USER MANUAL
FOR THE VHF/UHF RANGE OF THE NATR
AT PAARDEFONTEIN

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for

GEROTEK

Report Gerotek 03/2010, Ver. 2.0 26 July 2010

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ABBREVIATIONS, PREFIXES AND SYMBOLS

A	ampere
A	longitudinal amplitude taper
AF	antenna factor
AR	axial ratio
A_e	effective aperture
A_p	physical aperture
AUT	antenna under test
BW	beamwidth (half power unless stated)
COMINT	communications intelligence
CP	circularly polarized, circular polarization
CW	continuous wave
D	largest aperture dimension of AUT, m
DC	direct current
DF	direction finding, direction finder
d	diameter of source antenna, m
dB	decibel = 10 log (P_2/P_1)
dBi	decibels over isotropic
dBci	decibels over circularly polarized isotropic
dBli	decibels over linearly polarized isotropic
ELINT	electronic intelligence
E_i	incident electric field intensity, Vm^{-1}
E_n	normalized electric field intensity, Vm^{-1}
E_r	reflected electric field intensity, Vm^{-1}
F	force, N
f	frequency, Hz
G	giga = 10^9 (prefix)
G	gain
G_r	gain of test antenna
G_s	gain of standard antenna

g	gram
g_h	partial gain for horizontal polarization
g_v	partial gain for vertical polarization
H	horizontal
H	magnetic field, Am^{-1}
HPBW	half power beamwidth
HF	high frequency
Hz	hertz = 1 cycle per second
h_p	height of positioner above ground, m
h_r	height of centre of AUT above ground, m
h_t	height of centre of transmit antenna above ground, m
h_t'	apparent height of centre of transmit antenna above ground, m
ICR	integrated cancellation ratio
k	kilo = 10^3 (prefix)
k	ground reflection coefficient
kg	kilogram
kW	kilowatt
L	radar band, nominally 1 – 2 GHz
L	length of end-fire antenna, m
LHCP	left hand circularly polarized
LPDA	log-periodic dipole array
M	mega = 10^6 (prefix)
m	metre
m	milli = 10^{-3} (prefix)
N	newton
Nm	newton metre
NATR	National Antenna Test Range
P	polarization
P	power, W
P_i	power incident on antenna terminals, W
P_r	power reflected at antenna terminals, W
R	test range or test distance, m

RCS	radar cross section
RHCP	right hand circularly polarized
r	radius, m
rms	root mean square
RWR	radar warning receiver
S	radar band, nominally 2 – 4 GHz
SG	standard gain
SGA	standard gain antenna
SL	sidelobe
s	second
UHF	ultra high frequency
V	vertical
V	volt
VHF	very high frequency
VNA	vector network analyzer
VSWR	voltage standing wave ratio
V_i	incident voltage, V
V_r	reflected voltage, received voltage, V
W	watt
X	radar band, nominally 8 – 12 GHz
α	(alpha) subtended angle of AUT at range R
α_n	(alpha) depression angle from source antenna to base of test tower
Γ	(gamma) voltage reflection coefficient
ϵ_{ap}	(epsilon) aperture efficiency
λ	(lambda) wavelength, m
π	(pi) = 3.1416…
θ_{hp}	(theta) half power beamwidth

CAUTION – ELECTROSTATIC DISCHARGE (ESD)

ESD can damage the highly sensitive circuits in the VNA. ESD is most likely to occur as test devices are connected to or disconnected from the VNA test ports. The instrumentation can be protected by wearing a grounded static–discharge arm band. Alternately, the operator must ground himself by touching grounded metallic parts of the equipment (e.g. the outer chassis of the grounded VNA, the grounded test positioner, etc) before touching the VNA test ports or test cables connected to the VNA. Operators must avoid touching the centre conductors of test port connectors or test cables connected to the VNA unless they are properly grounded and have eliminated the possibility of static discharge. Ideally the centre conductors should not be touched if they are connected to the test equipment.

