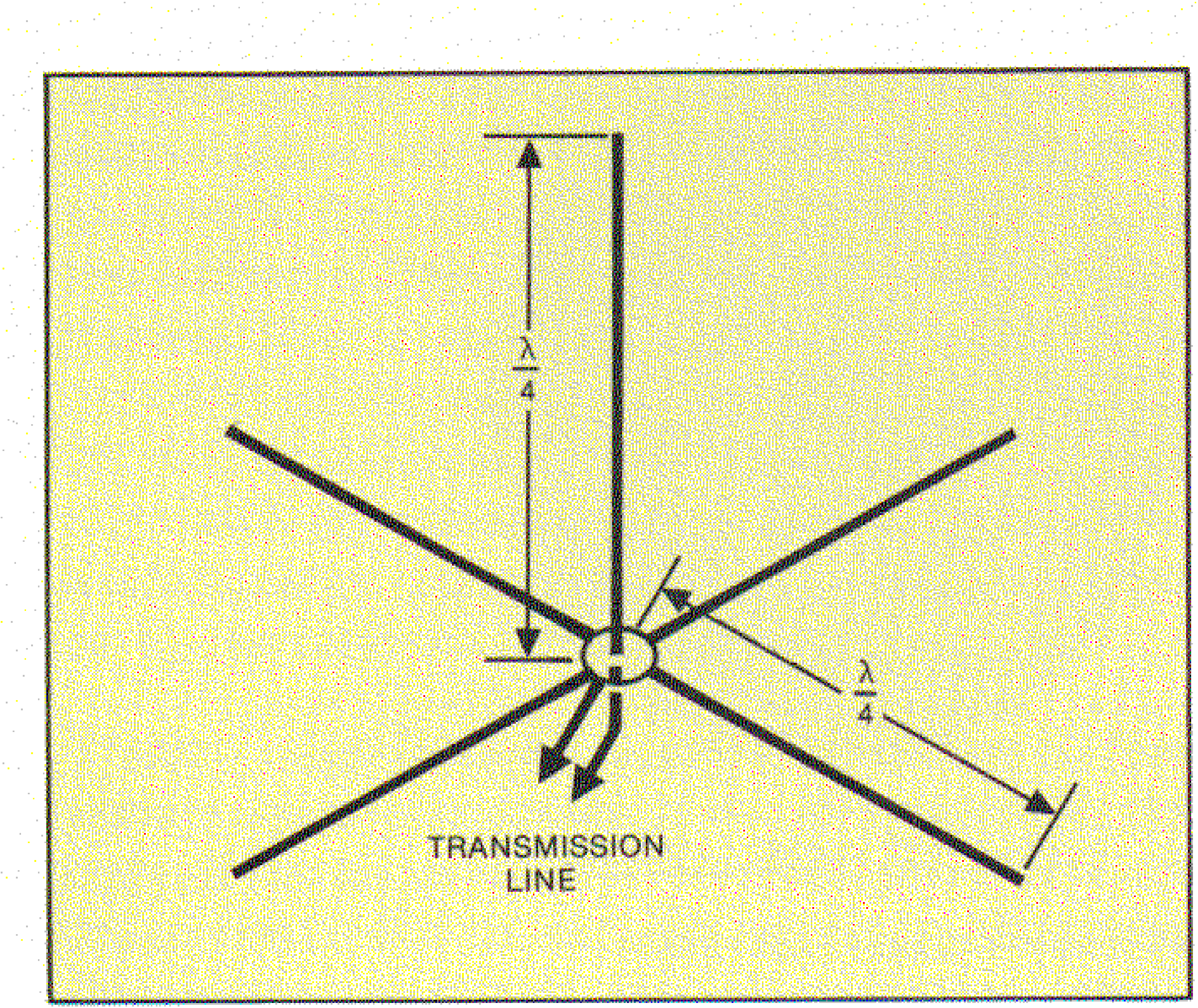


Figure 5. Basic Ground Plane Antenna

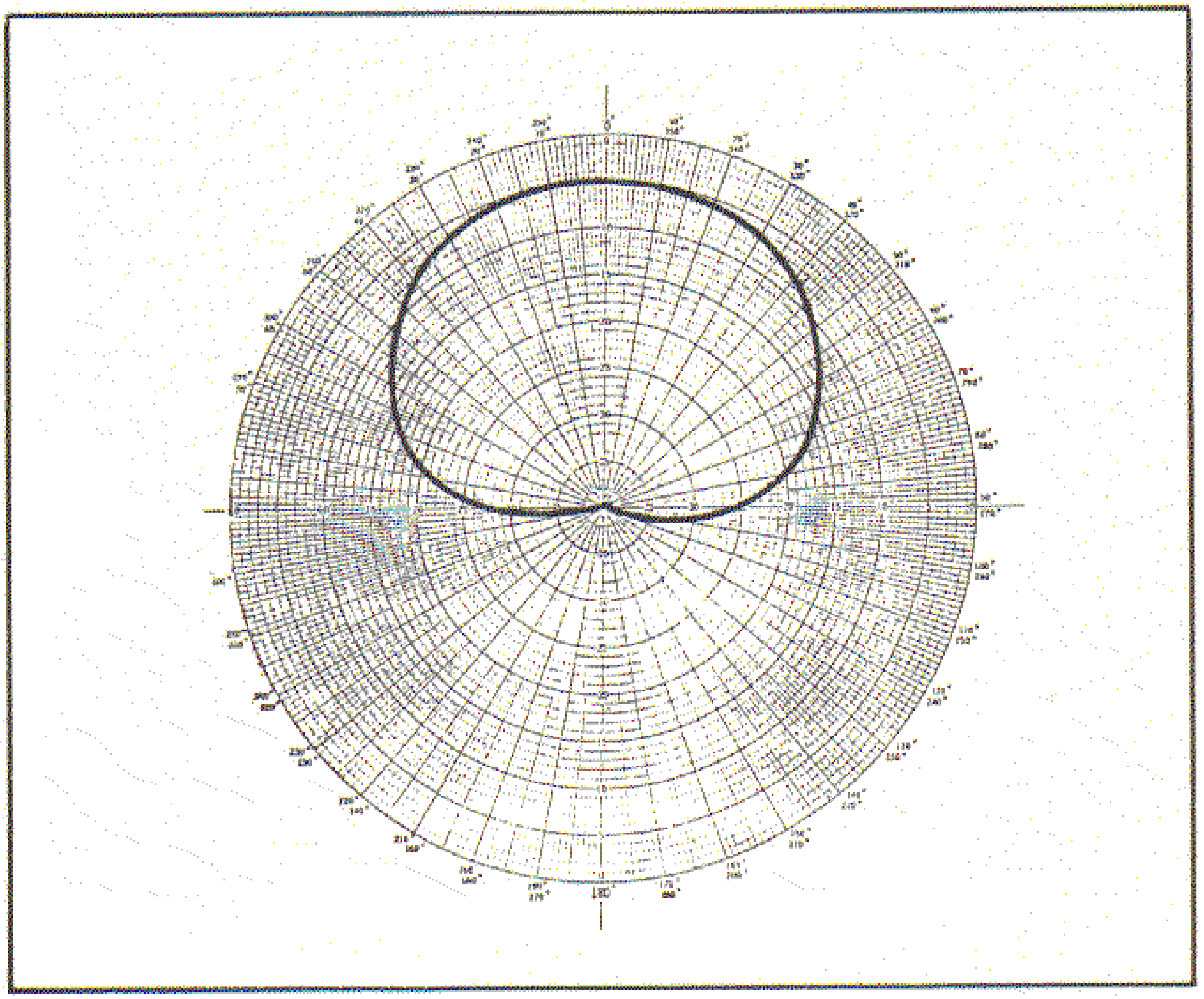


Figure 6. UHF Blade Antenna Radiation Plot

such antenna. Figure 5 shows the construction of a typical ground-plane antenna. The ground plane base can be either wires, a circular plate, or other configuration that provides an effective ground plane.

RADIATION PATTERNS Every antenna has a radiation pattern associated with its design characteristics. Typically, antenna radiation contours are drawn on circular coordinate plots, on which the spokes represent the degrees of a circle and the concentric rings represent the gain in decibels (dB). Figure 6 is a representative radiation plot for a UHF blade antenna. This radiation pattern has one major lobe. Such charts show the antenna's effective radiation pattern in polar coordinates, but for only one specific plane.

Computer simulation programs have produced significant advances in aircraft antenna design. New techniques have been developed, with the aid of computer graphics, to produce three-dimensional plots of antenna patterns (see Figure 7). These new charts depict the total radiation pattern of an antenna. They are much more valuable than circular coordinate plots for studying how interference affects an antenna radiation pattern, and how a radiation pattern is affected by

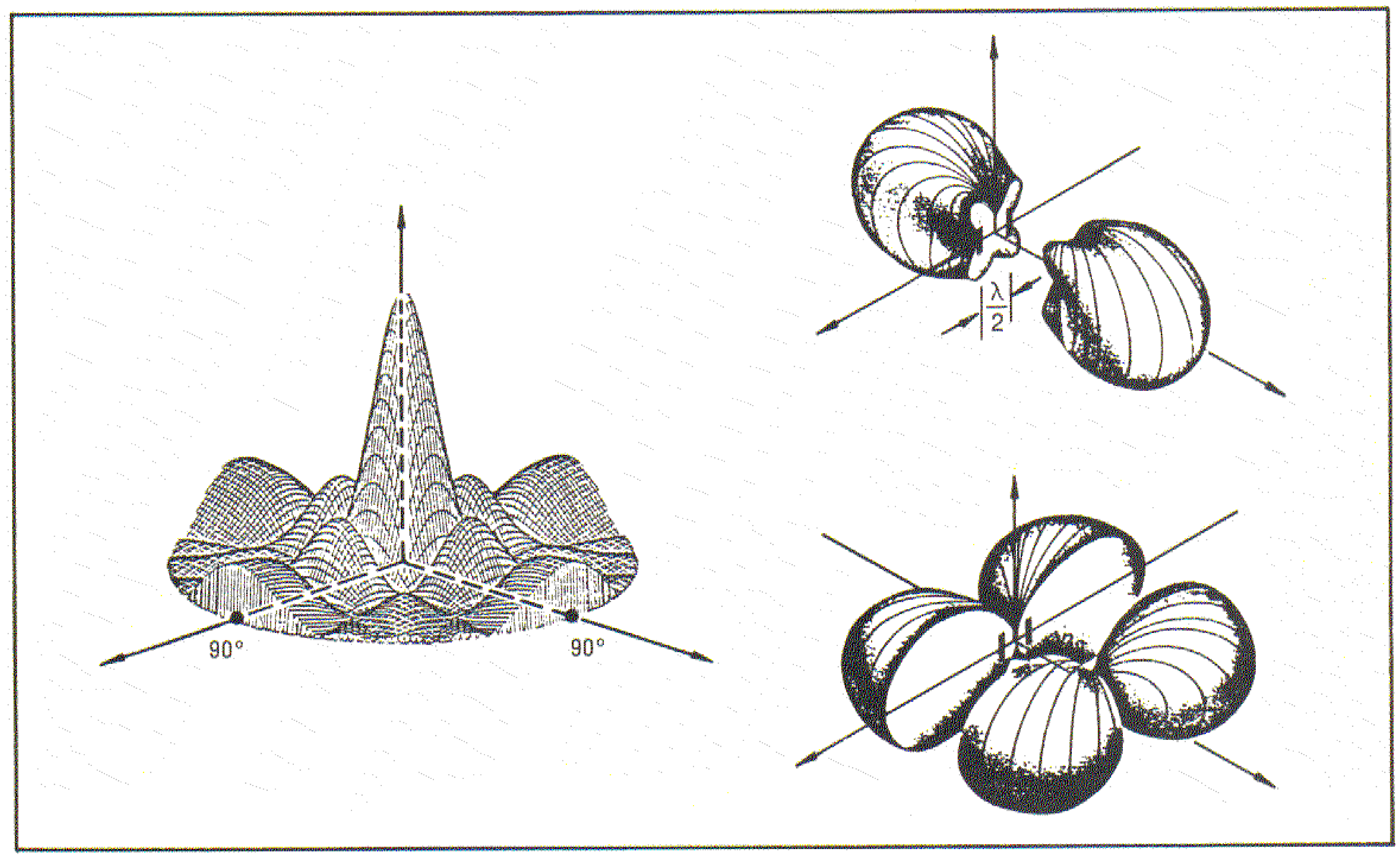


Figure 7. Three-Dimensional Antenna Radiation Plots

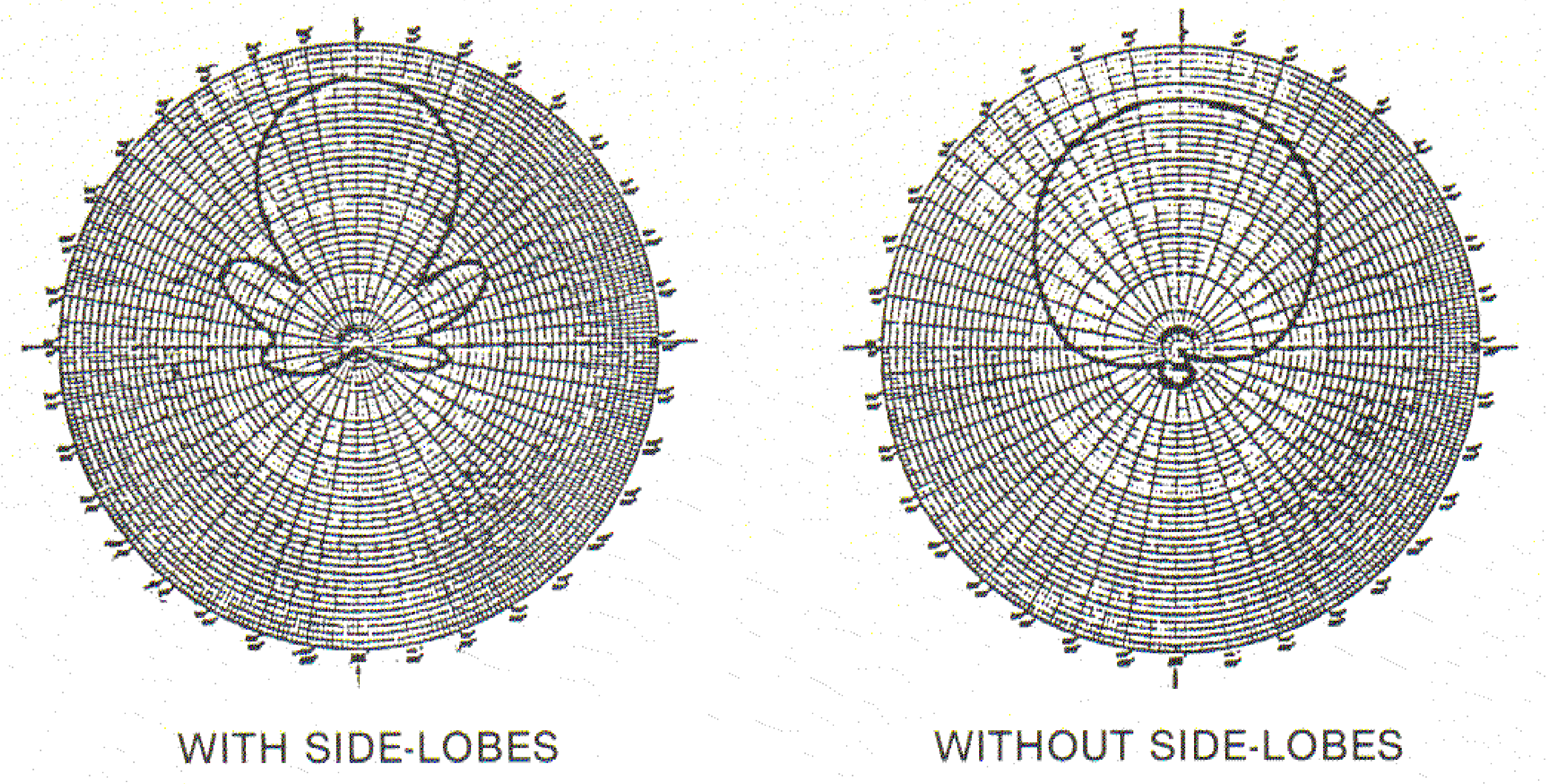


Figure 8. Antenna Radiation Patterns With and Without Side-lobes

the coexistence of several antennas within a given area. Computer programs also have been developed to calculate the interference present at all other points on and in an aircraft when one emission source is activated.

The radiation pattern of an antenna gives direct insight into the ability of an antenna to receive a signal. The measure of this ability is called the *gain* of the antenna. Since the antenna is a passive device, it cannot furnish "gain" in the true sense of the word. Improved signal gain in one direction is obtained by sacrificing signal reception in another direction. For example, parabolic reflector antennas can obtain effective gains of up to 20 or 30 dB by restricting the signal reception path to a small pencil beam in one direction.

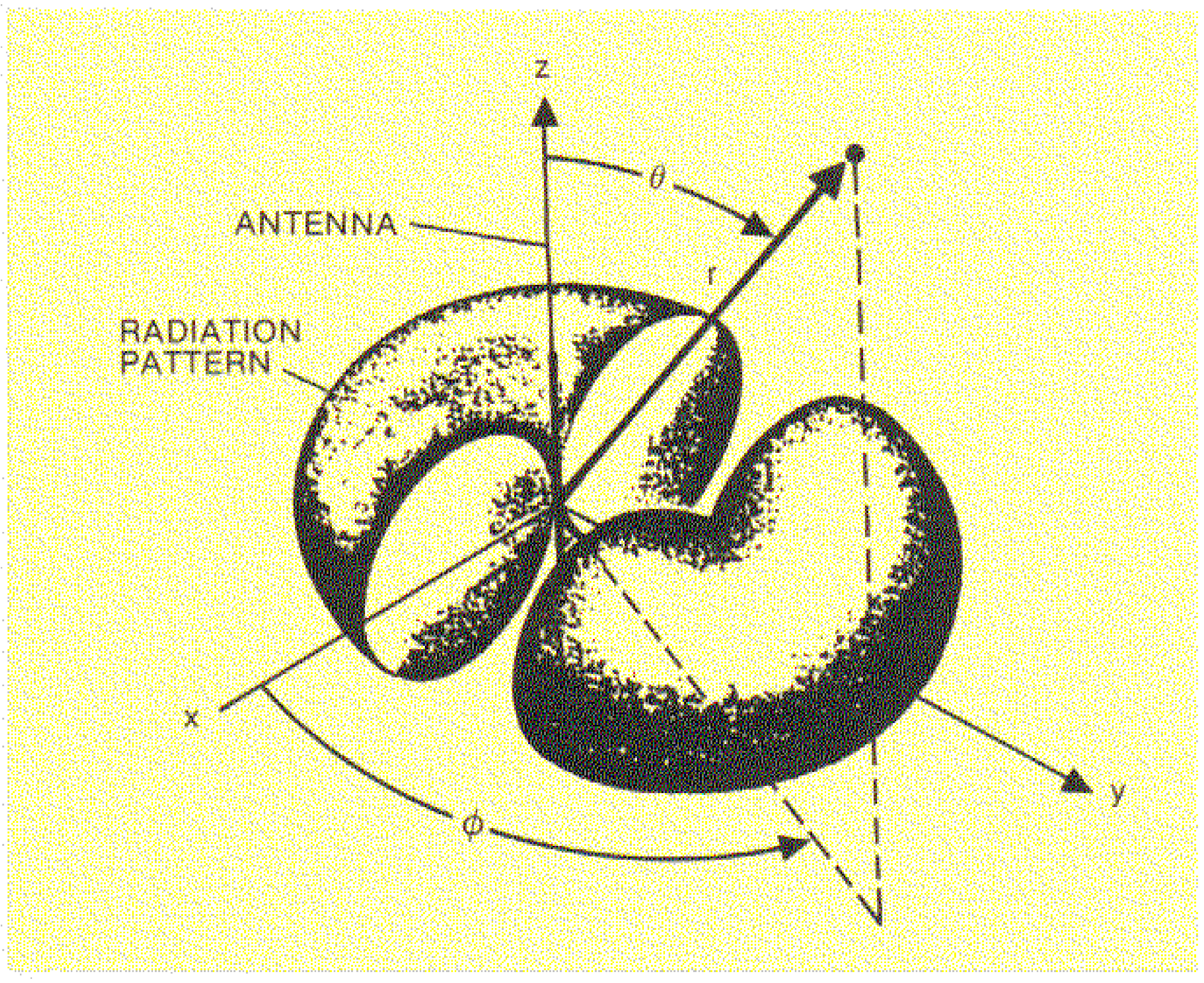


Figure 9. Basic Dipole Antenna Radiation Pattern

Most directive antenna radiation patterns have contours called side lobes, an example of which is shown in Figure 8. Normally, side lobes produce undesirable effects. For example, erroneous information can be produced if the receiving electronics interpret the side-lobe signal as the primary signal. Also, side lobes introduce noise into the system. Directive antennas are designed to reduce the effects of side lobes to negligible levels.

ANTENNA TERMINOLOGY Antenna data sheets and technical manuals use terms that are generic to the antenna field. A glossary of antenna terminology is presented in the back of this article to help the reader.

ANTENNA TYPES

BASIC ANTENNA The study of antenna theory usually begins by considering a hypothetical example in which radio waves are emitted from a point in free space, with no influence from any surrounding objects. This point is called an *isotropic radiator*, an energy source that radiates equal amounts of energy in all directions. Antenna power gain is defined as the effectiveness of a specific antenna to receive a signal in a given direction, when that antenna is compared to a reference standard such as an isotropic radiator. However, the isotropic radiator is only a mathematical concept. It cannot be duplicated in real life and is not a practical reference for real antennas. Therefore, antenna manufacturers have found it necessary to use other standards for their gain measurements.

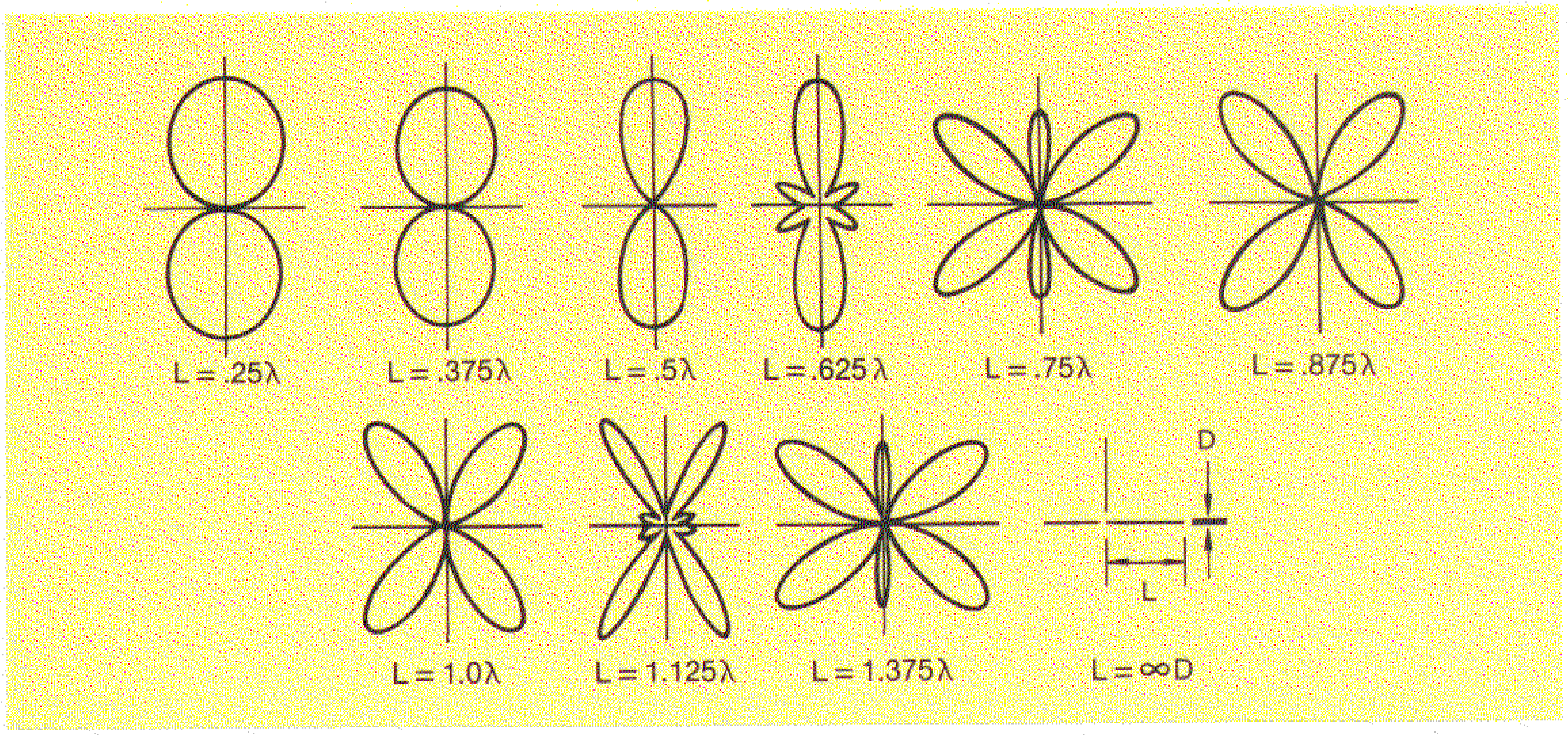


Figure 10. Radiation Patterns of Various Center - Driven Dipole Antennas

Many antenna manufacturers use a standard linear horn antenna as the reference for measuring antenna gain. Others use an isotropic radiator. The gain of the isotropic dipole antenna is considered to be 0 dB. The standard dipole and its radiation pattern are shown in Figure 9. The dipole antenna radiates a full 360 degrees in the rotational plane ϕ, with a cosine pattern in the vertical plane θ. This is known as an omnidirectional radiation pattern. However, there is a null in the pattern at each end of the dipole that causes the actual three-dimensional pattern to resemble the shape of a donut. These nulls occur because the current at the ends of any antenna is zero, so no energy is radiated from those points.

DIPOLE ANTENNA Most antennas are derivatives of the basic dipole. The most common dipole antenna is the half-wave (λ/2) dipole, with its characteristic donut radiation pattern. Figure 10 shows how different dipole lengths affect the radiation patterns of center-driven dipole antennas. This illustration shows that the normal reception pattern of a useful dipole antenna is omnidirectional, as characterized by the λ/4 or λ/2 dipole. Figure 11 shows that dipoles of differing wavelength have different current and voltage wave characteristics. (Note that the current is always zero at the ends of the antenna.) The dipole must be fed signals in a manner to match the current/voltage relationship of that particular dipole. For optimum dipole antenna performance, the actual physical length of a dipole should be 5 percent shorter than the calculated electrical length of the dipole, based on antenna theory. A handy equation for determining the physical length of a dipole is:

$\lambda/2$ in feet $= 468/f$ (in MHz).

DIPOLE ANTENNA VARIATIONS There are many variations of the basic dipole antenna. For example, when an antenna contains more than one element, it is called an array. An antenna array is called a *parasitic array* when only one dipole element is connected to the transmission line, and the remaining antenna elements are not. The connected dipole is called a driven element, and the remaining elements are called parasitic elements. The parasitic elements either direct or reflect energy through space to or from the driven element. When conductive connection is made between *each* antenna array element and the transmission line, the arrangement is called a *driven array.* Other major dipole antenna variations include the vertical dipole and the folded dipole. These dipole antenna variations, their characteristics, and their applications are discussed in the following paragraphs.

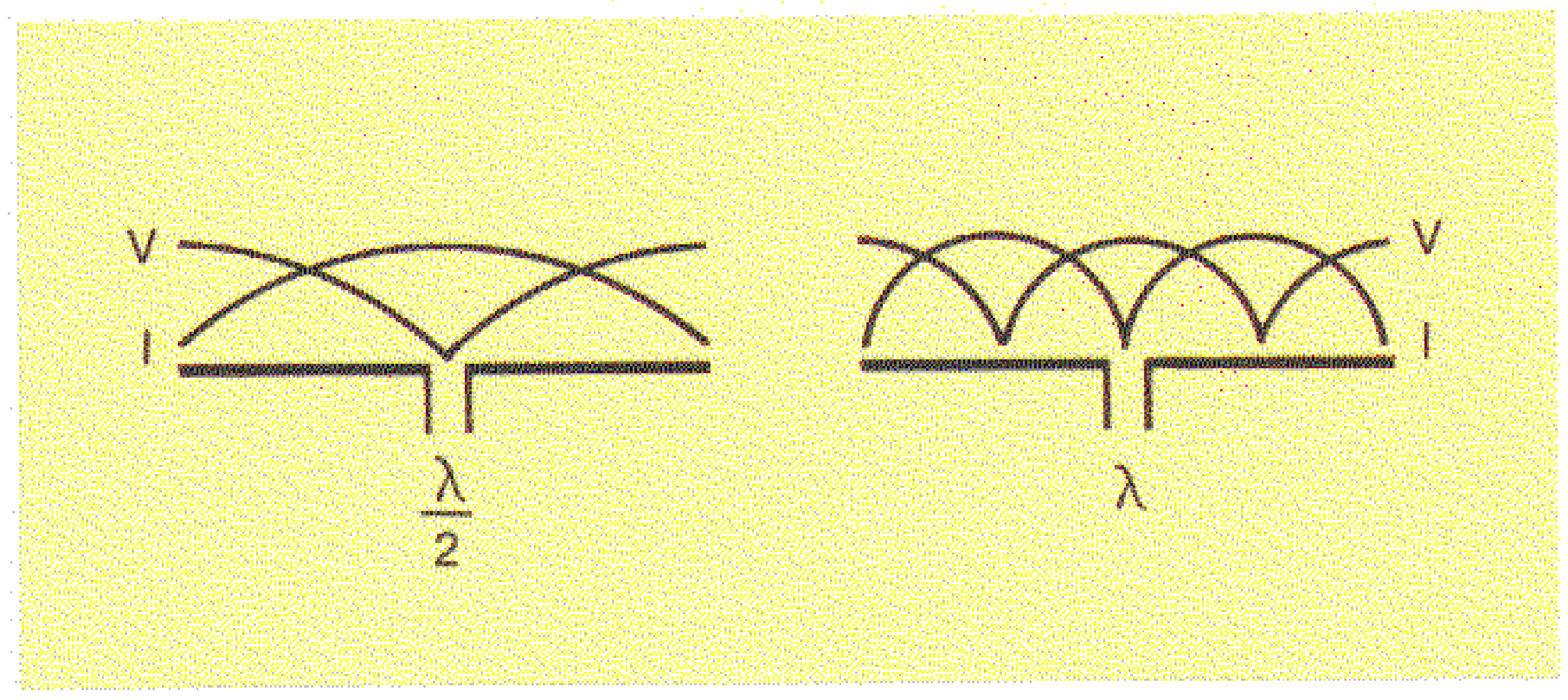


Figure 11. Current/Voltage Relationship in the Dipole Depends upon the Dipole Wavelength

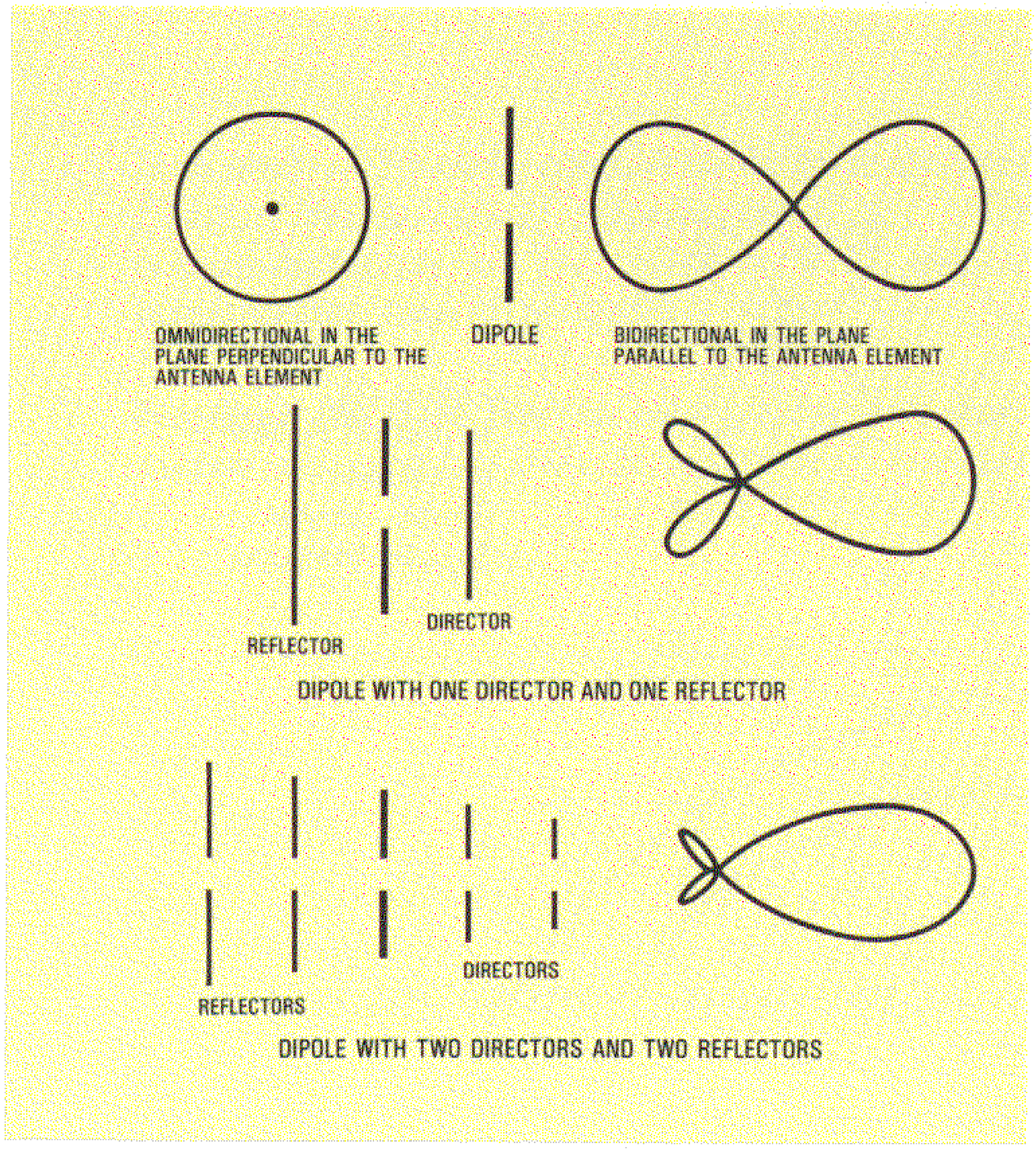


Figure 12. Radiation Patterns of Basic Dipole Antenna and Dipole Antennas with Director and Reflector Elements

Parasitic Arrays The *directivity* of an antenna system is that characteristic which enables the antenna to radiate or receive more energy from one direction than another. The directivity of a dipole antenna can be improved by incorporating nonradiating director and reflector elements into the antenna system to create a parasitic array. The parasitic array, with its directors and reflectors, is common in the TV and FM broadcast media because it can receive signals from desired directions and reject signals from undesired directions. However, this type of antenna occupies considerable space and is too bulky for mobile operations. The effect of the antenna's parasitic elements on the dipole radiation pattern is shown in Figure 12.

Driven Arrays Dipoles can be combined as arrays of driven antenna elements, rather than as an array of a dipole and parasitic elements. In the driven array, *all* of the antenna's elements are connected to the transmission line. The simplest driven array antenna is the two-element dipole array. Figure 13 shows variations in antenna radiation patterns that are possible when signals with different phase characteristics are fed to a two-element dipole array.

The most common basic driven array antennas are called *broadside* and *end-fire* arrays (see Figure 14). The driven array is named for the direction of its principal beam, with respect to antenna element placement. The driven array beam can be made sharper by increasing the number of antenna elements. All elements in the basic driven array are one-half wavelength long, and are fed with signals of the proper phase. Other more sophisticated driven arrays have been developed for special applications such as search radar, direction finding, and SATCOM.

Vertical Dipole/Monopole The vertical dipole/monopole antenna is so named because it is positioned vertical to the surface that it uses for the ground plane. It employs the principle of *imagery* (mirror-image signal reflection), which occurs when the signal from the antenna is reflected from the ground plane. Figure 15 illustrates the principle of imagery, and how the height of a transmitting antenna above the ground plane affects the antenna radiation pattern. In this example, the ground-based vertical antenna uses the

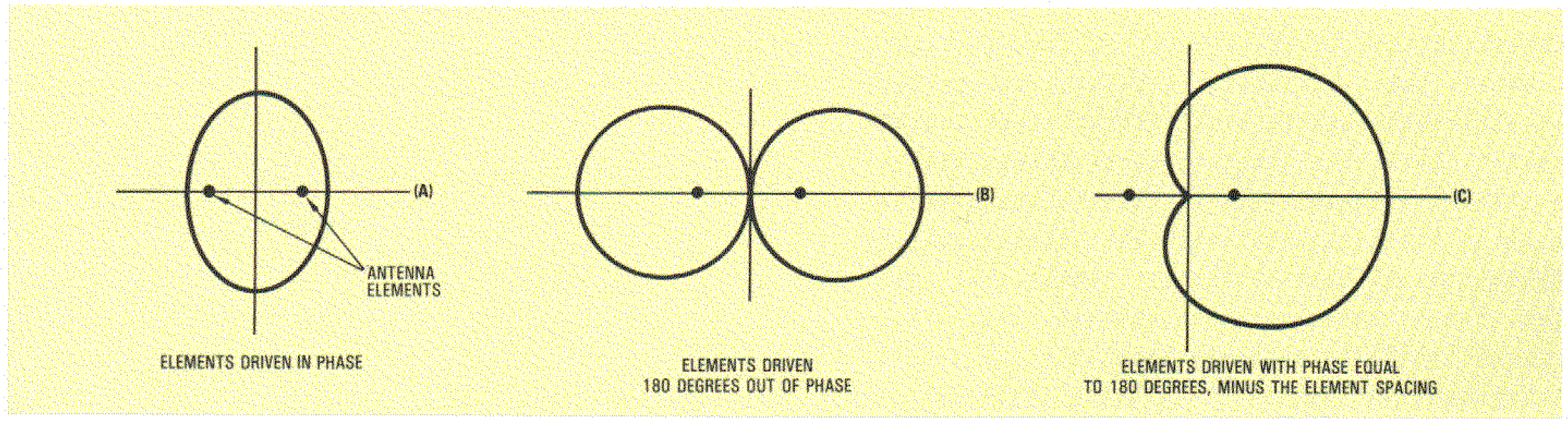
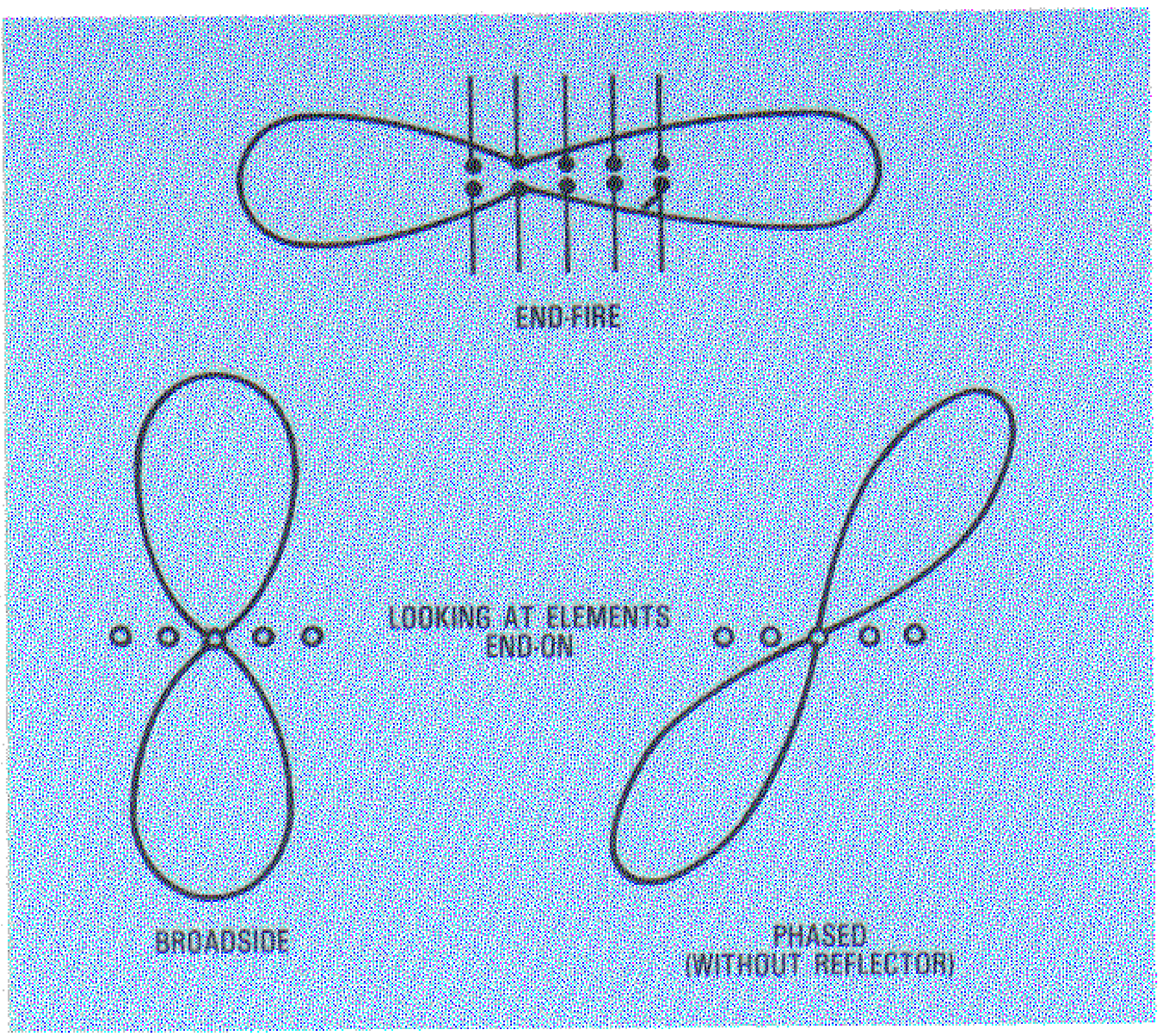


Figure 13. Radiation Patterns of Basic Dipole Driven–Element Array Antennas that have Different Phases of Signal Feed

surface of the earth for a ground plane. Most of the blade antennas used on the P-3C are examples of a vertical monopole antenna. On aircraft, the blade antenna uses the aircraft's metallic skin as its reflective ground plane. Predictable dipole antenna radiation patterns can be duplicated only if the antenna is located near the ground plane.

Folded Dipole The folded dipole's inherent characteristics have made it a popular variation of the basic dipole antenna. The folded dipole has a high characteristic impedance of 300 ohms, compared to the dipole's lower impedance of about 75 ohms. Its radiation pattern also has a more pronounced null that is perpendicular to its ends, which makes the folded dipole a superior antenna for direction finding. The ADF loop antenna is a form of the folded dipole.

LONG-WIRE ANTENNAS Long-wire antennas were familiar sights in the early days of radio, when almost every home required such an antenna to receive AM (amplitude modulated) broadcasts. Improved technology has enabled us to replace long-wire antennas with ferrite loops for home broadcast reception, but military and commercial broadcast reception requirements are more demanding for long-range performance. These maximum-efficiency reception requirements make the use of long-wire antennas mandatory. Long-wire antennas are used only in the LF or HF bands, where the lower frequencies dictate antennas of long wavelength. Base station transmitters often use long-wire antenna arrays to optimize signal directivity. Remote stations and transportable systems normally require single long-wire



NOTE:

END-FIRE	THE PRIMARY GAIN AXIS IS PARALLEL TO THE PLANE OF THE ARRAY.
BROADSIDE	THE PRIMARY GAIN AXIS IS PERPENDICULAR TO THE PLANE OF THE ARRAY.
PHASED	THE PRIMARY GAIN AXIS IS AT AN ANGLE BETWEEN THE PARALLEL AND PERPENDICULAR PLANES OF THE ARRAY.