Outdoor measurements using a sensitive vector network analyser (VNA) or other test receiver are particularly susceptible to static and/or lightning damage to the test equipment. Users must exercise all reasonable caution to eliminate damage to test equipment. Long coaxial cables can build up significant static charge on the outer jacket of the cable because of wind friction. Once the antenna or system to be tested is installed, the coaxial cables at the VNA/receiver end must be short-circuited to discharge the cable. It is good practice to install a 3 dB fixed attenuator at the output of the test cable. This reduces the dynamic range by 3 dB but the attenuator has a DC path to ground which provides continuous bleeding of charge build up to ground. This advantage far outweighs the loss of 3 dB of sensitivity. An additional safety precaution will be to add a DC block between the 3 dB attenuator and the test port. Custom high inductance circuits which provide a DC path to ground can also be used. The DC block and inductance circuits may have an effect on the sensitivity of the VNA and should be tested over the frequency ranges of interest before starting the measurement programme.

WARNINGS

1. The user must ensure that the earth connections of his test equipment are in place and that there are no 'floating earths'. Connect all equipment via a 3-pin grounded power outlet. If a grounded 3-pin outlet is not available, use a conversion adapter and connect the equipment ground terminal to ground. If mains power is supplied without grounding the equipment there is a risk of equipment damage and/or electrical shock to operators.
2. Do not exceed the rated input RF power levels of the VNA, particularly when power amplifiers are being used. The maximum rated power levels and DC voltages are normally stated on labels near the test ports. Typical values are + 27 dBm max and 40 VDC max. If there is uncertainty, consult the manufacturer's operating manuals.

1. INTRODUCTION

The VHF/UHF range was originally designed to measure antennas in the 30 MHz to 1 GHz frequency band [1]. This gave a small overlap in frequency with the microwave range from 500 to 1 000 MHz. Some of the earliest measurements were on 20 to 100, 100 to 1 000 and 20 to 1 000 MHz log periodic dipole array (LPDA) antennas and blade antennas mounted on large ground planes (3 m x 3 m). It is difficult to measure these antennas in "free space" and custom set-ups had to be devised. These test set-ups are described in this document. The tests on individual antennas have continued but over the last 10 to 15 years much more emphasis has been on the measurement of integrated systems.

Many communications intelligence (COMINT) direction finding (DF) systems cover the 30 to 3 000 MHz frequency band. The DF systems are generally compact being about 0.5 to 2 m in diameter and around 1 to 2 m high. The VHF/UHF range is ideally suited to measuring these compact DF systems. The VHF/UHF range is configured so that the COMINT system supplier can set up a source antenna at a distant point (200 m or more) down range, then transmit controlled signals in terms of power, frequency and modulation and receive these signals on his integrated DF system. The test positioner is then rotated and the angle of arrival is measured relative to the output of the test positioner. The elevation angle of the positioner can then be changed and a conical cut in azimuth taken. The COMINT systems use the range source and reference antennas, the range surface and the positioner at the receive site. Apart from using a vector network analyser (VNA) to do certain field quality tests, the COMINT systems are self-supporting.

Over the years the COMINT systems have extended downward in frequency to the HF band (300 KHz to 30 MHz) and upward in frequency to 3.6 GHz or even 6 GHz. This is a total frequency bandwidth of 20 000 : 1! Such a wide frequency range requires special measurement configurations for the VHF/UHF range. Most of the DF systems measured to date are vertically polarized.

The descriptions which follow are made specifically for the VHF/UHF range but apply equally well to the microwave range. The microwave range is being used more and more for COMINT DF system testing. Over the past four years there has been extensive testing of very compact systems covering the 300 kHz to 3 GHz frequency range (10 000 : 1 frequency bandwidth) on the microwave range which was configured in a VHF/UHF mode.

This user manual discusses the source antenna configurations to obtain the desired test field. Where individual antennas are measured (e.g. log periodic dipole array antennas) the size and frequency at which these antennas can be measured are discussed. The COMINT systems generally do not measure the gain and pattern parameters for the individual antennas making up the COMINT system. Rather system root mean square (RMS) DF accuracy is measured over azimuth and elevation. During the development phase of the individual COMINT DF antenna elements, these antenna elements must be evaluated and optimised. Amplitude and phase stability of the test field created by the source antenna at the test positioner are important parameters because modern DF systems use amplitude and phase information to achieve high-accuracy DF.