Figure 14. Typical Radiation Patterns of Broadside, End-Fire and Phased Dipole Array Antennas

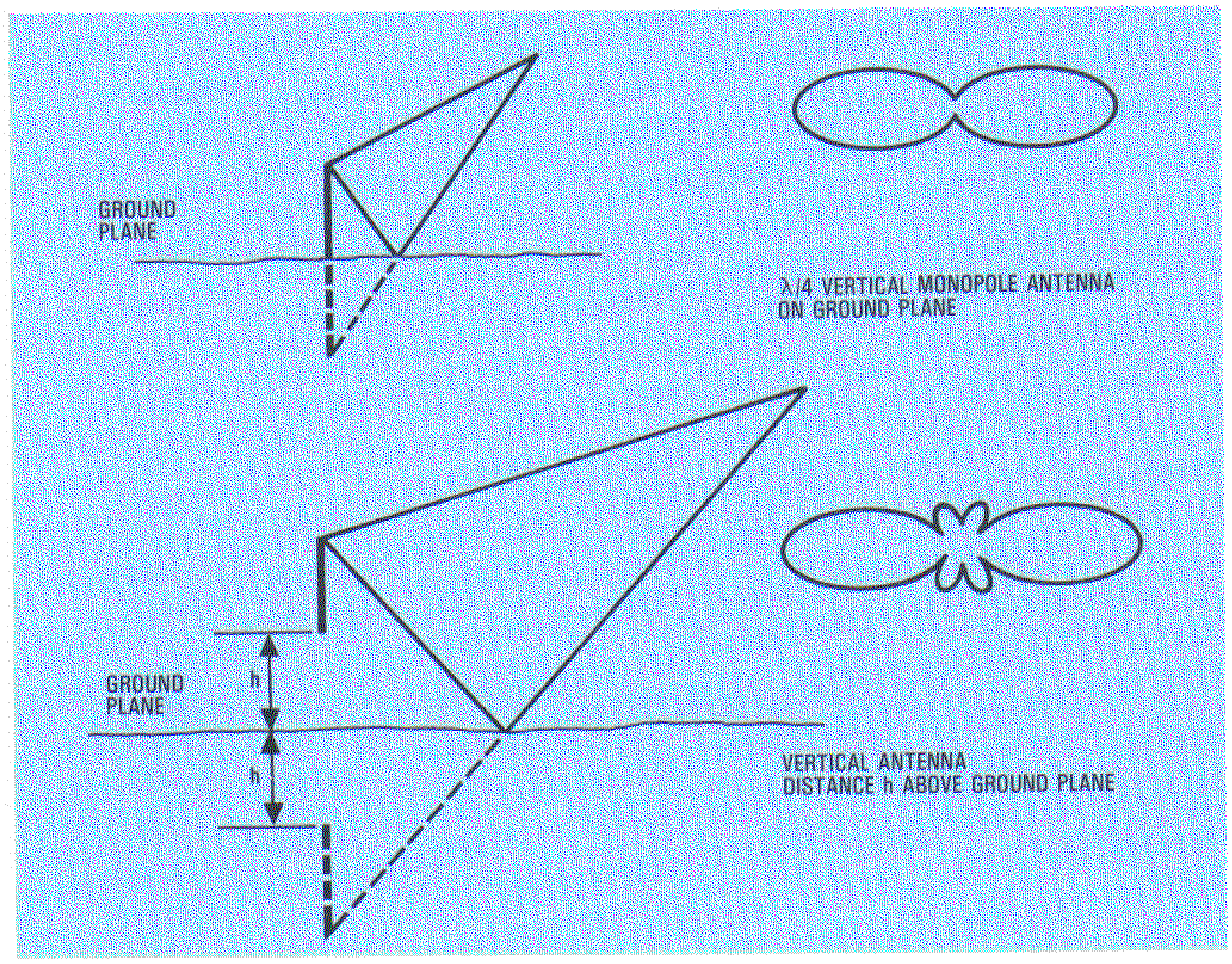


Figure 15.
Mirror Images Produced by a Vertical Monopole Antenna Located Near the Ground Plane, and by a Vertical Antenna Located Above the Ground Plane

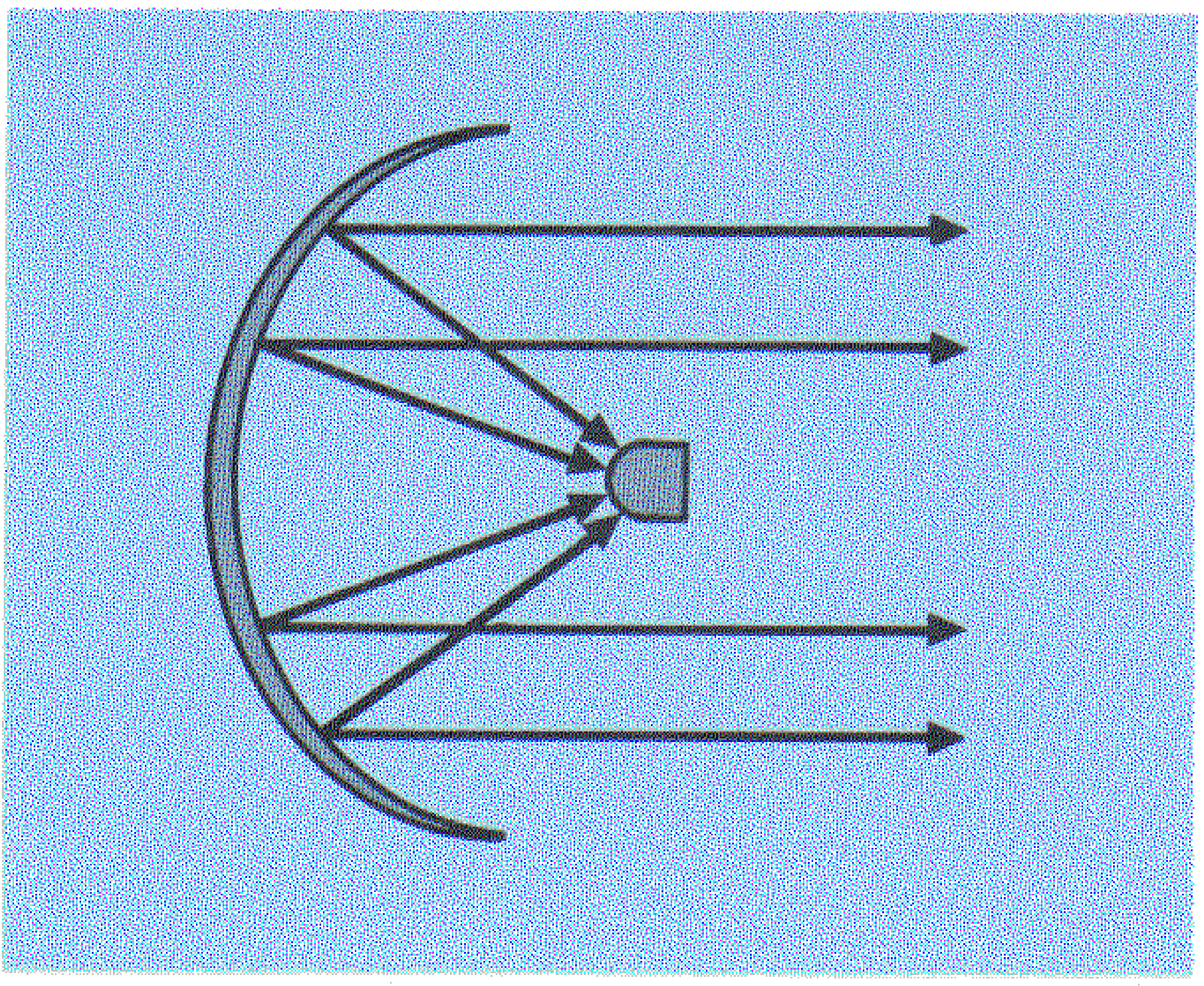


Figure 16. Basic Parabolic Antenna

antennas that are long enough to represent a significant portion of the wavelength of the RF signal transmissions. These long-wire antennas are frequently loaded with coils to artificially increase the antenna length.

VERTICAL ANTENNAS Vertical antennas are popular because they are relatively compact. They need be only half as long as horizontal antennas used for similar applications because they use the earth or their mounting surfaces as the ground plane to achieve the imagery effect. Vertical antennas are used almost exclusively for mobile applications because of their reduced drag characteristics, ease of mounting, and their ability to use the surface of the vehicle (or earth) as a ground plane.

PARABOLIC ANTENNAS Parabolic antennas exhibit the highest gain of all antennas currently available. This is because the parabolic antenna can generate an extremely sharp beam, using the lens-like characteristics of its parabolic reflector (see Figure 16). The signal feed to the antenna's parabolic reflector can be adjusted to produce either a pencil beam or a parallel-plane beam. The parallel-plane beam is useful for testing and for generating search patterns.

The beamwidth of a parabolic antenna is governed primarily by the size of its reflector, but aircraft installations restrict the size of the reflector. To obtain optimum performance from aircraft parabolic antennas, it is necessary to employ signals of extremely short wavelength. This requires the use of radio frequencies that are in the UHF, SHF or higher regions.

SPECIALIZED ANTENNAS Today, it is often necessary to design specialized antennas to meet specific radio transmission and reception requirements, while still remaining within the physical constraints of the antenna platform. Slot antennas, array antennas and broadband antennas are examples of specialized antennas. The following paragraphs describe these specialized antennas and some of their applications.

Slot Antenna The slot antenna is based on the principle that a slot in a large sheet of conducting metal will radiate energy like a magnetic dipole. In fact, a half-wave slot in a relatively large plate will exhibit a radiation pattern similar to that of the equivalent wire dipole. The slot may be energized by a cavity, a waveguide, or a transmission line connected to the sides of the slot. The radiation pattern of a slot antenna will vary, depending on the conformation of the surface on which it is located; that is, a slot antenna in a flat plate will radiate differently than the same slot antenna in a cylinder. Cavity-backed antennas and notch antennas used on P-3 aircraft are based on the slot antenna concept.

Array Antennas The array antenna is a series of radiators such as dipoles. They are connected in a manner to produce specific radiation patterns, or to provide special broadband characteristics. Array antennas are also popular where adjustable or rotating beam patterns are required. By properly phasing the elements in the array, the array antenna can shift a radiation pattern from one orientation to another. The use of high-speed diodes and modern switching circuits enable an array antenna to rotate its radiation pattern in a wide sector at rates sufficient for most search and weather radar applications. As new manufacturing techniques and materials have enabled the construction of relatively small array antennas, their popularity has increased.

Broadband Antennas Antenna design is based on the principle that a signal radiated by an antenna element has a specific wavelength at a specific frequency. Therefore, by definition, an antenna's performance should be optimum only at the frequency that matches its optimum wavelength characteristic. However, in most cases antenna systems must operate over a band of frequencies. This is difficult to do with an antenna that is designed for a specific frequency. Several design techniques are used to give an antenna specific broadband characteristics.

A broadband antenna can be constructed by assembling several dipole elements of different lengths. The dipole elements need not be connected as radiating elements, but instead may be connected as directors or reflectors. Figure 17 shows several such methods. Constructing a broadband antenna in this manner always affects its radiation pattern, but the radiation pattern for a particular application can actually be improved through proper selection of the array elements.

Another method that is frequently used to give an antenna broadband characteristics is to shape the antenna so that its dimensions vary throughout its length. The bowtie antenna is a prime example of this technique (see Figure 17). The spiral antenna, with its varying dimensions, also has broadband characteristics. An antenna's broadband characteristics can also be improved by "tuning" the antenna. This technique is used with HF longwire antennas, where it is impractical to use arrays or multiple elements.

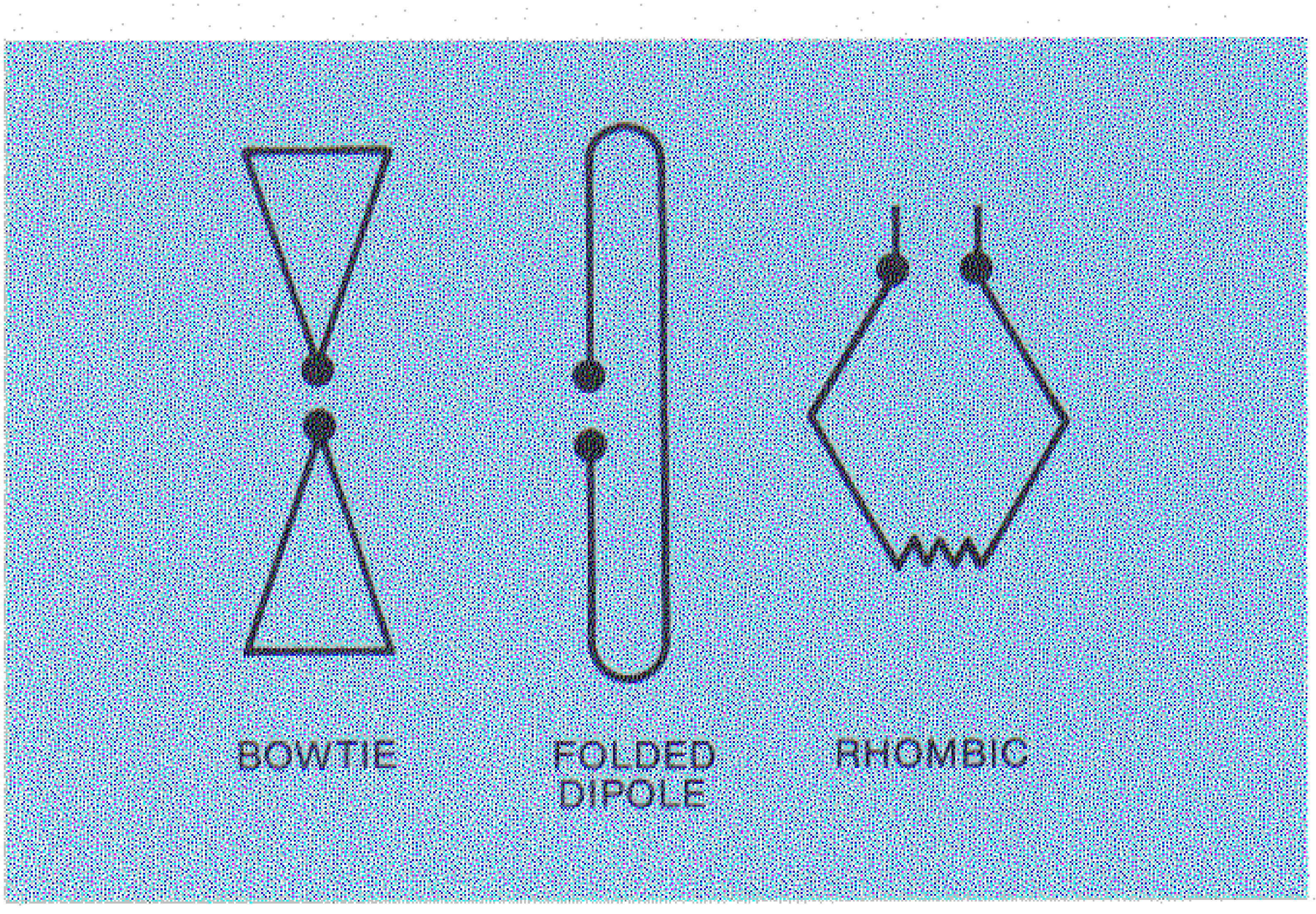
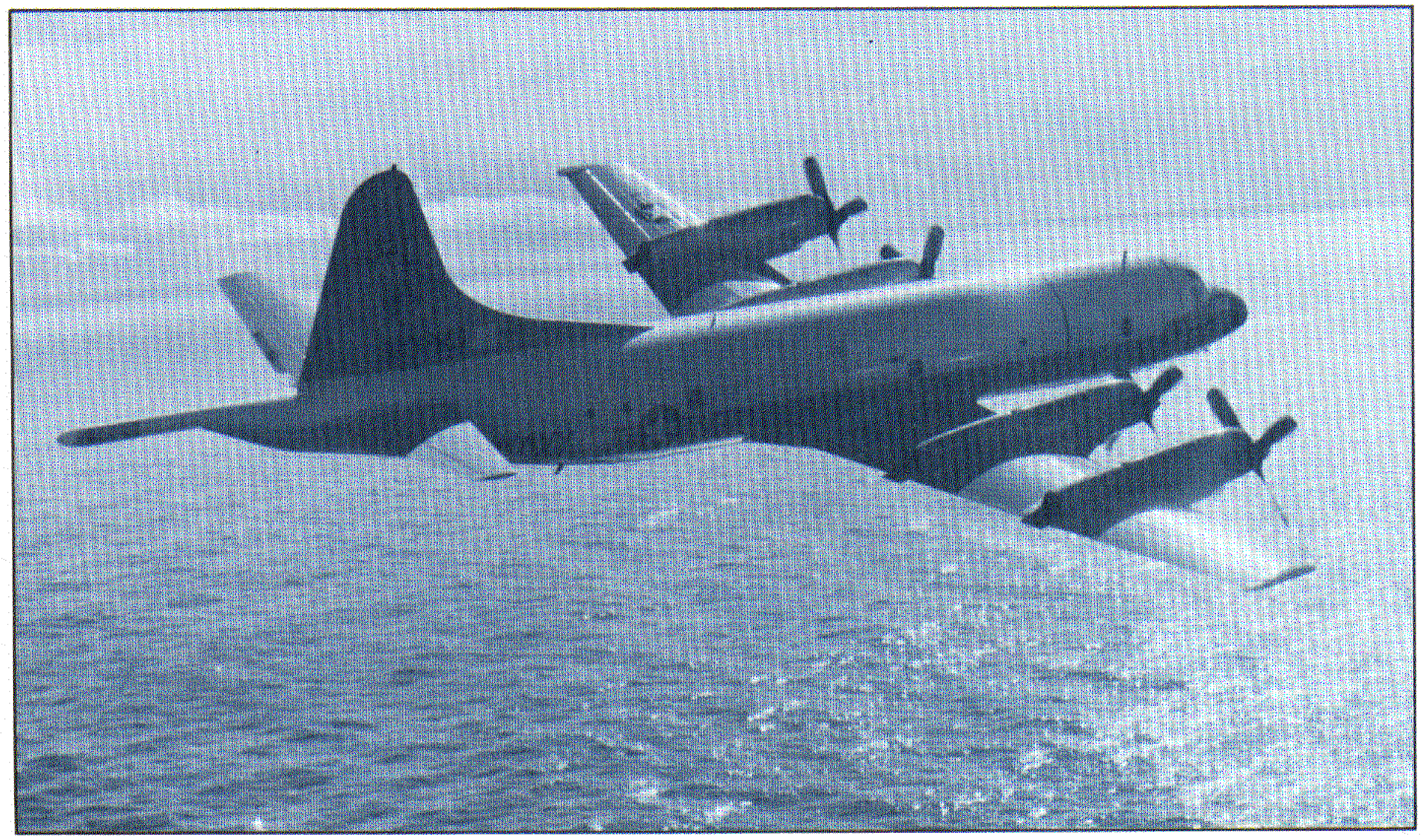


Figure 17. Bowtie, Folded Dipole and Rhombic Broadband Antennas

Lockheed ORION Service Digest



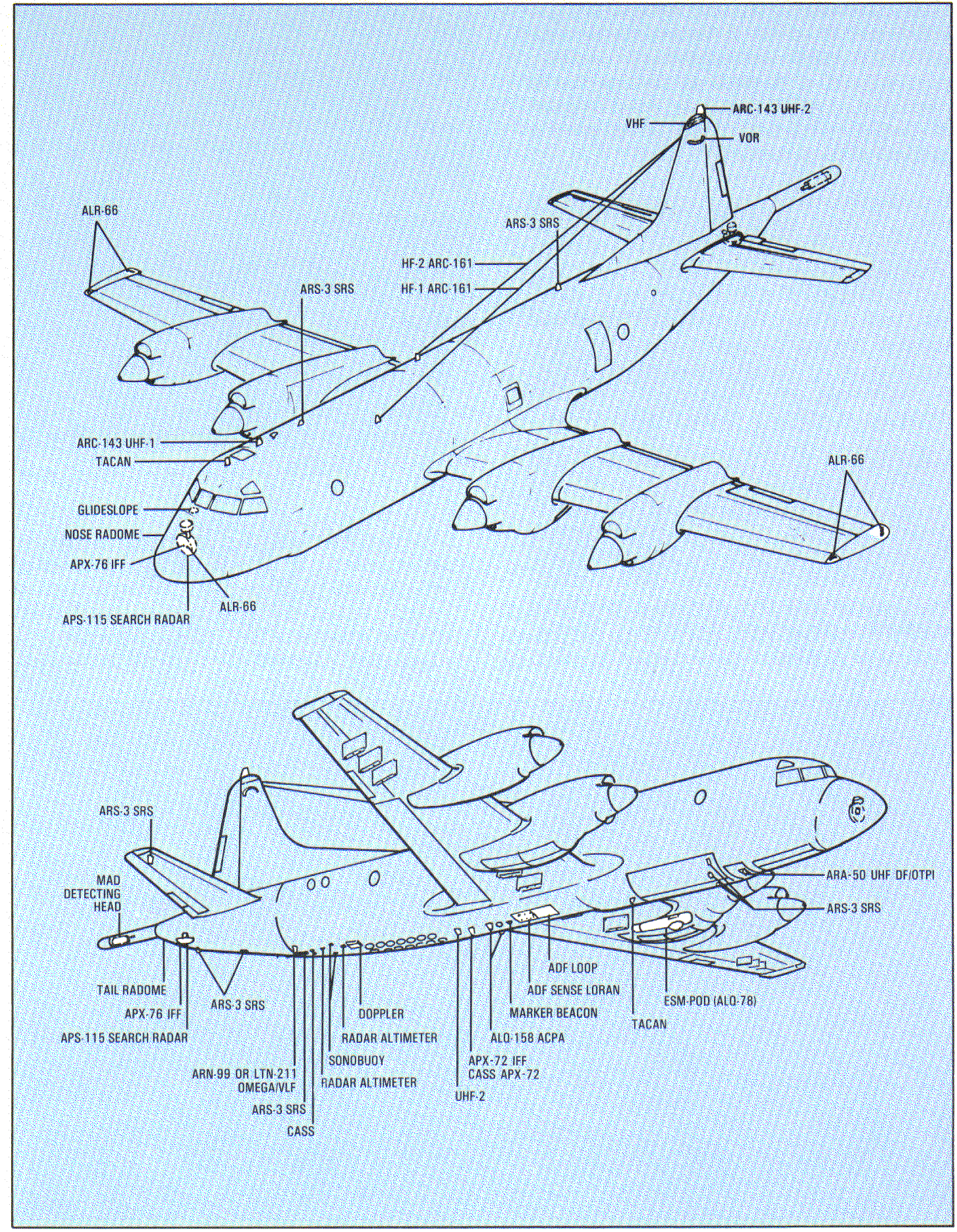


Figure 18. P-3C Antenna Locations

P-3 AIRCRAFT ANTENNAS

The greatest constraints that the aircraft antenna designer must face are the space available for an antenna installation and weight limitations. Often, antenna performance must be sacrificed to meet these restrictions. Usually, aircraft antennas are merely variations of those antenna types already discussed, adapted to the environment of the aircraft. Figure 18 shows a typical arrangement of the many antennas on the P-3C aircraft. This section presents discussions of the characteristics of the antennas installed on the P-3 aircraft and, where applicable, offers maintenance tips. However, we must emphasize that these maintenance suggestions *are for information only*. Maintenance personnel and operators must perform all maintenance actions in accordance with procedures published in the appropriate NAVAIR maintenance publications.

LONG-WIRE ANTENNAS Long-wire antennas are characteristic of HF radio communication because they are required to transmit and detect the long wavelengths of HF band signals. The P-3 Orion aircraft uses two wire antennas that are frequently referred to as long-wire antennas, although they are not sufficiently long to qualify electrically as long-wire antennas. There is one wire for each of the two HF radios. Figure 18 shows their location.

It is obvious that a half-wave long-wire antenna would be of prohibitive length for most aircraft. (For example, the wavelength of a 5-MHz signal is approximately 200 feet.) This problem is resolved by use of the *asymmetrical dipole* wire antenna, in which the wire section of the antenna acts as one part of an asymmetrical dipole, and the aircraft skin serves as the other part of the dipole. Although the asymmetrical dipole antenna has been the subject of research, its characteristics are not well understood and no absolute definition of its operational performance is available. The radiation pattern of the asymmetrical dipole antenna does not have the characteristic omnidirectional donut shape of the basic dipole. Instead, it has a very broken radiation pattern, with lobes that depend on the ratio of dipole asymmetry and wavelength.

HF radios that are used for long-distance communication require considerable power. For example, the HF radios on the P-3 aircraft are capable of transmitting 1000 watts. This places severe demands on the components that comprise a long-wire antenna installation. A typical installation set of a long-wire antenna and its hardware is shown in Figure 19.

The P-3 aircraft's two long-wire antennas each have a tunable coupler to optimize antenna performance over the wide frequency range of the aircraft's HF radios (2 to 30 MHz). The tunable

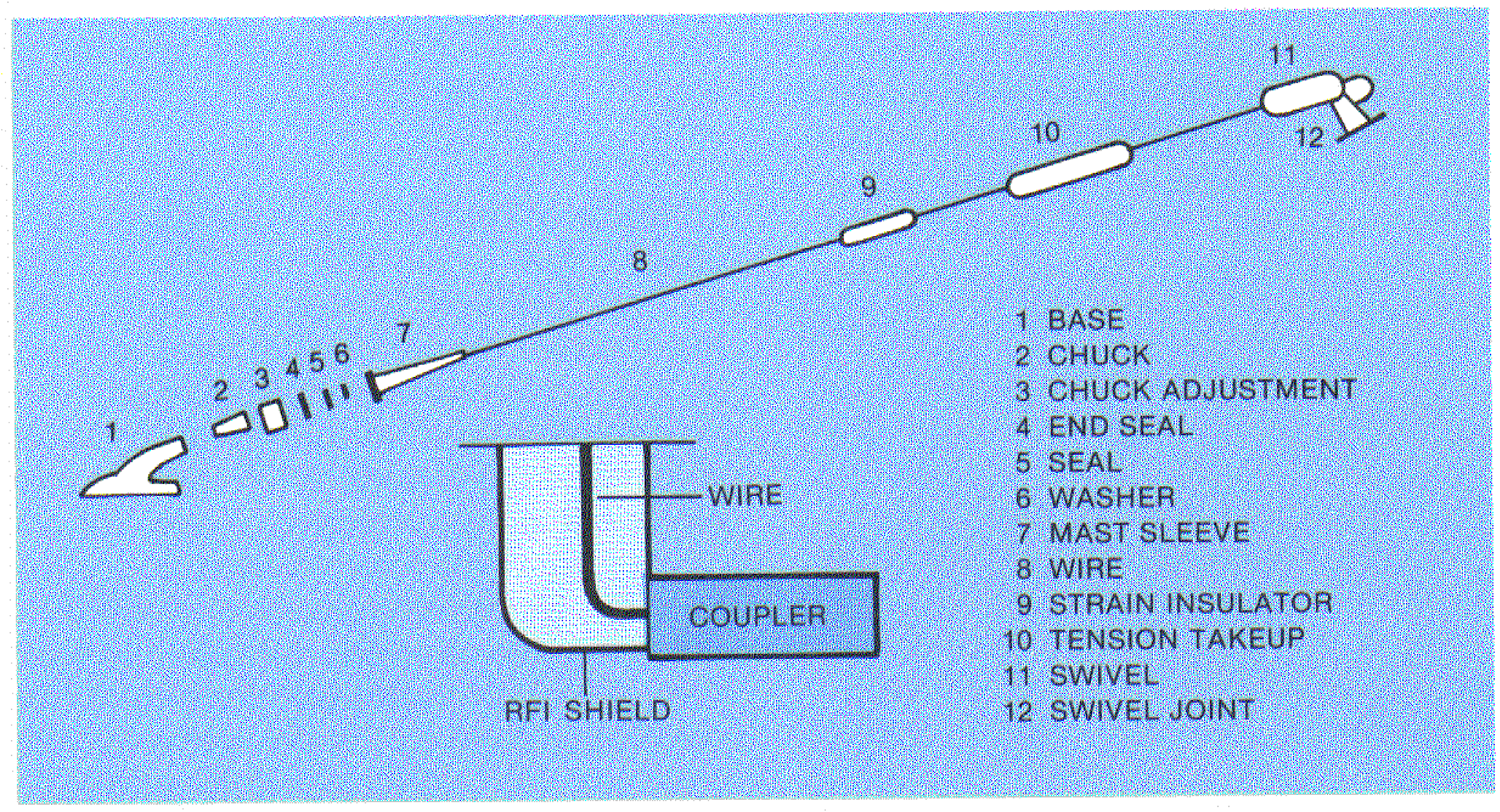


Figure 19. Typical Long-Wire HF Antenna Hardware

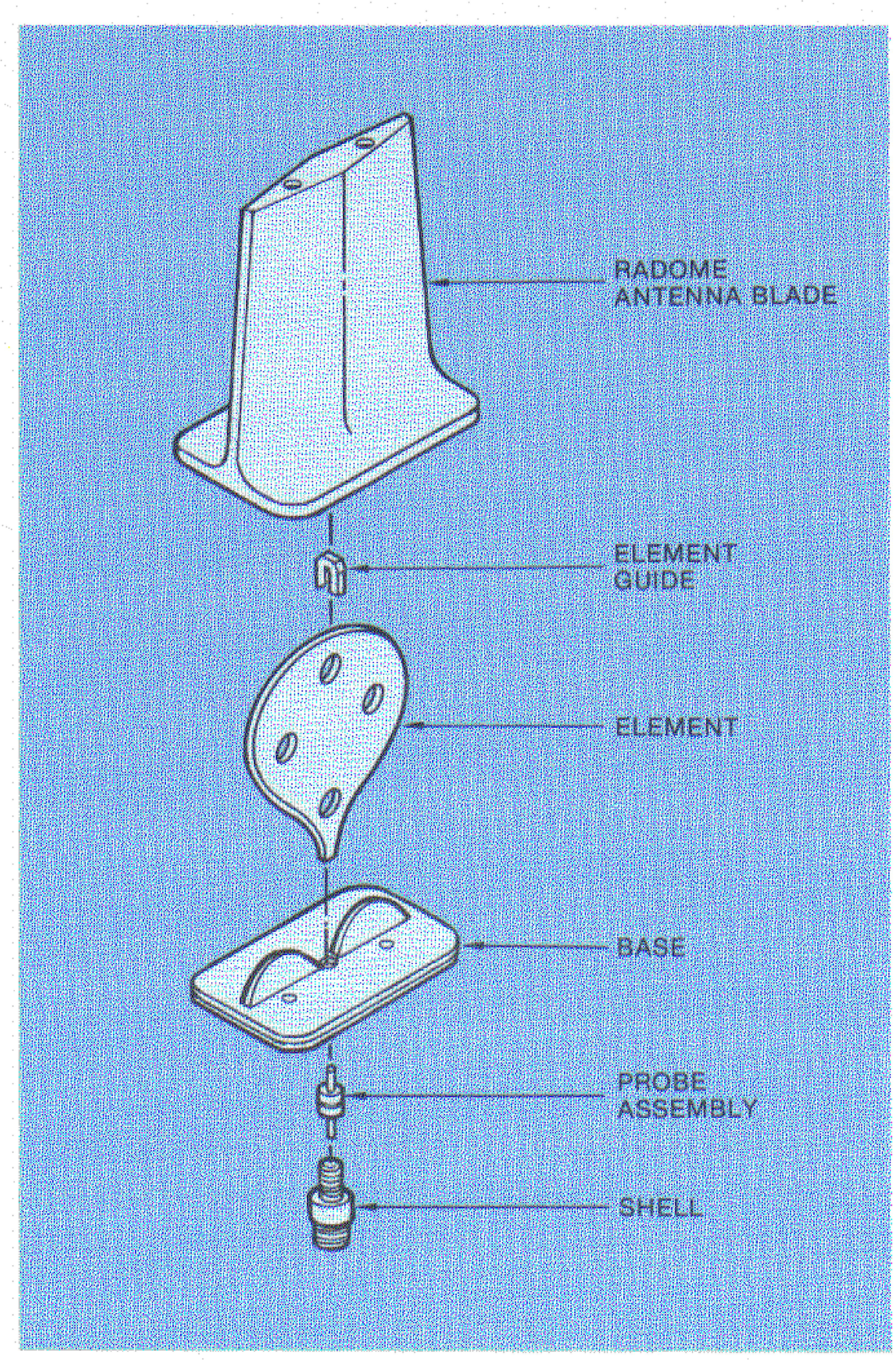


Figure 20. VHF Blade Antenna Construction

coupler must tune this wide range of frequencies, and still handle the 1000 watts of power produced by the radio. This is not an easy task, and this is the reason why a reliable tunable antenna coupler is vital in the design of aircraft HF communication systems. Designers have examined other techniques to broadband the P-3 aircraft's HF antennas, but no satisfactory alternate means has yet been demonstrated.

Maintenance Tips Preventive maintenance for the HF long-wire antenna primarily consists of checking the condition of its mounting hardware and inspecting the antenna wire to determine if it is frayed. If the antenna wire must be replaced, clean the jaws of the antenna wire feed-through mast before installing the new wire. Any material from the old antenna wire that remains on the feed-through mast jaws will prevent them from maintaining a good grip on the new wire.

Moisture is always a problem for the long-wire antenna because it can collect in the strain insulator body, cause corrosion, and promote antenna failure. A good connection is required to prevent moisture from entering the antenna insulator at the end caps. It is recommended that silicone compound MIL-S-8660 be applied liberally to the cavity behind the insulator chucks and to the end cap threads. Before reassembling the antenna strain insulator with the antenna wire, roughen the surface of the antenna wire insulation so that the chuck jaws can gain the best grip possible on the wire to assure a tight connection. After reassembling the strain insulator, wipe the excess silicone compound from its exterior surfaces. Application of proper tension to the long-wire is essential to extending the life of the antenna.

TAILCAP ANTENNA The VHF antenna currently used on the P-3 aircraft is a slot antenna that is located in the leading edge of the vertical stabilizer. This design dates back to the original Lockheed Electra commercial aircraft, from which the P-3 Orion was derived. The slot antenna, like the long-wire antenna, excites the aircraft skin into radiation to simulate longer antenna length for these relatively lower-frequency radiations. The slot antenna is very popular in aircraft system design, because it can be incorporated into the contour of the aircraft and adapts to numerous locations. For critical VHF reception requirements, more modern techniques can be used to tune an antenna to perform well over the entire VHF region. These tuned VHF antennas outperform the untuned slot antenna, and one such antenna is used on certain versions of the P-3 aircraft.

Maintenance Tips The VHF tailcap antenna is an integral part of the P-3 aircraft's tail assembly, and requires very little maintenance. The main maintenance precaution that must be observed is: *do not apply lead-based paint to any surface of this antenna.* Lead-based paint on the antenna will inhibit the passage of RF signals during both reception and transmission.

Most problems experienced by the VHF tailcap antenna system are due to faults in its transmission cable. This transmission cable runs from the galley area, through the tail assembly, and has a matching stub that is in-line with part of the VHF tailcap antenna assembly. If problems are experienced with this antenna, the antenna and its transmission line should be checked with a time domain reflectometer or similar test equipment. The VHF antenna system connectors should be visually inspected whenever possible.

BLADE ANTENNAS The blade antenna is the most common form of antenna found on P-3 aircraft. This type of antenna is used mainly for frequencies that include UHF and L-band. The blade antenna is durable, and it presents a small drag coefficient to the aircraft. This latter characteristic is particularly important. For example, Figure 18 shows that one version of the P-3 aircraft has fifteen blade antennas.

The blade antenna is nothing more than a vertical dipole, and its typical construction is shown in Figure 20. During final assembly, the space between the antenna element and its housing is filled with foam to protect the antenna from vibration. The blade antenna can be constructed either as a monopole or a dipole. When it is constructed as a monopole, the blade antenna is merely a vertical dipole that uses the aircraft skin as a ground plane to provide the virtual image necessary for the other half of the dipole.

The location of the antenna on the aircraft is important. The ground plane *must* be located at the base of the antenna in order for the monopole antenna to produce the reflective virtual image. As discussed previously, the length of a ground plane must be at least five wavelengths in order for it to act as a true ground plane. In most cases, the aircraft satisfies this requirement for radio frequencies from 200 MHz and up. For the blade antenna to work effectively, the aircraft skin must provide a *good* ground plane. This is why it is critical that the antenna be properly bonded to the aircraft.

The blade antenna located on the tip of the P-3 aircraft's vertical stabilizer is a monopole. This is not a good location for a monopole blade antenna, because the antenna does not have an effective ground plane until the radiated signal has passed the distance from the antenna base to the vertical stabilizer. However, this particular antenna was placed on the tip of the vertical stabilizer to give it an unobstructed location. At this location, this blade antenna *does* have sufficient radiation to satisfy its requirements for close air support. A dipole blade antenna would perform better at this location, but the problems posed by its added height outweigh the benefits that would be realized.

The blade antenna is ideal for aircraft installations because it is better suited for coaxial connection than is the standard dipole antenna (see Figure 21). When signals are fed to the standard dipole antenna with coaxial cable, the antenna must be fed asymmetrically. This inherently breeds unequal currents that require special isolation or matching feed points. The vertical monopole blade antenna does not have these problems because it is an asymmetrically-fed antenna by design, and it matches the coaxial feed exactly.

Maintenance Tips Besides being the most popular aircraft antenna, the blade antenna is also the most reliable antenna. Blade antenna failure rarely occurs for any reason other than physical damage or deterioration. Like all antennas, preventive maintenance for the blade antenna consists mainly of periodic visual inspection of the antenna and checks of its cable connections. Those blade antennas that have drain holes should be inspected to ensure that the drain holes are free of obstruction.

The popularity of the blade antenna is responsible for one problem that occurs during maintenance and testing. Since the blade antenna is so popular, there are many manufacturers of each antenna type. Consequently, each "brand" of functionally equivalent blade antenna may have slightly dif-

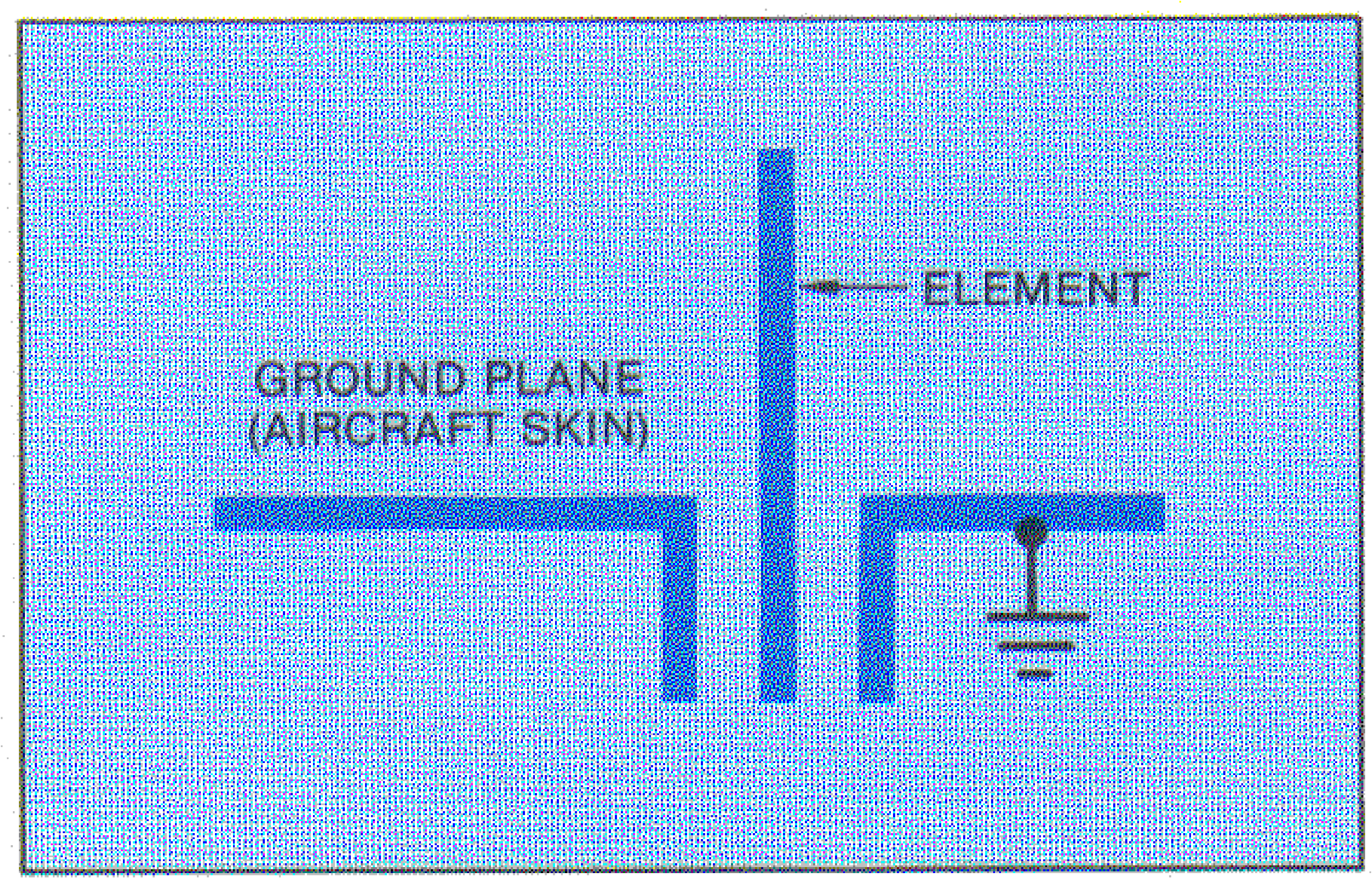


Figure 21. Typical Blade Antenna Connection

ferent test procedures and maintenance requirements. Whenever there is a problem with a blade antenna, the identity of its manufacturer should be noted if the results of the tests differ from those specified for another manufacturer's equivalent antenna. For example, one manufacturer of a blade antenna may specify a particular dc resistance measurement value, while the manufacturer of a *functionally equivalent* blade antenna may specify an entirely different value.

LOOP ANTENNA The loop antenna is derived from the folded dipole. It is the magnetic equivalent of a dipole. The design maximizes the antenna's null point and minimizes its side lobes. This type of antenna is useful for direction finding.

The P-3 aircraft uses loop antennas for VOR navigation, localizer beam reception, and for glide slope beam reception. The balanced characteristics of the loop antenna reject reception of vertically polarized error-producing signals. The glide slope antenna is located within the P-3 aircraft's forward radome to protect it from the elements, and to provide a clear reception path for the signal transmitted from the ground. The VOR antenna is located on the vertical stabilizer, and is specially designed for VOR navigation signal reception.

Maintenance Tip The loop antenna's maintenance requirements are similar to those for blade and other surface-mount antennas, except that orientation and alignment of ADF antennas can be critical. After an ADF antenna has been removed or replaced, precaution must be taken to assure that system alignment has not been disturbed.

ADF SENSE ANTENNA The P-3 aircraft's ADF system sense antenna is a specially tuned dipole antenna that requires careful capacitance matching to the ADF receiver. The location requirements for the ADF sense antenna are precise, because the antenna must be placed so that its vertical component is perpendicular to the ground during level flight.

Maintenance Tip The ADF system sense antenna must be precisely tuned for the system to function properly. Thus, it is critical to ensure that the characteristics of the ADF system transmission cables are carefully matched to the sense antenna's characteristics. If it is necessary to replace an ADF sense antenna cable, the substitute cable must have identical characteristics.

UHF/DF ANTENNA The AS-909/ARA-48 UHF/DF Antenna is a lightweight, airborne direction-finding (DF) antenna operated in the UHF range between 225 MHz and 400 MHz. It is used with other equipment for automatic direction-finding and communications applications. In the P-3C aircraft, the ARA-48 antenna is part of the AN/ARA-50 Automatic Direction Finder system. It is mounted inside the battery inspection hatch, immediately behind the nose landing gear wheel. The ARA-48 antenna is a repairable assembly, but it must be removed from the aircraft if maintenance is necessary. For this reason, the antenna assembly joints are not permanently sealed. The antenna is protected from moisture by a removable water-resistant cover.

The antenna element of the ARA-48 antenna is rotatable, and has a cardioid pattern that is switched 180 degrees at a 155-Hz rate by interchanging the feed and the termination points. Unless the axis of the antenna element is aligned perfectly with the transmitting station (nulled), its received signal will be modulated at a 155-Hz rate. The modulation is detected in a UHF receiver, and the resulting audio is used to drive a servo system which, in turn, rotates the antenna element until it is nulled on the transmitting station. A synchro transmitter geared to the rotating element drives a bearing pointer in the flight station. This UHF/DF antenna has no operating controls. All means for applying power, presenting the bearing information, and selecting the operating frequency are contained in external equipment.

Maintenance Tips Good electrical bonding between the ARA-48 antenna case and the aircraft structure is essential to maintaining an equal ground potential between the two points. The direction finder antenna access door can be painted *only* on those areas where no bonding is required between the door and the antenna. The fiberglass panel, 13 bonding springs, the gasket, and Velcro must not be painted. In addition, the recessed areas where the access door's bonding springs contact the aircraft structure must be free of sealant, paint, or anything else that could degrade electrical bonding. The antenna mounting blocks *may* be painted only if spot bonding is performed before antenna installation.

There have been reports of corrosion on the ARA-48 antenna/battery access door assembly, plus reports of antenna corrosion that may have been caused by water intrusion through the interface of the access door and the fuselage skin. The standard corrosion prevention procedure for the ARA-48 antenna installation is to apply a light coat of VV-L-800 (or equal) lubricating preservative oil to this access door interface every week, and to ensure that the access door is properly secured. Refer to the appropriate NAVAIR Maintenance Publications for the authorized maintenance and corrosion control procedures.

CAVITY ANTENNA A cavity antenna is a specialized slot antenna that is used for only a single frequency or for a small band of frequencies. The P-3 aircraft uses a cavity antenna for the marker beacon. The marker beacon operates at 75 MHz, and the cavity antenna is tuned specifically to that frequency.

Maintenance Tip The cavity antenna requires very little maintenance because its sealed enclosure precludes exposure of the antenna cavity to the environment. However, because the cavity antenna is a tuned antenna system, it cannot be tested in the usual manner with a time domain reflectometer. Instead, the tuned cavity must be checked with a swept-frequency oscillator to determine if the antenna system is responding to the correct frequency.

PARABOLIC ANTENNAS The parabolic antennas used on aircraft are similar in design to parabolic antennas used in ground installations. However, an aircraft parabolic antenna installation must be shielded with a radome that is strong enough to prevent the high-speed wind stream from damaging the antenna, yet still pass radar signals. Fiberglass is the standard material for this task because it is transparent to radio waves. The search radar used on the P-3 aircraft operates in the 9-GHz region, which permits an efficient antenna to be installed within the space available.

Maintenance Tip The parabolic antennas on P-3 aircraft are large and heavy precision devices. During maintenance activities, personnel must strictly observe the procedures presented in the NAVAIR Maintenance Publications to ensure the safety of maintenance personnel and to avoid damage to the antennas.

MICROSTRIP ANTENNA The microstrip antenna is a relatively new design that is the product of dielectric material research and the development of

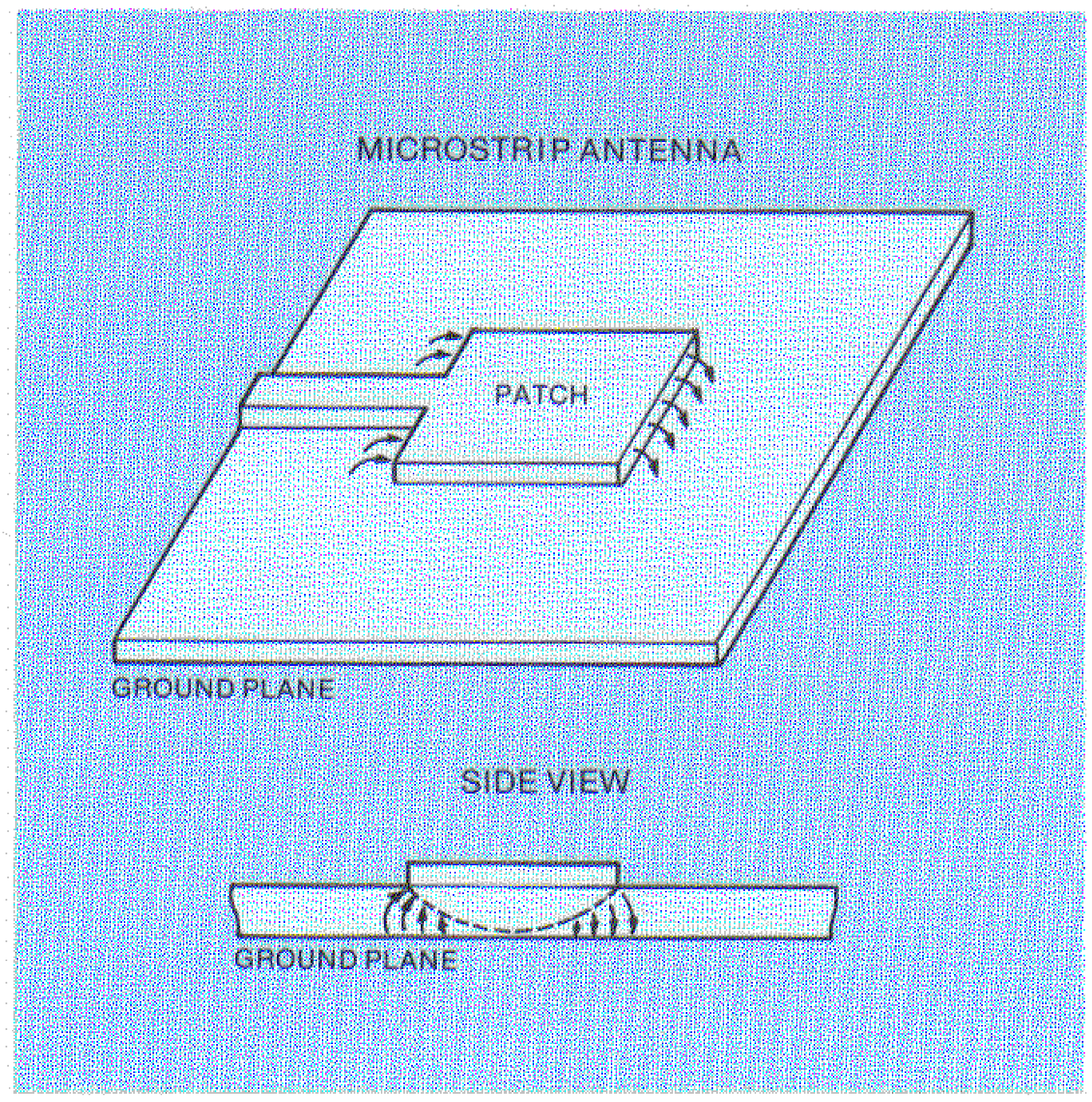


Figure 22. Microstrip Antenna Construction

the printed circuit (Figure 22). On the P-3 aircraft, the microstrip antenna is used as the antenna for the radar altimeter. The microstrip antenna's obvious advantages are its small size and its proximity to the aircraft skin. The microstrip antenna works on the principle of a fractional wavelength antenna that is in proximity with a ground plane. This situation is ideal for mounting an antenna on an aircraft. The disadvantages of the microstrip antenna are that it can handle only very low power, and that it is a narrow-band antenna. Microstrip antennas can be constructed in many forms, including arrays for specialized pattern applications.

SPECIAL PURPOSE ANTENNAS The P-3 aircraft uses several special purpose antennas for specific applications. The characteristics of these antennas and their applications are discussed briefly in the following paragraphs.

Horn Antenna The horn antenna is used primarily in radar applications because it is a natural radiator for the termination of a waveguide. The horn antenna is widely used as a feed for large radio astronomy telescopes, phased array antennas, and as a standard for calibration of other antenna systems. The popularity of the horn antenna stems from its ease of construction, versatility of shape, and predictable performance. Figure 23 shows some of the basic horn antenna configurations.

Spiral Array Antenna The spiral array antenna is a broadband antenna that is the product of the application of printed circuit technology to antenna

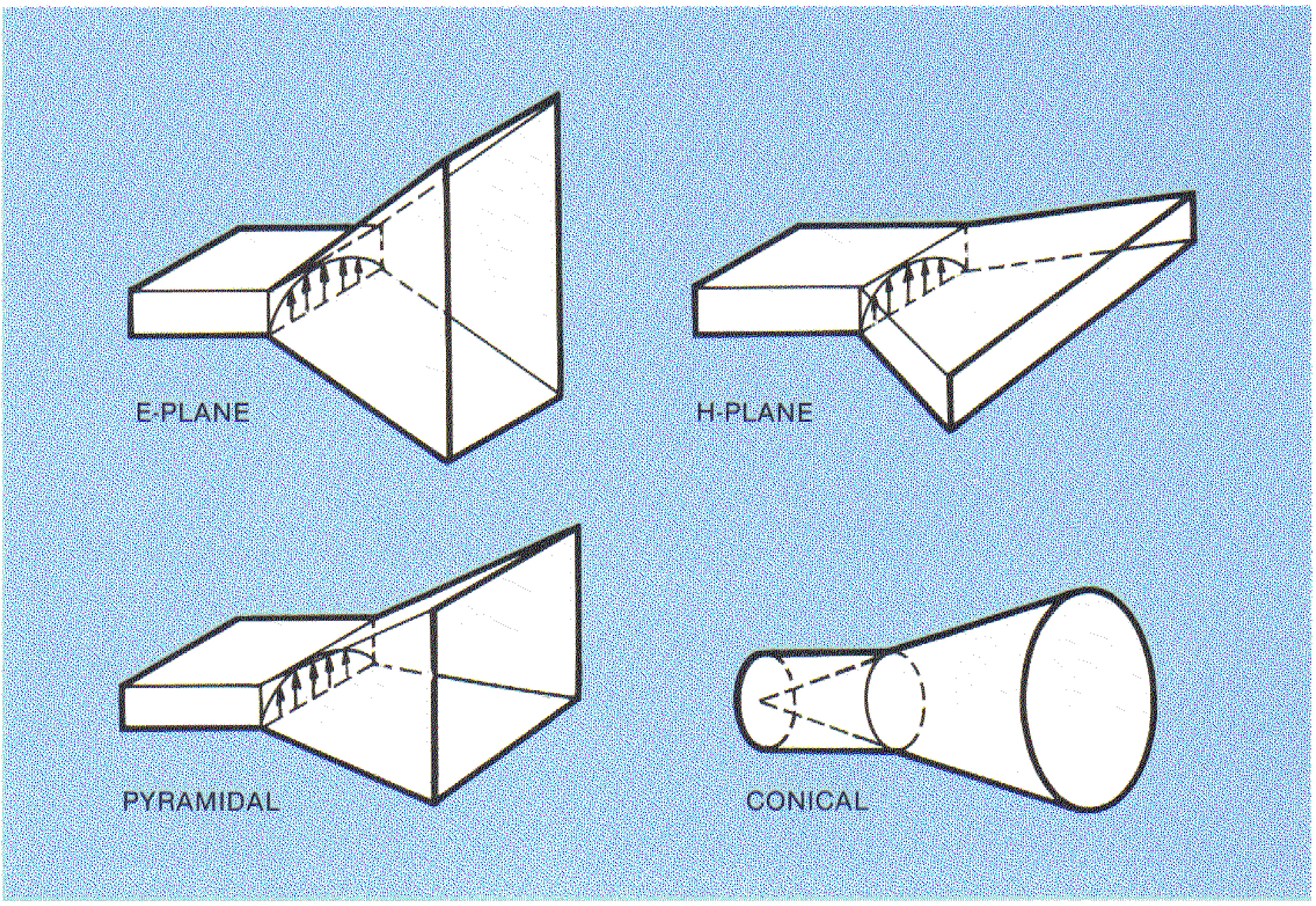


Figure 23. Basic Horn Antenna Configurations

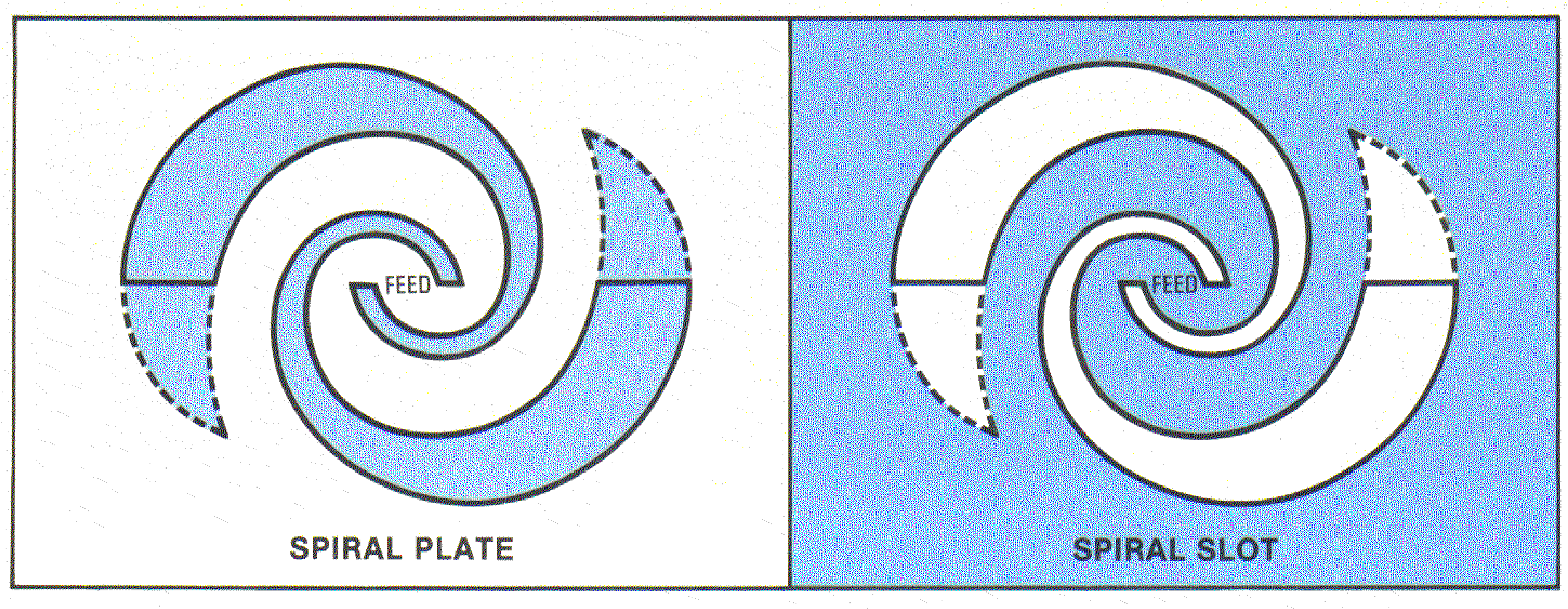


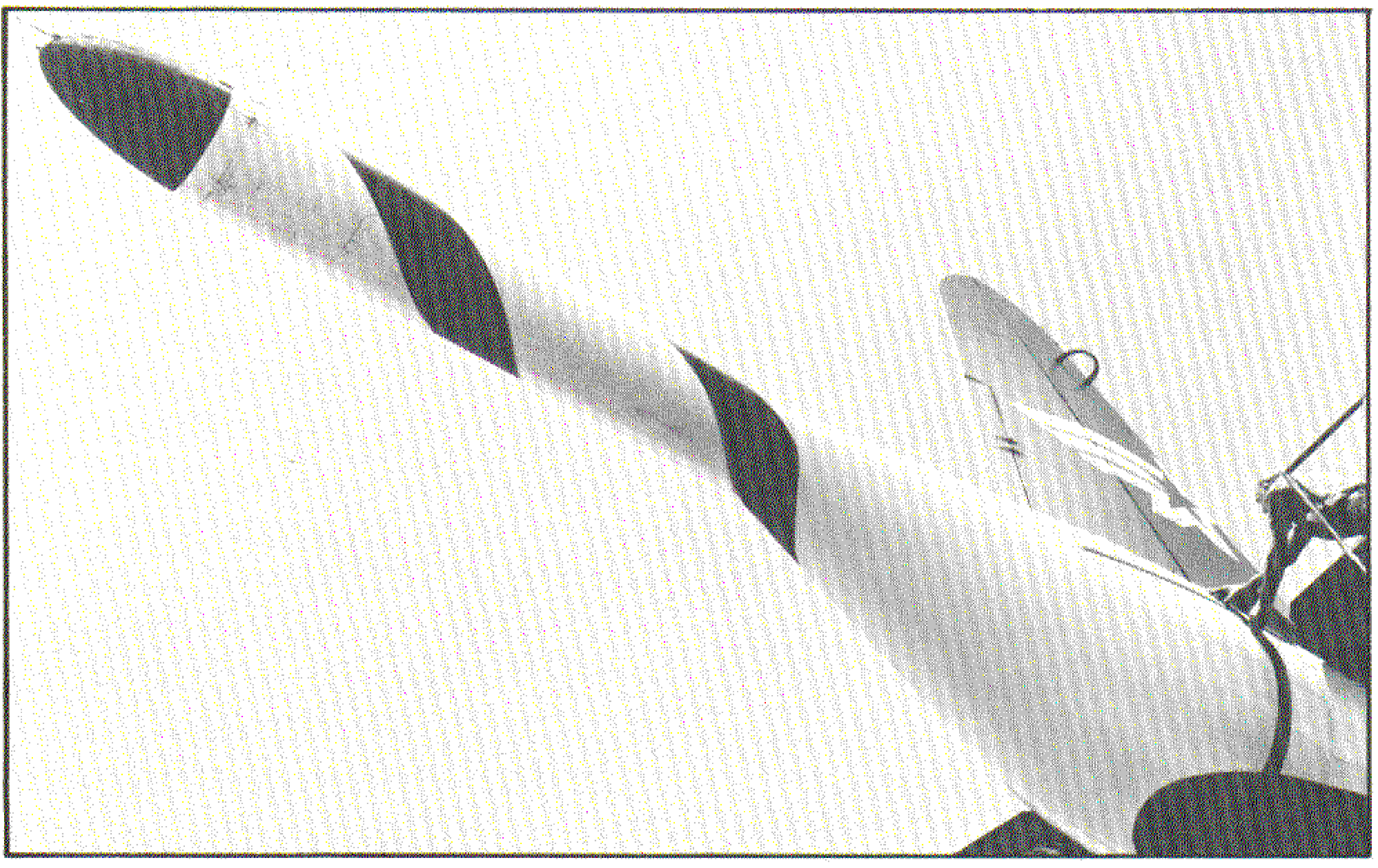
Figure 24. Basic Spiral Array Antennas

construction. It consists of tapered spiral "arms" or elements that progress outward from the same starting point, as shown in Figure 24. On aircraft, the spiral array antenna is used only for very high frequency applications, because at lower frequencies the size of the antenna would be prohibitive. The radiation pattern of the spiral array antenna can be readily modified by adjusting the phase relationship between the antenna's various spiral elements. Solid-state switching circuits make this a practical technique for modern communication antenna applications. Since the spiral array antenna is very thin in one dimension, it can be conformally adapted to the shape of the aircraft fuselage during antenna design. The spiral array antenna is used extensively for satellite communications. The P-3 aircraft is likely to use a spiral array antenna for this purpose in the near future.

The conical spiral antenna is a variation of the spiral array antenna, in which the elements are wound around a cylinder or cone (see Figure 25). A version of the conical spiral antenna is being developed for special P-3 aircraft applications.

PHOTO BY GLENN SUNDERLAND

COURTESY
AMERICAN ELECTRONIC LABORATORIES, INC.



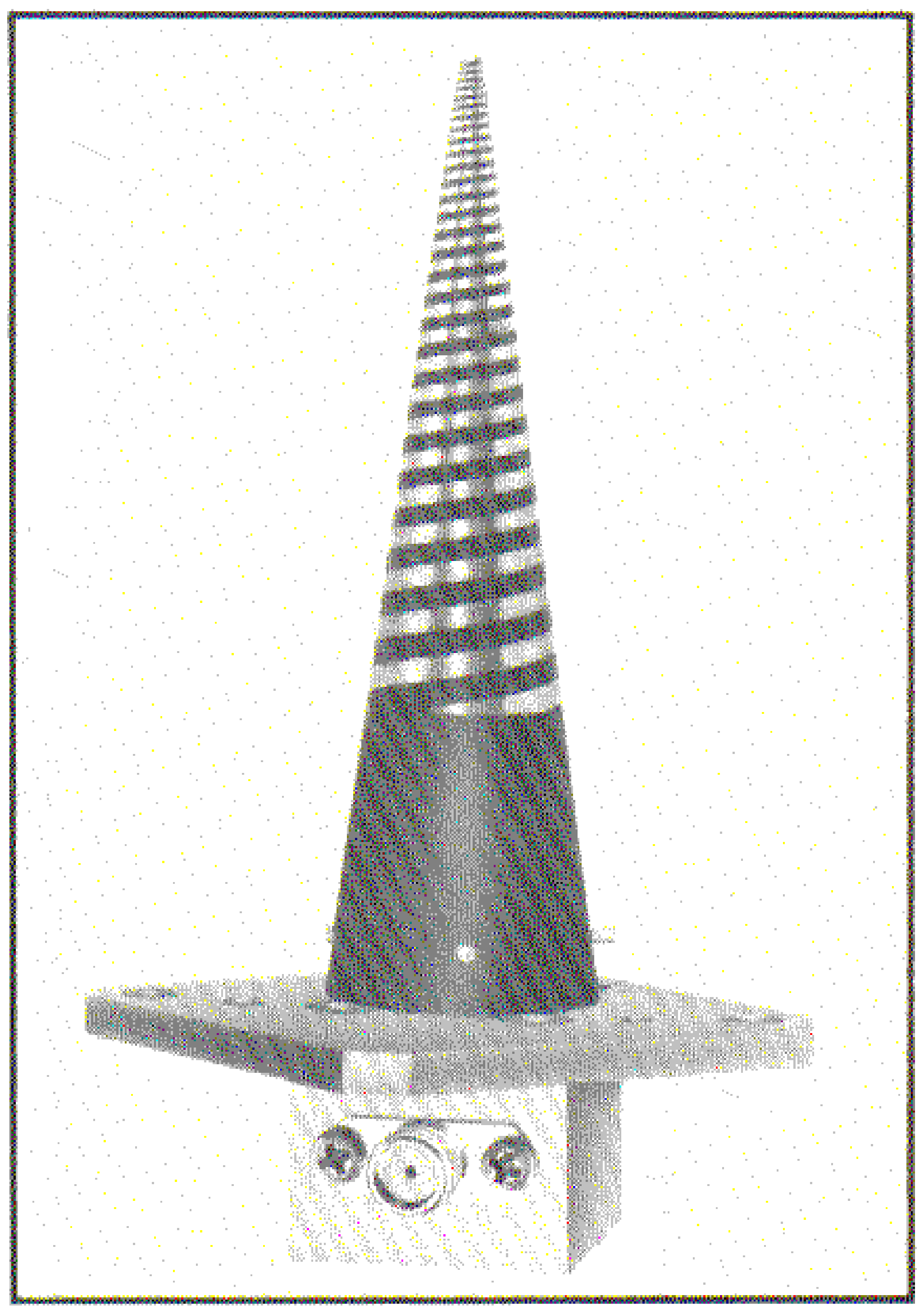


Figure 25. Conical Spiral Antennas

COMBINATION ANTENNAS A combination antenna is just what the name implies. It is an assembly that consists of a single mount incorporating two or more antennas, which are connected to different avionics systems. The most common type of combination antenna is one in which two blade antennas of different frequencies are located on a single mount. Signal separation is performed by electromechanical means or by a diplexer. The IFF/CASS antenna is one such example in which a UHF and an L-band antenna are combined on the same mount. As space becomes less available, more antennas of this type will be used. A new combination antenna that likely will be seen soon on certain P-3 aircraft combines antennas for VHF/UHF and L-band signals into one housing.

Lockheed ORION Service Digest

ANTENNA LOCATION

Antenna location is often as critical a design consideration as antenna type. Commercial radio and television station transmitting antennas are placed as high from the ground as possible to increase the distance that the signal is radiated. Similarly, receiving antennas for commercial broadcast signals are located as high from the ground as possible to obtain optimum signal reception. On the other hand, VLF transmitting antennas are located low to the ground to generate a strong ground wave. Antennas also must be located to clear any nearby obstructions and to avoid interfering metallic objects that could have a shielding effect or could reflect signals. Probably the greatest challenge to the antenna designer is the placement of aircraft antenna installations.

The aircraft is not an ideal carrier for antennas — it is round, relatively small, and possesses many appendages. All of these characteristics tend to reduce the effectiveness of communication antennas. The P-3 aircraft has large wing and tail surfaces relative to its body size. It also carries external stores that tend to interfere with the radiation patterns of those antennas located on the bottom of the aircraft. Antennas required for communication with the ground *must* be located on the bottom of the aircraft. Examples of such are the Doppler, IFF and sonobuoy antennas. Antennas required for communication with other aircraft are better located on the top. The nose and tail of the aircraft are taken up with radar antennas, which must be located where the field of signal radiation is unobstructed. To avoid cross coupling, each antenna should be located several wavelengths from any other antenna. This practice, though desirable, cannot be observed for many aircraft antenna installations, as is apparent from a brief look at Figure 18.

Locating an antenna on an aircraft is no easy task. The lack of ideal locations for aircraft antennas means that the antenna systems are usually operating at less than optimum performance. This is further reason for antennas to be maintained in prime operating condition.

ANTENNA CABLES

Each radio system must be connected to its antenna system. Ultimately, the performance of the radio system depends on how effective this connection is made. Many systems require that the connecting transmission cables be of precise length and specific type. For example, both the ARS-3 Sonobuoy Receiver System and the Automatic Direction Finder Loop System require that the cable phase contribution be computed into the final calculation of system characteristics in order to ensure system accuracy. Any change in transmission cable characteristics can render the radio system unusable.

IMPEDANCE The impedance of an antenna cable must be matched to that of the antenna and associated equipment. Any impedance mismatch will produce excess standing waves, which will degrade system performance. The dipole antenna has a characteristic impedance of around 75 ohms, the impedance of the folded dipole antenna is 300 ohms, and other typical antennas exhibit impedance values of from 20 to 600 ohms. The easiest way to match the transmission line to the antenna is to use a transmission line that has the same characteristic impedance as the antenna.

The official maintenance publications list the characteristic impedance of standard military coaxial cables and antenna systems.

For basic antenna designs such as the dipole, the impedance of the cable can be matched to that of the antenna without difficulty. However, special antennas often have special impedance characteristics, and cables may not be readily available to match them. In such situations, an impedance-matching auxiliary device must be used. Several impedance matching methods are available, the most popular of which are discussed below.

Balun One variation of the balun is a physical quarter-wave section that is used as a current-canceling device to neutralize the reflected or unbalanced current in the shield of a coaxially-connected antenna (see Figure 26a). This device isolates the outer conductor of the coaxial cable to prevent the return of unwanted current. This reduces the SWR and "fools" the Receiver/Transmitter into thinking that it is matched to the antenna. The balun is especially effective in matching a coaxial transmission line to a balanced antenna.

Bazooka Matching Stub The impedance of an antenna and transmission line can be matched by connecting a short or an open-circuit stub to the transmission line at the point where the lowest SWR is achieved (see Figure 26b). The matching stub traps the unwanted reflected current at that point to provide an efficient impedance match. This type of device is effective only for single-frequency or very narrow-band operation, because of the critical location of the stub.

Quarter-wave Transformer The quarter-wave transformer can be used to match the impedance of a transmission line to an antenna. The impedance for the quarter-wave transformer is determined by using the equation:

$$Z_O = (Z_r Z_S)^{1/2},$$

where Z_O is the characteristic impedance of the quarter-wave transformer, Z_r is the impedance of the antenna, and Z_s is the impedance of the transmission line.

A typical quarter-wave transformer installation is shown in Figure 26c. The P-3 aircraft uses a 16-

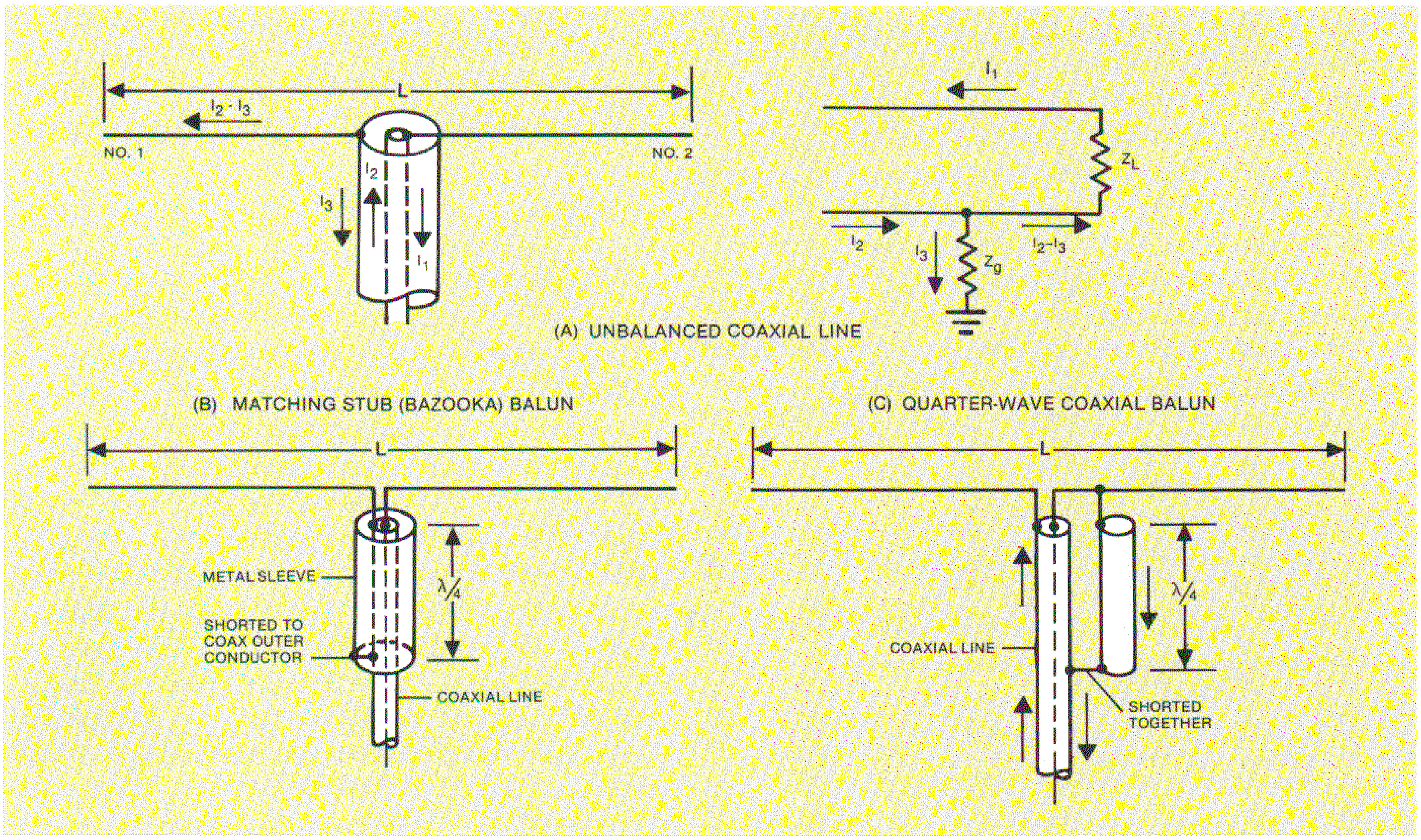
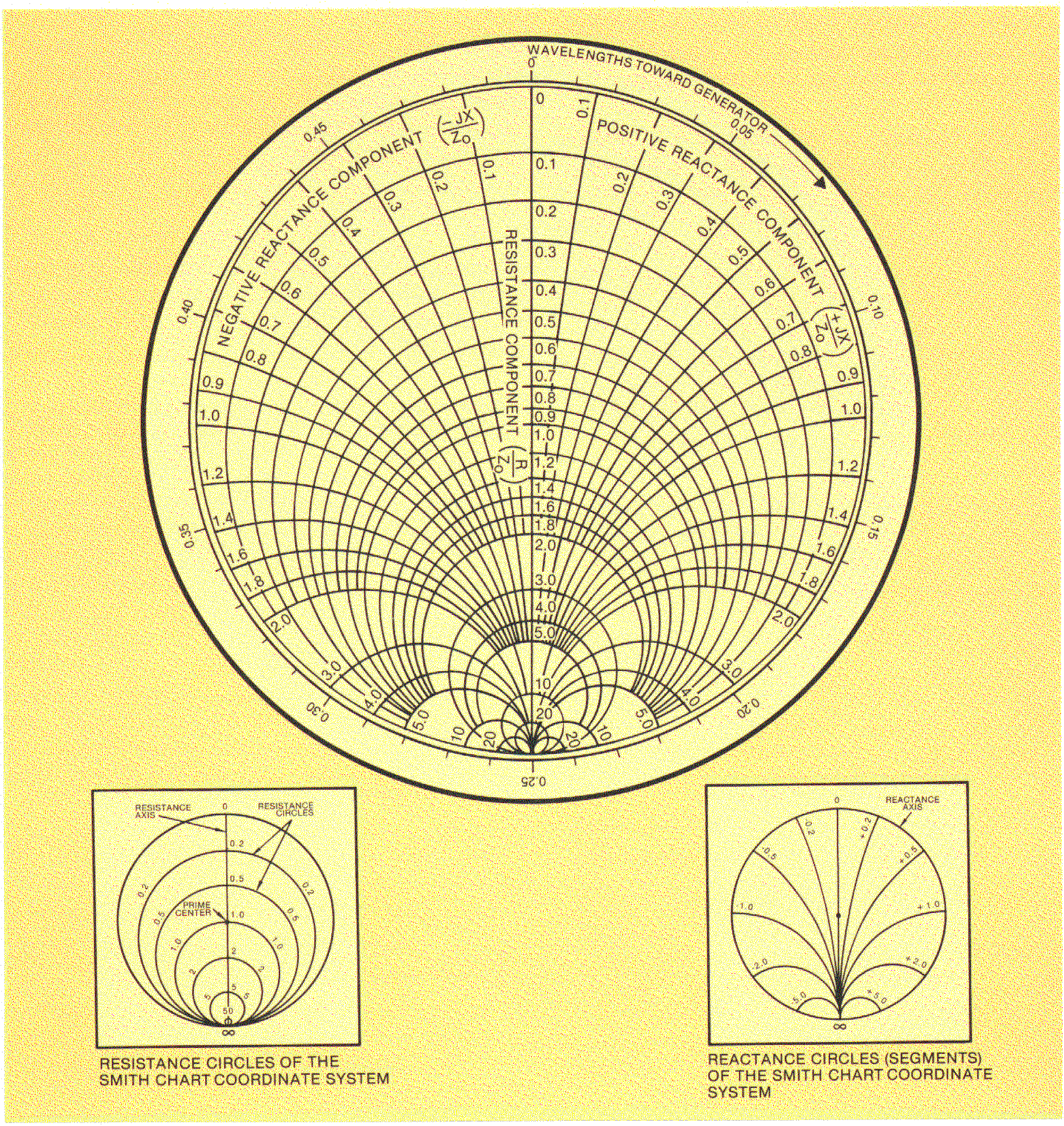


Figure 26. Techniques for Matching the Impedance of the Transmission Line to the Antenna

inch stub of 73-ohm coaxial cable to match the 22-ohm characteristic impedance of the VHF tailcap antennas to the 50-ohm VHF system transmission line impedance.

Broadband Matching Devices All of the above techniques are used for impedance matching within limited bandwidths. Special techniques must be used for broadband impedance matching. Among these techniques are the use of ferrite-core transformers that exhibit high impedance over a wide band, and the use of specialized connections that broadband the termination of the transmission line to the antenna.



RESISTANCE CIRCLES OF THE SMITH CHART COORDINATE SYSTEM

REACTANCE CIRCLES (SEGMENTS) OF THE SMITH CHART COORDINATE SYSTEM

Figure 27. The Composite Smith Chart

TERMINATIONS The proper way to terminate a transmission line that feeds an antenna system is to match the characteristic impedances of the transmission line equipment and antenna. If a lossless line is assumed and the impedance is matched, all the energy generated by the transmitter will be delivered to the antenna. Impedance mismatch generates standing waves, and this reflected energy reduces the effective energy accepted by the antenna for transmission.

Transmission lines are usually connected to feed signals across the center of the antenna or at the ends of the antenna's driven elements. These are called center-fed or end-fed antennas. However, signals are sometimes fed "off-center" to antennas to obtain special radiation patterns or to match impedance characteristics.

At the ends of the antenna, the current is always zero and the voltage is maximum. The opposite is true at the center of the antenna. The point on the antenna where the transmission line is connected must have the proper current/voltage relationship, otherwise the antenna cannot achieve the proper form of excitation. When the transmission line feed is connected to the antenna at a point of maximum current, the antenna is a *current-fed system;* when the transmission line feed is connected to the antenna at a point of maximum voltage, the antenna is a *voltage-fed* system.

WAVEGUIDES The waveguide is a conducting tube through which energy is transmitted as electromagnetic waves. It is a low-loss means of conducting higher frequency signal transmissions that is used when considerable power is employed. The waveguide is a conductor that is especially suited for connection to horn radiators, which is why they are used by many radar systems. Like transmission lines, waveguides must be matched to the antennas that they feed. However, the maintenance and care of waveguides differ considerably from that for the transmission line, as will be discussed later in this article.

SMITH CHARTS Whenever complex problems require frequent evaluation, it is inevitable that some means will be developed to make the solution to these problems easier. One such complex area is the solution of SWR and impedance functions of cables and waveguides. The impedance circle diagram or *Smith Chart* (developed by Philip H. Smith in 1939) is a graphic tool that can help the designer resolve these problems. Figure 27 shows the various resistance and reactance curves that make up a composite Smith Chart. Like many graphic tools, it appears overwhelming at first, but a few trial applications will reveal its usefulness. It is not, however, the intent of this article to discuss the Smith Chart at length. These charts are used primarily for design and installation computations, and are rarely used during maintenance (except at times of major rework).

Lockheed
ORION
Service
Digest

EMI/EMC/EMP CONSIDERATIONS

The proximity of P-3 aircraft antennas to one another and the broad bandwidth required for most system operations pose an extremely difficult environment for controlling electromagnetic interference (EMI) and electromagnetic pulses (EMP), and for achieving electromagnetic compatibility (EMC). Antenna installations are designed to minimize detrimental electromagnetic emissions. Maintenance personnel must scrupulously observe the following recommendations to ensure optimum antenna system performance.

- Properly terminate the system transmission lines to keep the SWR low. This reduces unwanted radiation from the cable between the receiver/transmitter and the antenna.
- Use only recommended connectors, and maintain their effective connectivity.
- Ensure that the antennas, filters and cables are properly bonded to aircraft ground.
- Ensure that all equipment meets the required EMI specifications, and continues to do so after installation.
- Maintain filters in antenna feedpaths, because the antenna will radiate any signals sent to it within the response of its frequency range. These signals are often beyond the frequency range of the specific system to which the antenna is attached.

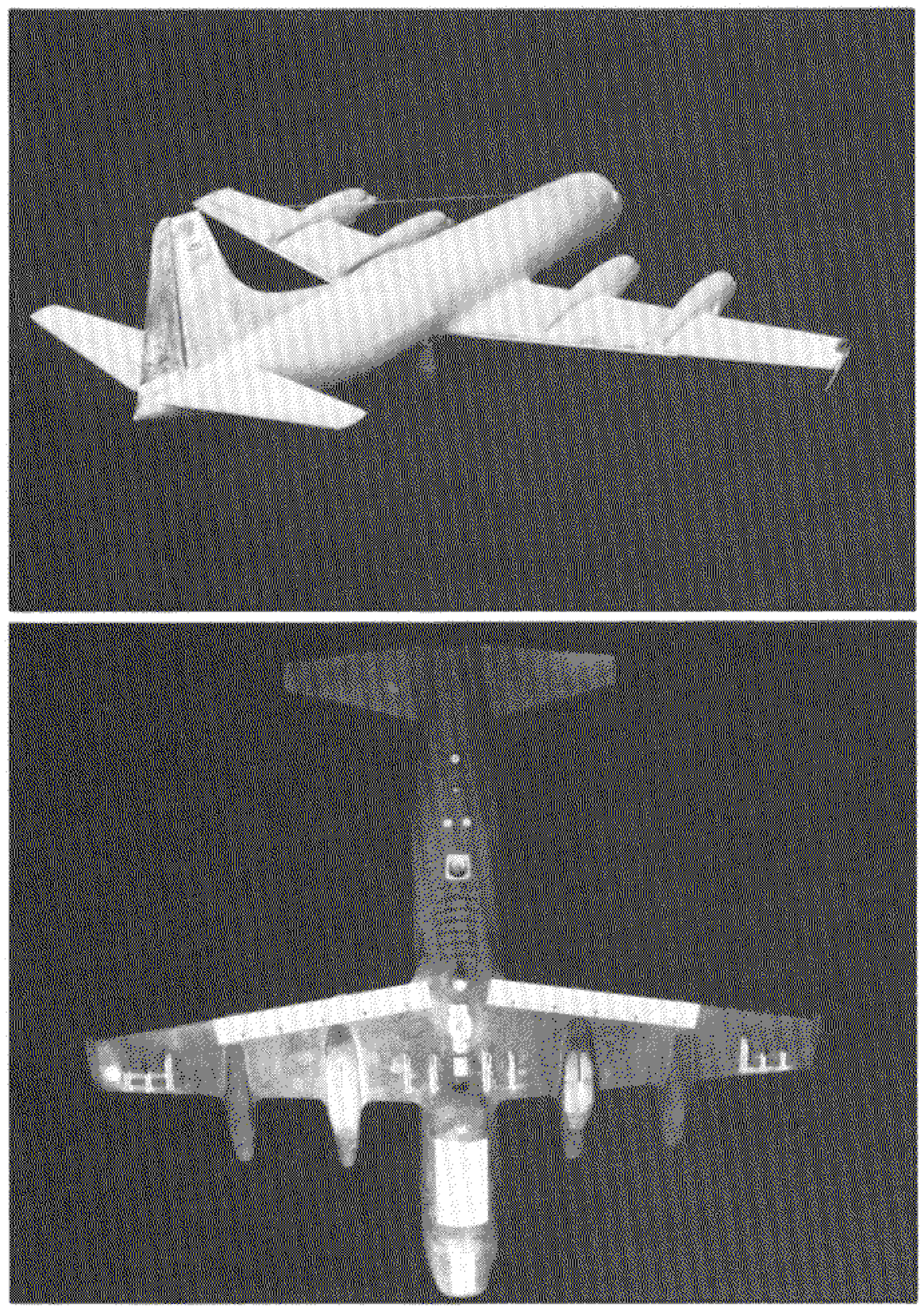


Figure 28. One-Twentieth Scale P-3C Model with Mounted Antennas

Since most antennas are simple dipoles or forms of that design, they will radiate energy at frequencies well above their specified operating bands, even though at reduced levels. Out-of-band radiation can be limited by the use of filters or by installing tunable antennas. Tunable antennas help reduce out-of-band radiation, but they are more expensive and are of limited availability. Several P-3 aircraft antenna installations use filters to improve system performance and limit electromagnetic interference.

ANTENNA SCALE MODELING

The size and complexity of aircraft antenna systems and the expense of flight-testing them have led to the development of a specialized procedure for evaluating antennas known as scale modeling. By using the basic formula $\lambda = c/f$, it can be seen that when a signal's *frequency* is multiplied by ten, its *wavelength* is divided by ten. This mathematical relationship permits the designer to scale down the size of the antenna system before performing tests. The typical scale of the aircraft model is from 1:4 to 1:20. Lockheed has conducted tests and analyses of scaled models of aircraft with antenna installations at its Rye Canyon, California and Marietta, Georgia facilities. Through use of the scale modeling method, new antenna installations can be evaluated in a laboratory environment to determine their influence on other aircraft systems. A typical scale model aircraft, with mounted antennas, is shown in Figure 28.

CARE OF ANTENNA SYSTEMS

Antennas are one of the most reliable aircraft system components. Even so, they require proper care and maintenance to ensure that they perform to their fullest capability throughout their operational life. By necessity, antennas are located on the exterior of the aircraft. Consequently, they are subjected to the full effect of the elements, and their performance can deteriorate due to corrosion, lightning strikes, breakage, or loosening. Most of these factors can be controlled by periodic maintenance, as specified in the appropriate NAVAIR Maintenance Publications. The following paragraphs are a general discussion of some of the main preventative maintenance techniques for aircraft antennas.

CLEANING AND PAINTING Corrosion can best be prevented by periodically cleaning the antenna installation, and repainting it when necessary. Only paints that meet authorized specifications may be used, and none may be used that have *lead* as a base. Special care must be taken *not* to use paint that contains metallic compounds on radar antenna radomes, because the metallic compounds will attenuate the radar signal and can distort the radar antenna beam pattern.

CABLES AND CONNECTORS Cables and connectors are reliable components when they are considered as part of complex electronic systems. However, frequent installation and removal of equipment can cause premature fatigue of cables and connectors. Any cable and connector assembly that is disconnected should be inspected carefully for corrosion and damage.

REMOVAL AND REPLACEMENT Antennas should last for the useful life of the aircraft. However, if an antenna is damaged or has minor internal defects, it must be replaced. When an antenna is replaced, care must be exercised to follow the procedures called for in the applicable NAVAIR Maintenance Publications. Particular care must be taken to ensure that the mounting surface on the aircraft is clean and free from burrs, because a rough, dirty surface can impair the antenna's bond to the aircraft. This, in turn, would adversely affect antenna performance and lightning protection. The surface of the aircraft is prepared for antenna installation by removing dirt, old sealing compound and other residue with an approved cleaning compound, and then rubbing the surface with crocus cloth to remove any residual dirt or burrs.

ANTENNA TESTING AND REPAIRS Antenna systems require unique test and measurement techniques to determine their serviceability. Three of the most commonly-measured antenna system characteristics are the Standing Wave Ratio, power, and insertion loss. These characteristics will be briefly discussed in the next few paragraphs. Figure 29 is a block diagram of a test setup that includes a signal generator and a standing wave indicator, two of the typical equipments used to perform tests and measurements on antenna systems.

Once an antenna is found to be defective, it must be replaced. The defective unit should be discarded or returned to the depot for disposition, as specified by official procedures. Very few antennas can actually be repaired unless the damage is superficial. Occasionally, nicks and breaks in the protective shell of an antenna can be repaired. When antenna internal assemblies are potted, disassembly and repair are infeasible. Instructions for repairs to antennas that are practical are presented in the appropriate NAVAIR Maintenance Instruction Manuals.

SWR Measurement The most frequently measured antenna system parameter is the Standing Wave Ratio (SWR). The SWR enables the designer (or operator) to determine how effectively the impedance of the antenna is matched to that of the transmit/receive system. An improper impedance match produces a high SWR, which results in poor system efficiency and can damage the antenna or transmit/receive equipment.

The SWR is normally measured by making a slot in a section of the shielded transmission line or waveguide, then examining the standing waves in the line with a traveling detecting probe that is connected to a standing wave meter. The probe is free to move along the slot, and the peaks and dips of the standing wave pattern in the matched cable line can be easily read with the standing wave meter.

The standing wave meter is a highly accurate device, but it is not practical for most field applications because each frequency must be measured

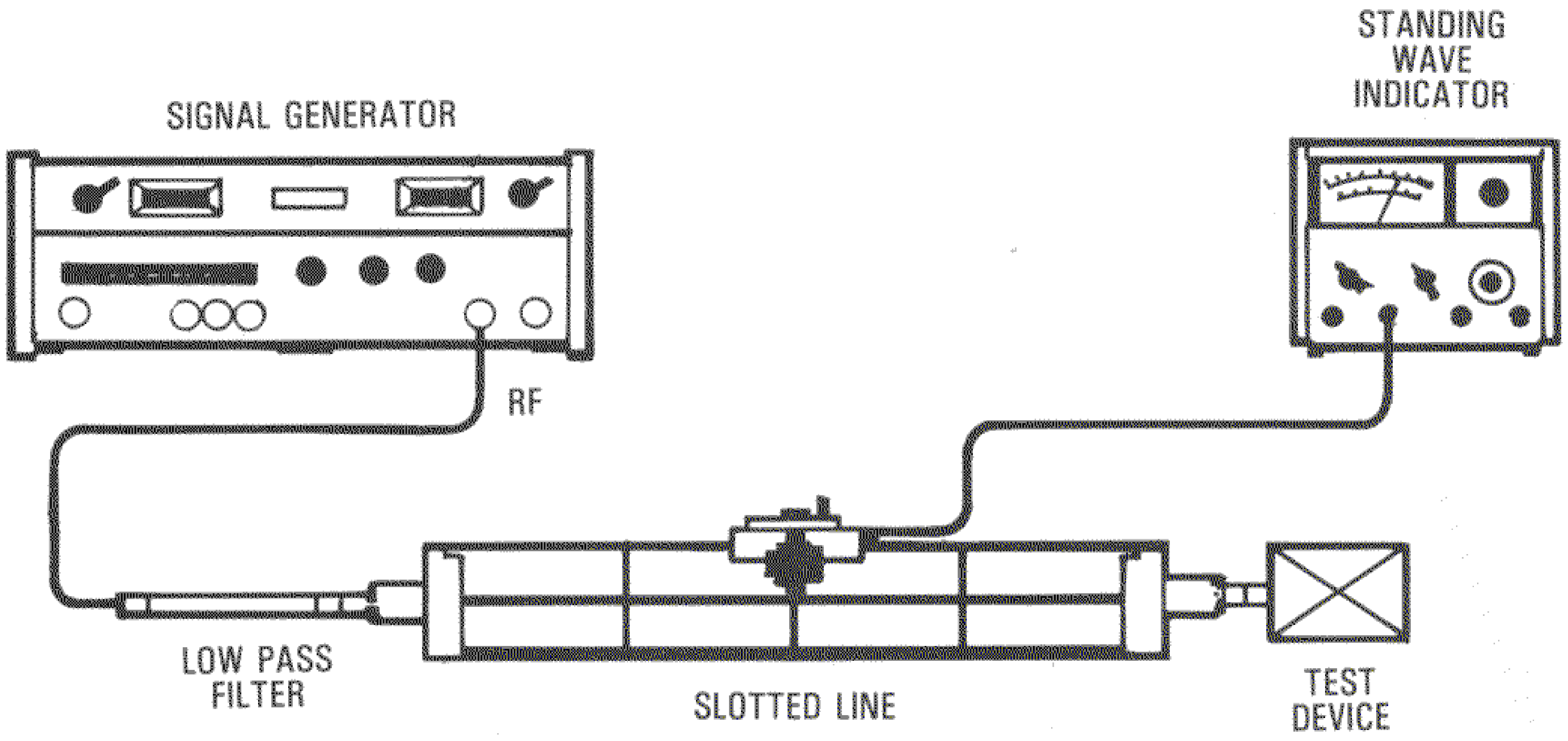


Figure 29. Block Diagram of Typical Set-up of Antenna Test and Measurement Equipment

independently when it is used. This is particularly time-consuming when SWR measurements are performed on broadband systems. Other more sophisticated techniques such as swept spectrum analysis can be used to measure SWR, but cost then becomes a factor. In any case, the impedance of the SWR measuring equipment must be closely matched to the impedance of the equipment under test. Fortunately, it is rarely necessary to measure SWR in the field. Several impedance measurement techniques are compared in Table IV.

Table IV. Comparison of Impedance Measurement Techniques

	MEASUREMENT TECHNIQUE
COAXIAL	**SQUARE LAW** Frequency Range: 10 MHz - 26.5 GHz Typical Accuracy: ±0.4 dB to ±1.0 dB* Typical Measurement Range: 30 dB (415E), 50 dB (8755) Remarks, Cost, Accuracy, Speed: Low cost; moderate accuracy.
	DESKTOP-COMPUTER POWER METER METHOD Frequency Range: 10 MHz - 26.5 MHz Typical Accuracy: ±0.5 dB to ±0.8 dB* Typical Measurement Range: 80 dB Remarks, Cost, Accuracy, Speed: Medium cost; uses standard HP-1B instruments; computes uncertainty from SWR information; very high accuracy.
	RF SUBSTITUTION Frequency Range: 10 MHz - 26.5 GHz Typical Accuracy: ±0.5 dB to ±1.0 dB* Typical Measurement Range: 50 dB Remarks, Cost, Accuracy, Speed: Moderate cost; uses 8495 Step Attenuators as RF substitution; requires X-Y recorder.
	HIGH POWER SOURCE, RF POWER AMPLIFIER METHOD Frequency Range: 10 MHz - 18 GHz (2 GHz bands) Typical Accuracy: ±1 dB to ±2 dB* Typical Measurement Range: 105 dB Remarks, Cost, Accuracy, Speed: Applications usually limited to 2 GHz sweeps; requires low-noise broadband RF amplifiers and high power sources.
	IF SUBSTITUTION Frequency Range: 10 MHz - 18 GHz Typical Accuracy: ±0.1 dB per 10 dB* Typical Measurement Range: 50 dB - 120 dB Remarks, Cost, Accuracy, Speed: High cost; high complexity; high accuracy. Best measuring range.
	COMPUTER-SYSTEM Frequency Range: 0.11 - 18 GHz; 0.5 - 1300 MHz Typical Accuracy: ±0.02 to ±0.1 per 10 dB* Typical Measurement Range: 0 - 110 dB Remarks, Cost, Accuracy, Speed: Highest accuracy. Uses Vector Error Correction techniques to remove system's residual errors (mismatch).
WAVEGUIDE	**SQUARE-LAW** Frequency Range: 3.95 - 50 GHz (7 bands) Typical Accuracy: ±0.2 dB to ±0.4 dB* Typical Measurement Range: 30 dB (415E), 50 dB (8755) Remarks, Cost, Accuracy, Speed: Simple; moderate accuracy.
	RF SUBSTITUTION Frequency Range: 3.95 - 40 GHz (7 bands) Typical Accuracy: ±0.3 dB to ±0.5 dB* Typical Measurement Range: 50 dB Remarks, Cost, Accuracy, Speed: High accuracy; uses rotary vane attenuator as RF substitution; requires X-Y recorder.
	IF SUBSTITUTION Frequency Range: 3.95 - 18 GHz (7 bands) Typical Accuracy: ±0.05 dB per 10 dB* Typical Measurement Range: 30 dB - 110 dB Remarks, Cost, Accuracy, Speed: High cost, complexity; highest accuracy. Best measuring range.

*Assumes DUT match of approximately 1.3; assumes source and detector match of approximately 1.2.

Power Measurements Power is the basic measurement of antenna system performance, since power remains constant throughout a lossless line whereas voltage and current vary continuously. The most widely-accepted method for measuring RF power is with a thermocouple power meter. In-line wattmeters are the easiest meter of this type to use. Power measurements are effective in determining whether a problem exists in the cable leading to the antenna, and whether there are power losses in the coupling devices. Each ARC-161 HF radio system installed in the P-3 aircraft has an in-line wattmeter to provide a continuous check of system operation.

Insertion Loss Insertion loss is the measurement of attenuation in the transmission line. It is most frequently measured by using the Square Law (power ratio) method. Insertion loss is a complex measurement that requires expensive test equipment, and it is not normally performed in the field.

CABLE TESTING AND REPAIRS Several techniques are used to measure the integrity of a cable system. The most popular technique is time domain reflectometry. Other techniques include time domain metrology, frequency domain reflectometry, and three-dimensional reflectometry.

Time Domain Reflectometry Time domain reflectometry (TDR) is the most popular method of cable troubleshooting, primarily because TDR equipment is relatively inexpensive, portable, and easy to use. TDR uses radar techniques, in which a pulse of energy is transmitted down the line and reflected off a fault or the end of the cable. The return time of the reflected pulse is used as a measure of the distance to the fault or to the cable end. The characteristics of the returned pulse also convey information. For example, a positive return of a positive pulse indicates an open circuit or high impedance, while a negative return indicates a short circuit or low impedance (Figure 30). An experienced operator can even locate splitters and other passive devices in the line by analysis of the shape and duration of the pulse.

Time delay reflectometry equipment offers enough flexibility to troubleshoot cables of many types and lengths. However, TDR equipment

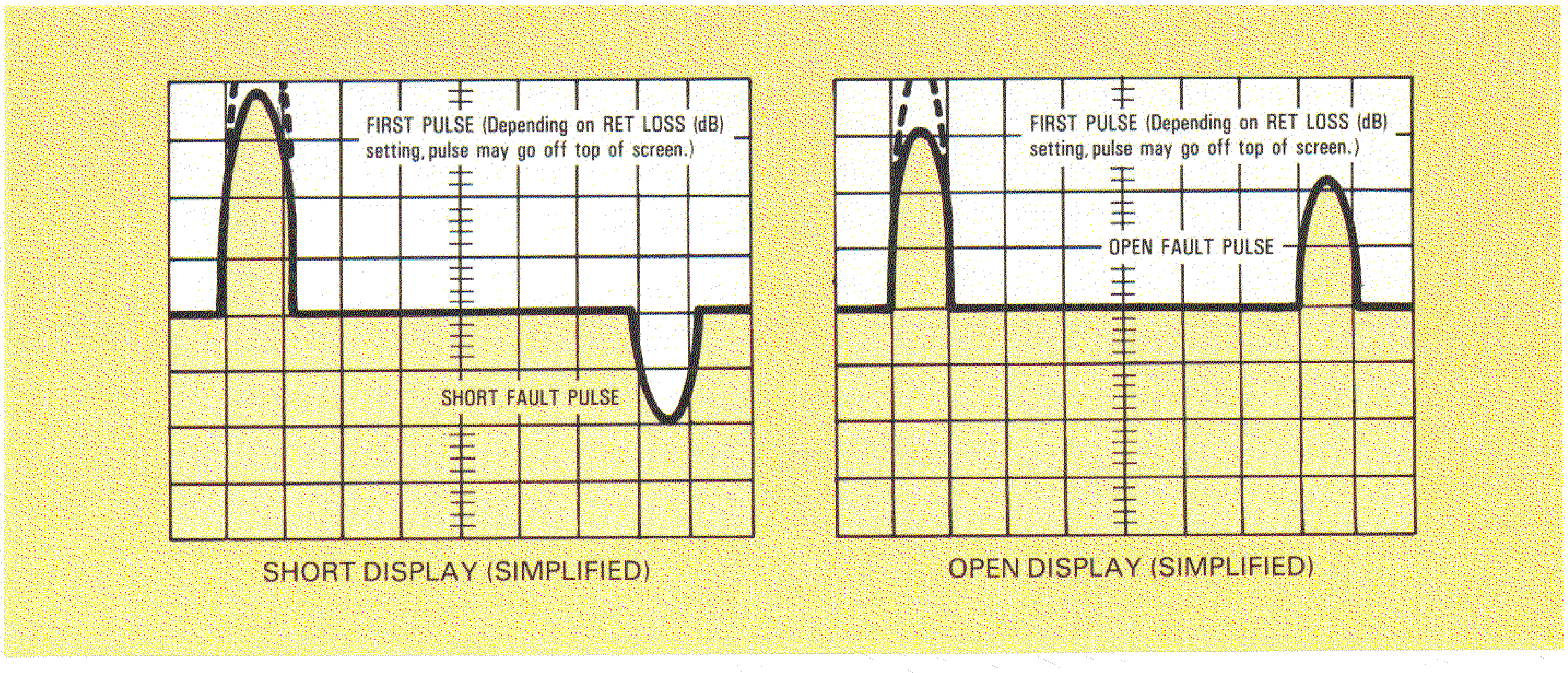


Figure 30. Time Domain Reflectometry Pulse Returns

cannot check waveguides or passive devices such as filters or splitters. TDR is a valuable tool for locating broken or damaged antenna cable in the P-3 aircraft. To realize the full accuracy of the system, the equipment manufacturer's operating procedures must be carefully observed. TDR measurements in the field can be performed with the Tektronix Model 1502 Time Delay Reflectometer, which is readily available.

Time Domain Metrology Time domain metrology (TDM) is a method of troubleshooting that uses a computer in conjunction with time domain reflectometry techniques to add fast Fourier transform analysis of the resultant waveform. TDM equipment is expensive, bulky and not practical for field use, and it requires a highly-trained operator. However, TDM is a good shop tool for cable analysis.

Frequency Domain Reflectometry Frequency domain reflectometry (FDR) identifies transmission line defects by using insertion-loss and return-loss measurements of a frequency-swept signal over a specified band of frequencies. Thus, with FDR, the analysis is made at the actual frequency band of the microwave system. Unlike time domain reflectometry, FDR *can* be used on waveguides and tuned antennas, and it provides more information on cable faults than is obtainable with TDR. However, FDR equipment is bulky and more expensive than TDR equipment, and it requires a highly-skilled operator to analyze the signal returns.

Three-Dimensional Reflectometry Three-dimensional reflectometry (3-DR) is a refinement of frequency domain reflectometry that uses a mixer rather than a bridge, and provides more automatic signal analysis. It is a versatile troubleshooting tool that can be used to check both waveguides and cables. However, 3-DR is very expensive and requires skilled operators.

Cable Repairs The basic repair for defective cables is cable replacement. It is *never* recommended to splice a cable unless the cable run is long and access to the cable is difficult. Loose connectors, poor splice connections, and susceptibility to corrosion are potential sources of trouble that can be traced to installation of cable splices.

Cables should always be replaced with cables of the same type or an approved substitute. Even though a recommended replacement cable may have the same impedance and size, it may not be a suitable replacement for some applications because of its dielectric constant or capacitance characteristics. Always consult the appropriate NAVAIR Maintenance Publications or Depot Maintenance before replacing a cable with a substitute. Specifications for cables recommended for use are presented in Supplement 1A-MIL-C-17D, or its latest revision.

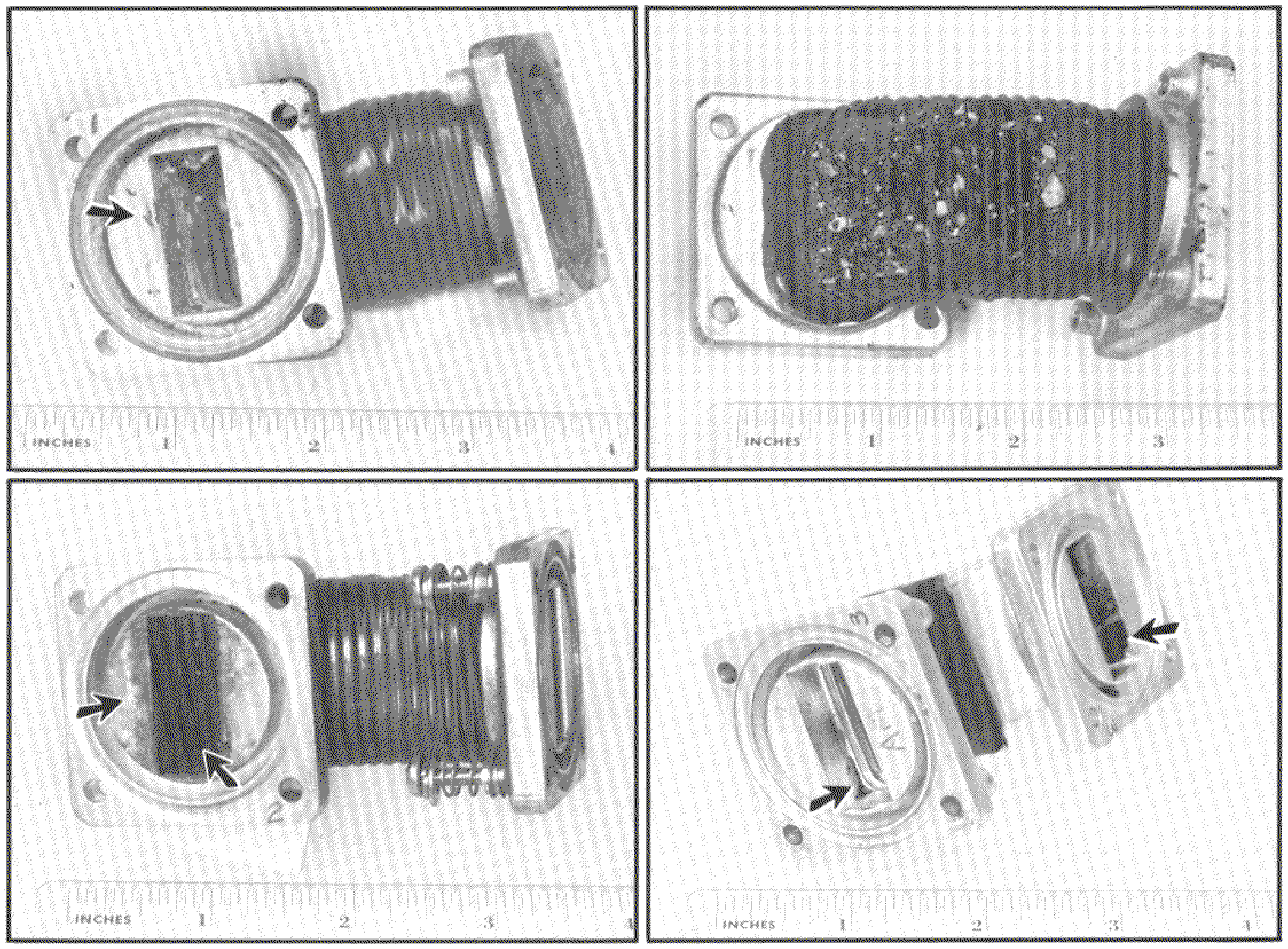


Figure 31. Corrosion Damage to Waveguides

ANTENNA PROBLEMS AND REMEDIES

The following paragraphs describe typical antenna system problems, and discuss how they can be corrected or controlled by proper preventive maintenance.

CORROSION The marine atmosphere contains chlorides in the form of salt particles or droplets of salt-saturated water, plus many contaminants from local industrial sources. The continual bombardment of antennas by airborne contaminants can cause them to erode and corrode, as would almost any metallic substance exposed to these conditions.

Antennas Most antennas are protected with an epoxy anti-corrosive coating to prevent excessive wear and inhibit corrosion. On some blade antennas, the leading edge is protected by a polyurethane rubber strip. Although corrosion cannot be prevented, it can be inhibited by proper preventive maintenance. Approved maintenance procedures, which include cleaning and painting, are presented in the appropriate NAVAIR Maintenance Publications.

One common source of corrosion occurs when moisture accumulates in the antenna housing. Some antenna housings are sealed. If the seal is intact, the interior of that antenna should be protected from moisture. Other antennas have drain holes through which accumulated moisture can be vented. If a drain hole becomes clogged, moisture can collect and bring corrosive agents in contact with the antenna's internal surfaces. If allowed to remain, the corrosive agents will permeate protective coatings and attack the antenna's metallic surfaces. Therefore, the drain holes on all antennas must be periodically checked to ensure that they are free of blockage.

Cables and Waveguides Antenna cables and waveguides are also susceptible to corrosion. Coaxial cables are not normally affected by corrosion unless the outer shield is damaged or has been stripped away. However, cable connectors should be inspected periodically for corrosion, and replaced if corrosion is detected.

The interior surfaces of a receiver/transmitter and its waveguide are in a sealed, pressurized environment. There is little danger of corrosion in these areas unless contaminants are introduced by improper maintenance procedures or through a defective seal. Periodic inspection of the waveguide will reveal if any of the connections have become loose, and whether the seals are intact. If contaminants *are* introduced into a waveguide system, the waveguides will be susceptible to corrosion on their interior surfaces. The build-up of corrosion products within a waveguide system will gradually cause degraded system performance. When high voltage is applied to the corroded waveguide, arcing may occur, which can further damage the waveguide system. Figure 31 shows examples of waveguides damaged by corrosion.

The rotary joints that connect the search radar parabolic antenna feed horn to the waveguide system are inherently susceptible to the introduction of contaminants, although effective seals are a basic part of their design. If contaminants are introduced into the waveguide system through these rotary joints, corrosion is likely to occur. The presence of corrosion products in these joints and the waveguide system can cause degraded performance of the avionics system of which the waveguide and antenna are an integral part. As mentioned previously, the presence of corrosion products may cause arcing when high voltage is applied, which can further damage the waveguide system. Contaminants may also cause the waveguide system switches to operate improperly. This also can cause arcing and damage when high voltage is applied to a waveguide system.

In each of these cases, the cause of waveguide system malfunction can be traced to the introduction of moisture and/or other contaminants to the waveguide system or its interfacing components. The solution to the problem is to exclude or remove the contaminants from the waveguide system. Before applying high voltage to the waveguide, purge the waveguide with dry air and ensure that the waveguide system desiccants are not saturated. Replace the desiccants if necessary. This will minimize the presence of moisture in the waveguide system.

The condition of the waveguide system's moisture-absorbing desiccants should be monitored regularly, and the desiccants should be replaced as specified by the appropriate NAVAIR Maintenance Publications. For example, inspection of the desiccator cartridge on an AN/APS-115 R/T compressor assembly (Figure 32) will reveal if its crystals are saturated with moisture. When pink, the desiccant crystals are saturated. If the pink color has progressed to the indicating mark on the viewing window, the cartridge must be replaced. Inspect the new desiccator cartridge prior to installation to ensure that the tape on its ends has been removed. (Tape is installed over the openings on the ends of the cartridge to exclude moisture from the desiccant while the cartridge is in storage.) Failure to remove the tape from the ends of the desiccant cartridge will render it ineffective, and may cause damage to the R/T compressor pump.

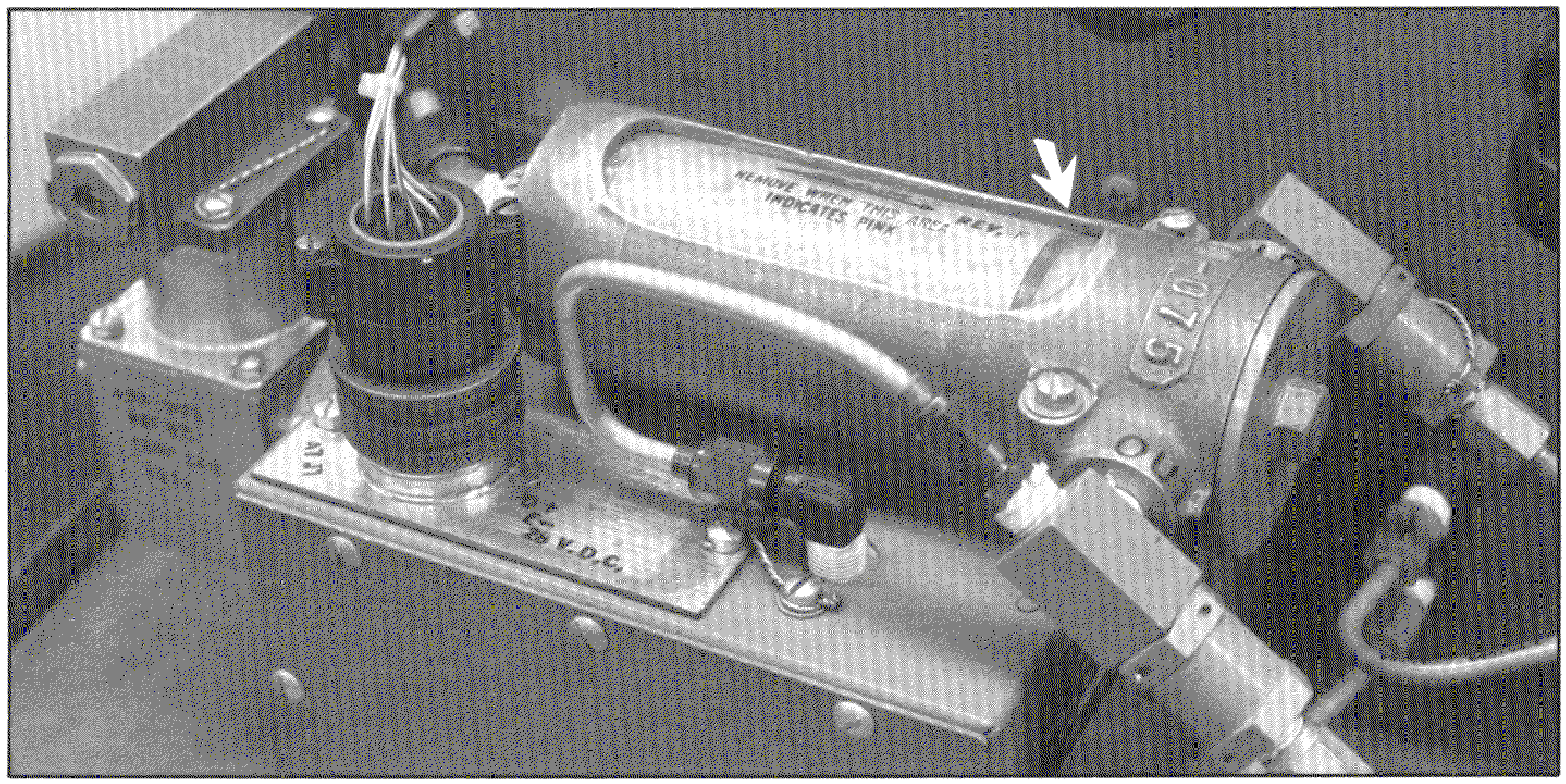


Figure 32. Compressor Assembly on APS-115 Radio Receiver/Transmitter. Replace the Desiccator Cartridge if the Pink Color has Progressed to the Indicating Line

The most likely opportunity for moisture to enter a waveguide system occurs when it is disconnected during routine equipment replacement. The maintenance procedures for waveguide disassembly, storage, and installation are specific, but often these procedures are not observed to the letter. The precaution overlooked most often is that of capping all open waveguide sections during disassembly. A waveguide cap-off plate and two types of caps are shown in Figure 33. Also, the plumbing ports on the waveguide compressor must be capped when the compressor is disconnected from the system. Although these precautions may seem inconvenient, they are necessary because moisture can rapidly enter an uncapped waveguide system. Uncapped waveguide systems are particularly vulnerable in the high-humidity environment in which P-3 aircraft operate.

Corrosion cannot be prevented entirely. It is the natural result of the chemical reaction between metallic and (in most cases) nonmetallic substances within their environment, usually in the presence of moisture. Corrosion is also influenced by physical factors such as temperature, stress, fatigue, etc. However, corrosion of avionics equipment, cables and waveguides can be minimized by ensuring that they have a clean, dry environment.

P-STATIC Precipitation static, also known as St. Elmo's fire or P-static interference, has been a radio communication problem ever since the first radio was installed aboard an aircraft. It occurs when an aircraft flies through clouds, precipitation, or a concentration of dust, snow or ice particles. The friction that occurs when these particles impinge on the aircraft skin causes the aircraft to accumulate a charge of static electricity. When this static electricity discharges to a nearby surface or into the air, it causes a noisy disturbance at radio frequencies in the low to VHF range. P-static is most severe when ice crystals precipitate from a cold-moist atmosphere. This causes the receiver to produce a loud "frying" noise that tends to mask normal communications. P-static interference is most detrimental at low radio frequencies, but it still is a severe problem on the VHF frequency band.

The characteristic shape of the airplane tends to concentrate P-static interference at certain specific surface areas. Figure 34 shows the most active P-Static areas on the P-3 aircraft. This illustration shows that the tip of the vertical stabilizer is an area prone to P-static interference, while the belly of the aircraft is an area that is relatively quiet.

P-static interference can be reduced by controlling the rate of static discharge, or by distributing the discharge to areas where it will cause less interference. The most common technique is to install static dischargers or wicks on the trailing edges of the aircraft. These devices discharge static electricity at a steady, reduced rate, which greatly reduces the P-static interference problem. Locating radio antennas in areas of minimum P-static interference also will significantly reduce the effect of these static disturbances. The susceptibility of radio antennas to P-static interference can be further controlled by use of surface coatings specified by MIL-B-5087.

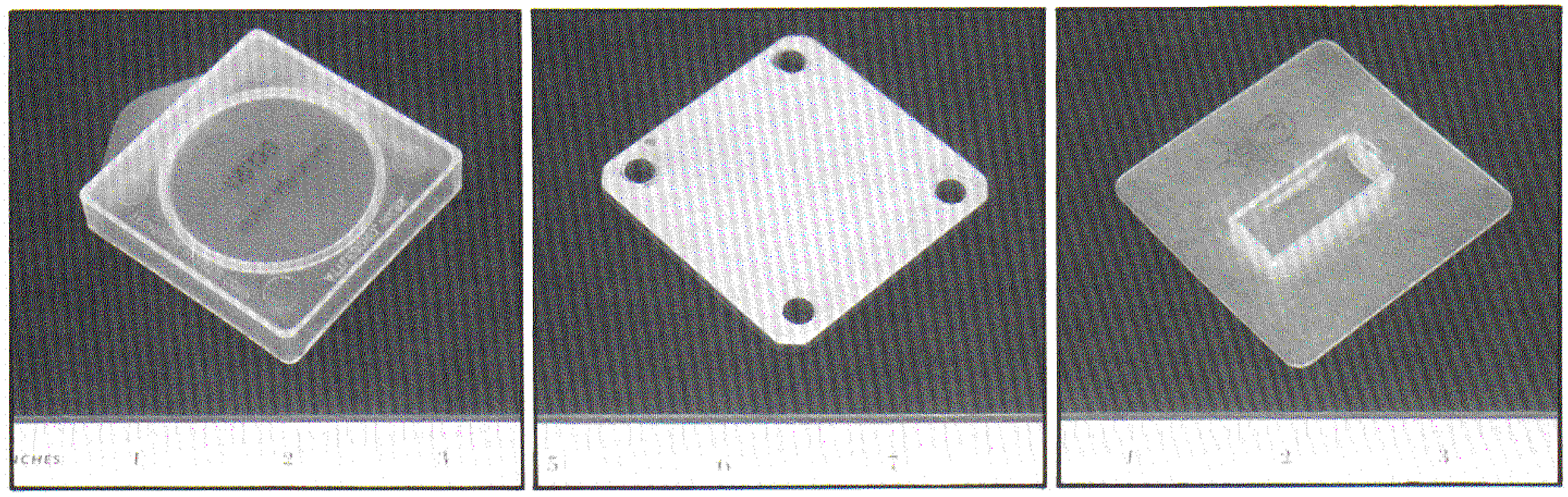


Figure 33. Waveguide Cap-off Plate (Center) and Caps

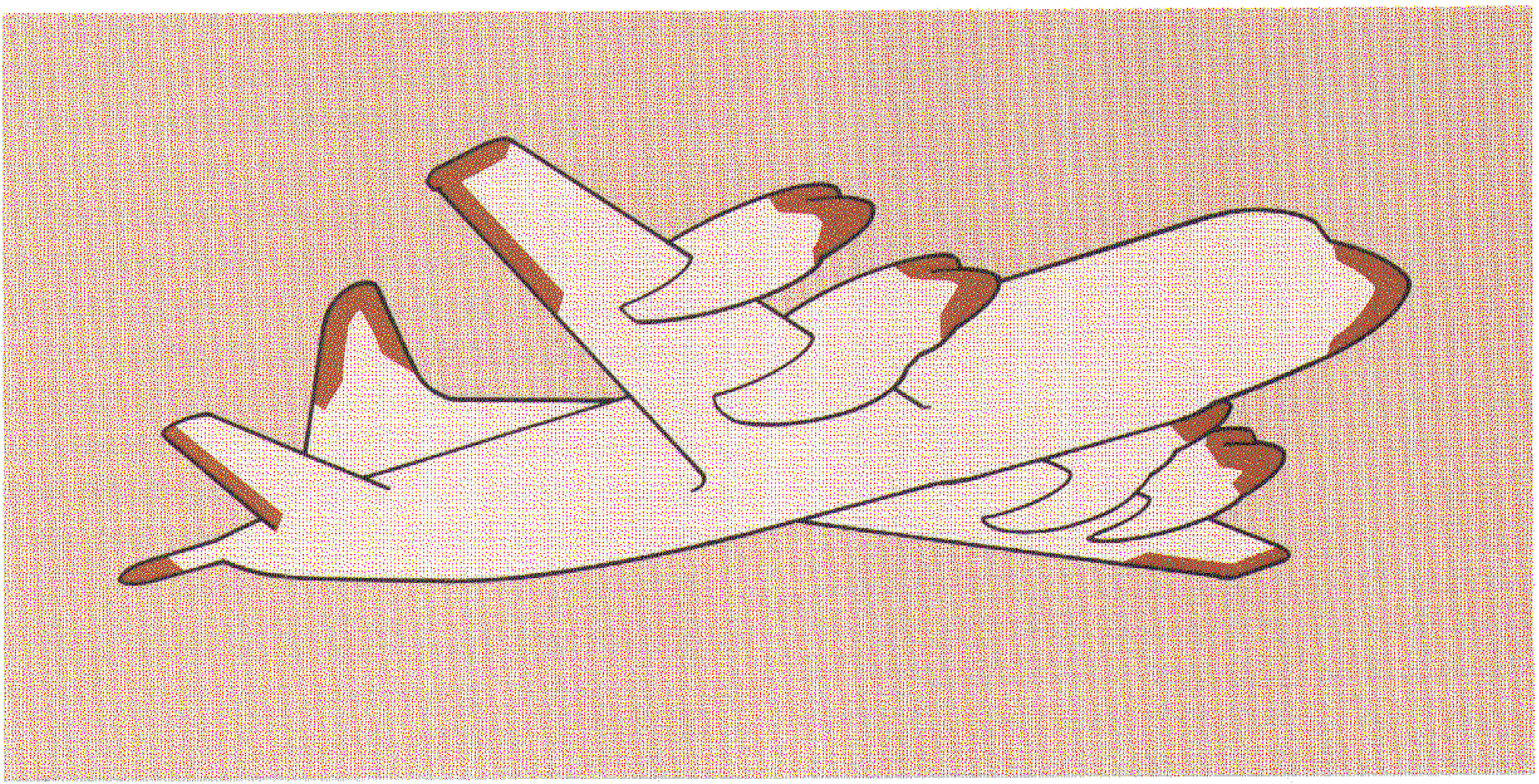


Figure 34. P-Static Concentration Areas on the P-3 Aircraft

During the design of the P-3A Orion aircraft, Lockheed Engineering was aware of the potential affect of P-static interference on the aircraft's communication systems. As a consequence, static discharge wicks were included in the initial aircraft design, strategically located to minimize P-static interference. Later, during the early phases of P-3C aircraft production, the U.S. Navy conducted an analysis to determine the optimum number and placement of static wicks on the P-3 Orion aircraft. As a result of this study and subsequent updates, the configuration of the 41 wicks currently employed on the aircraft was derived. Figure 35 shows the current location of the P-static wicks. During the twenty-plus years of P-3 aircraft operation, improvements in static

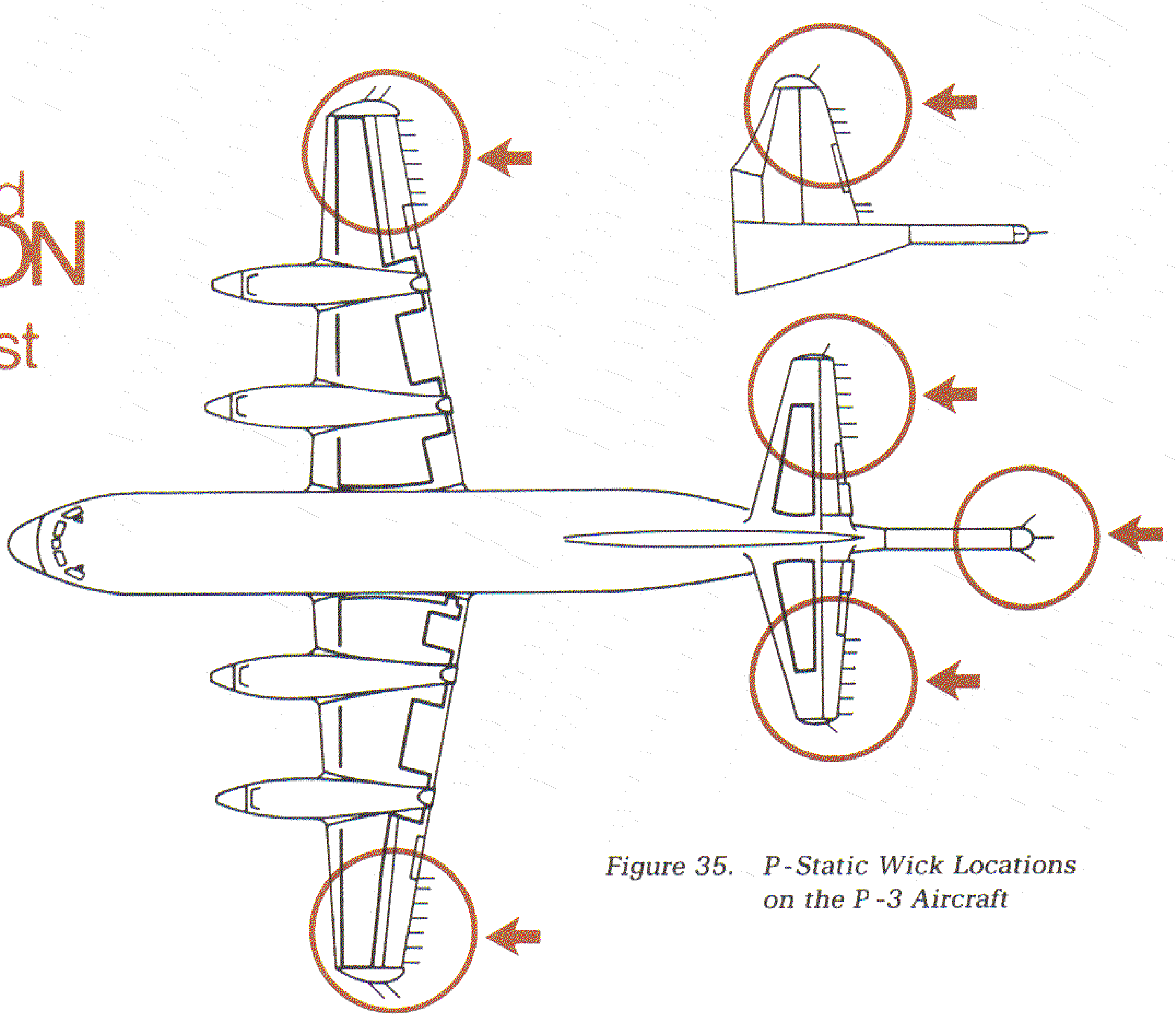


Figure 35. P-Static Wick Locations on the P-3 Aircraft

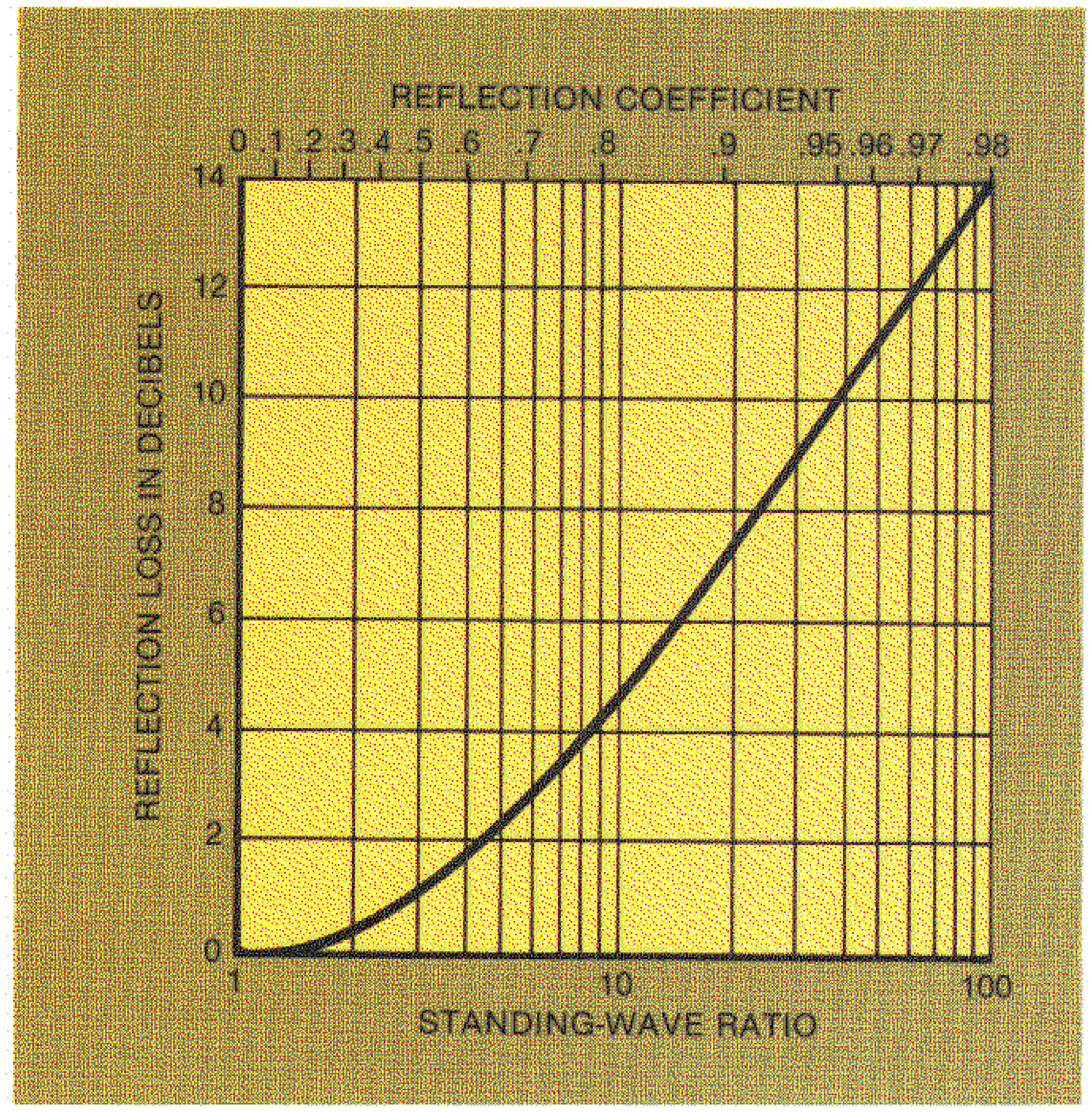


Figure 36. Standing-Wave Ratio Versus Reflection Loss

wicks and bonding techniques have resulted in improved P-static discharge performance. Lately, relatively few recorded problems with P-3 aircraft communication systems have been attributed to P-static interference.

Proper maintenance of static discharge wicks can minimize P-static interference. They should be inspected frequently, and the condition of their bonding to the aircraft should be monitored carefully. Static discharge wicks are susceptible to breakage, and become worn from static discharges during normal operation. When defective or worn wicks are found, approved replacements must be installed and their bonding to the aircraft must be checked. The maintenance technician can check a wick with a high impedance tester, then compare the test readings with the proper readings noted by the wick manufacturer. Care must be exercised when applying paint in the vicinity of conductive paths and antennas. Nonconductive paint must be used on radomes, and paint must be removed in areas where bonding strips are installed to ensure effective grounding between faying surfaces.

LIGHTNING Aircraft antennas are prime targets for lightning strikes because they protrude from the aircraft. They are vulnerable because of their shape, location, and attachment to the fuselage shell. Because of this, all aircraft antenna systems are protected by lightning arresters. The lightning arrester provides a low-impedance path to the aircraft ground for the high potential bursts of lightning. The antenna must be well bonded to the aircraft skin to ensure the effectiveness of this protection. A high-resistance path between the antenna and the aircraft caused by poor bonding would totally defeat the shunting effect of the lightning arrester. Without this protection, a lightning strike to an antenna would probably damage the connected equipment and wiring.

INTERFERENCE Interference between antennas is not a problem of antenna operation, but instead is related to system design. Antennas should be located several wavelengths away from other antennas with which they might interfere, but this is seldom possible on aircraft. When antenna spacing is not ideal, interference is likely to result. Filtering or frequency management can help compensate for such interference. Several electronic systems on the P-3 aircraft are equipped with filters for the express purpose of reducing interference. These filters are essential to the performance of their electronic systems, and they should be checked for proper operation if interference is experienced. Filters must be properly grounded to the aircraft to ensure that they perform their function.

IMPEDANCE MISMATCH The need to properly match the impedance of cables and antennas has been discussed previously, but it is of such importance that it is also addressed in this section of the article. The primary indication of system mismatch is an increase in SWR. Figure 36 shows a nomograph of SWR versus reflection loss, and indicates the seriousness of a high SWR. The reflection coefficient is a function of the termination match, and is expressed by:

$$Z_l - Z_o / Z_l + Z_o,$$

where Z_l is the characteristic impedance of the load, and Z_o is the characteristic impedance of the cable or source. The electronic systems in the aircraft have been designed for proper termination at the antenna, so impedance mismatch problems should not occur unless the connectors have become corroded or cables have been replaced with unacceptable substitutes.

CABLES AND CONNECTORS As stated previously, cables and connectors *must* be replaced with identical parts or approved replacements. Such installations must be performed in strict accordance with the manufacturer's instructions, or as prescribed by the appropriate NAVAIR Maintenance Publications for that specific product. Carelessly terminated cables can produce increases in the SWR, which will cause degraded system performance.

Lockheed
ORION
Service
Digest

ANTENNAS OF THE FUTURE

Antenna technology, though an old art, is continually being revitalized by the introduction of new materials. Most recently, the use of microstrip and printed circuit techniques have resulted in widespread use of microstrip and spiral antennas. These antennas permit controlled directivity, with limited requirements for space and weight. Also, advances in receiver technology have enabled radio systems to obtain suitable performance with smaller, lower-gain antennas, which could be obtained previously only by use of large, bulky antenna arrays. For example, special array antennas, in conjunction with solid-state switching, have replaced the large mechanical-scanning antennas used for search radar.

Improved knowledge of the atmosphere, coupled with advanced computing techniques, has enabled radio communicators to take advantage of natural phenomena that once were considered a liability. Meteor burst communication is one such example. The P-3 aircraft, when it is equipped for satellite communication, will be fitted with two new antennas — the GPS and SATCOM circular polarized antennas. The SATCOM antenna is most commonly found in the crossed-dipole configuration or the spiral array, both of which provide good circular polarization with at least 6 dB gain. The spiral antenna is also used by GPS systems. These new antennas will be located on the upper portion of the aircraft fuselage to provide access to satellite signals. Since signals transmitted from satellites are very weak, the new antenna systems will require more careful maintenance than existing systems to assure optimum performance.

Although significant advances in antenna technology are not anticipated in the near future, continued improvements in material and electronics will enable further reduction of antenna size and weight. The future of aircraft antennas appears to lie in the area of multipurpose antennas and solid-state antennas. This will help avoid further crowding of the already densely-packed aircraft antenna installations.

GLOSSARY

Term	Definition
dBi	Antenna Gain, related to an isotropic antenna.
E-field	The electric component of a radiated signal.
Efficiency	Effective radiated power divided by the input power times 100.
Gain (dBi)	Gain of the antenna, referenced to an isotropic radiator.
Gain (dBLi)	Gain of the antenna, referenced to the Linear standard horn.
H-field	The magnetic component of a radiated signal.
Impedance	Characteristic Load as seen by the source.
Pattern	Shape of radiated electromagnetic wave.
Polarization	Orientation of E-field (horizontal, vertical, circular, or elliptical).
Propagation	The passing of radio waves through space.
SWR	Standing wave ratio.
VSWR	Voltage standing wave ratio.

CONCLUSION

Antennas have long been taken for granted in radio installations, and rightly so. They are the most reliable piece of equipment in the radio system. Yet, with the increased dependence on radar for survival, it is important that the antenna systems be maintained at peak performance. This article was prepared to present, in one volume, information about antennas that is normally found only by consulting several publications, including text books, technical bulletins and journals. The intent is to provide the operator and maintenance personnel with sufficient exposure to the theory of antennas to enable them to feel comfortable working with these antenna systems. This article should serve as a ready reference source for many years to come, since the field of antenna technology has not advanced with the rapid jumps experienced in such fields as computers and solid-state electronics.

Communication is gradually being taken away from the operator and given to automatic data transmission or ciphered-net voice communication. This makes it more difficult for operating personnel to get a "feel" for the effectivity of the system. Consequently, system performance can degrade gradually without operator awareness. For this reason, regularly scheduled maintenance is even more important, and certainly the antenna system must be included in the aircraft maintenance schedule. Fortunately, routine antenna maintenance can be performed without expensive test equipment, and it can usually be done by visual inspection and minor system tests. This article was prepared to acquaint operators and maintenance personnel with the basics of the mystic science of antennas, and to shed some light on a field frequently classed with Black Magic.

ACKNOWLEDGEMENT

This article was authored by Mr. E. Rockwell James, with the assistance of Messrs. Nadathur S. Jayaraman and David A. Lopez who carried on with the task while Mr. James was assigned to another project. The following consultants, reviewers, and individuals also provided invaluable assistance during preparation of this article.

Thomas W. Blakely
Nolan M. Cox
John V. DeThomas
Herbert A. Franck
John E. Harris, Jr.
Reuben C. Mack, Jr.
William H. Moule
Stephen E. Peña
Thomas T. Schreiber
William G. Welsh
Lynn J. Woolford

of Lockheed Aeronautical Systems Company - Burbank
and

LeeAnn J. Augustine, American Electronic Laboratories, Inc.

Collectively, their devoted efforts made production of this article possible.

Editor

LOCKHEED AERONAUTICAL SYSTEMS COMPANY-HEADQUARTERS OPERATIONS

PRODUCT SUPPORT

B.F. BERNSTEIN, Vice President – LASC

RELIABILITY, MAINTAINABILITY AND SUPPORTABILITY DESIGN DIVISION

J.L. Gaffney, Manager

Reliability, Maintainability & Logistics Engineering
H.D. Little, Manager

Automatic Test Systems/ Support Equipment
G.S. Beier, Manager

Training Systems
R. Callejas, Manager

GOVERNMENT PRODUCT SUPPORT

A. G. Hunt, Director

P-3 Integrated Logistics Support - U.S. Navy
J. R. Mercer, Manager

P-3 Integrated Logistics Support - International
D. B. Pierce, Manager

S-3 Integrated Logistics Support
A. J. Neibauer, Manager

Integrated Logistics Support Proposals
D. E. Sedillo, Manager

SUPPLY SUPPORT DIVISION

D.R. Steele, Manager

Customer Support
G.M. Lowe, Manager

Supply Services
A. Cozzolino, Manager

Logistics Services
R.G. Stearns, Manager

Overhaul & Repair
M.D. Shreeve, Manager

FIELD SUPPORT DIVISION—H.A. Franck, Manager

Field Modifications
D. K. Payne, Manager

Commercial Technical Publications
M. H. Wells, Manager

Field Service
P.M. Schrimscher, Manager

Technical Operations Support
T. L. Crawford, Manager

Military Technical Publications
P.A. Maine, Manager

MILITARY FIELD SERVICE OFFICES

MAJOR LOCATION	MAILING ADDRESS AND BUSINESS TELEPHONE
NAVAVNDEPOT Alameda S.H. Lomax	P.O. Box 1363 NAS Alameda, CA 94501 (415) 869-4696/521-2283
NAVAIRSYSCOM, Arlington E.O. Skidmore J.M. Parolise (PMA-240)	Lockheed Aeronautical Systems Co. 1235 Jefferson Davis Hwy Suite 1200, Crystal Gateway 1 Arlington, VA 22202 (703) 553-8400
NAS Barbers Point W.J. Biggs	P.O. Box 268 NAS Barbers Point, HI 96862 (808) 681-3444/682-3671
NAS Brunswick D.W. Weyers	P.O. Box 38 Brunswick, ME 04011 (207) 921-2472/921-2521
NAS Cecil Field E.E. Winistorfer	P.O. Box 162 NAS Cecil Field Jacksonville, FL 32215 (904) 772-8517/772-0369
NS Cubi Point, R.P. F. Stores	P.O. Box 48 FPO San Francisco, CA 96654-2920 Cubi Point 63-89-8853540/8853715
NAS Jacksonville F.A. Warner	P.O. Box 31300 Jacksonville, FL 32230-1300 (904)772-3535/772-1527
NAS Moffett Field A.W. Vitaglin	P.O. Box 159 Moffett Field, CA 94035 (415) 966-5461
CNAVRES New Orleans R.G. Baumgarten	P.O. Box 3906 New Orleans, LA 70177 (504) 948-1220
NAS North Island E.S. Skultety	P.O. Box 5, NAS North Island San Diego, CA 92135 (619) 435-8910
NATC Patuxent River N.R. Rockwell	P.O. Box 218 NATC Patuxent River, MD 20670 (301) 863-8186
ASO Philadelphia J. Logan	P.O. Box 7051, Blvd Station Philadelphia, PA 19149-0051 (215) 697-2249
NADC Warminster G. Sink	196 West Street Rd. Warminster, PA 18974 (215) 674-3550

EAGLES

PATROL SQUADRON SIXTEEN

LOCKHEED AERONAUTICAL SYSTEMS COMPANY • A DIVISION OF LOCKHEED CORPORATION