2. TEST RANGE CONFIGURATION

2.1 Test range lay out

The VHF/UHF range is situated to the west of the NATR site as shown in Figure 2.1. There is a small operations building which has an azimuth-over-elevation test positioner mounted on a custom designed reinforced concrete structure on the one corner of the operations building. The range axis runs from the positioner parallel to the N-W boundary fence at a distance of about 170 m from the fence. The range axis from the positioner to the N-E boundary fence is about 570 m. The boundary fences are sufficiently far away to make the VHF/UHF range what is called 'a large open test range' – such sites are rare. In the original implementation of the range, underground service ducts ran from the operations building along the range axis for a distance of about 400 m. The ducts are about 5 m below the range surface to reduce coupling effects. Access to the ducts was provided at 50 m intervals to give greater flexibility in the selection of measurement distances. Many of these ducts have fallen into disuse mainly because of flooding.

At a distance of 300 m down range there is a circular concrete platform which is flush with the ground. Directly below the centre of the concrete platform there is an underground room which is accessed via an underground walkway from the N-W side. The intention had been to install an automated vehicle turntable to measure installed performance of antennas on vehicles, aircraft and helicopters. The automated turntable was not installed but a manual turntable was built and this has been used extensively to make installed performance measurements. The underground room is ideal for doing high power antenna testing. The power amplifiers are in the room and the test cables to the antennas go through the centre of the concrete slab. Personnel are then able to conduct the high power tests from the underground room while not being exposed to radiation hazard.

There had been plans to cover the concrete slab at the vehicle turntable with lead sheet to simulate the conductivity of sea water. In addition, radial wires were to extend from the slab to create a 100 m "perfect" ground plane for VSWR and power testing of HF antennas. These radial wires were never installed because most of the HF tests were done at the actual site where the antennas were operated by the user.

2.2 Basic operation of the VHF/UHF range

The discussion that follows is aimed at the VHF/UHF range as shown in Figure 2.1. However, all the comments and range configurations apply equally well to the microwave range when it is operated in a VHF/UHF mode. The test positioner is an azimuth over elevation positioner which allows the antenna under test (AUT) to be tilted forward in elevation and then to rotate the azimuth axis to take a true azimuth cut. The elevation axis can tilt forward by 90 degrees and backwards by 45 degrees. This allows the axis of the DF system to be set at right angles to the line from the centre of the DF system to the effective phase centre of the source antenna.

The operation of the VHF/UHF range is described for two different applications, these being

(a) integrated DF system tests, and

(b) testing E- and H-plane patterns of individual antennas.

2.2.1 Integrated DF system tests

The integrated DF systems are normally quite compact (0.5 to 2 m in diameter and around 1 to 2 m high) and do not occupy a very large portion of the test field. Most of the current communications intelligence (COMINT) DF systems are vertically polarized. The discussion that follows is aimed mainly at these conditions. For horizontally polarized DF systems additional test field evaluations must be done to evaluate the quality of the test field.

The azimuth turntable is 8.5 m above ground. With an interface jig and half the height of the DF system, the centre of the DF system is about 10 m above ground. At the microwave range this height is about 12.7 m. In the 30 to 3 000 MHz frequency range tests are normally done at a distance of about 200 m. A wideband "bilog" antenna is normally used as the source (transmit antenna) for these measurements. For example, the Schaffner model CBL6143 is available at the NATR. This antenna comprises a flattened biconical dipole (the "bi" part) and a log periodic dipole array antenna (the "log" part) integrated as a single wideband antenna operating from 30 to 3 000 MHz. From 30 MHz to around 150 MHz, the CBL6143 has the patterns of a dipole antenna and above 150 MHz the patterns become those of a LPDA antenna. The major advantage of this antenna (as we shall see) is that it is extremely compact. It has a height across the dipole of 970 mm and has a total length of 1 526 mm. The gain of this antenna is low in the 30 to 100 MHz frequency range because of the small size.

Figure 2.2 shows a typical test set-up for the VHF/UHF range. The transmit antenna is a bilog antenna and the receive antenna is shown as a bilog reference or standard gain antenna. The receive bilog is used to measure the field strength in the test zone and can also be used to probe the field distribution in the test zone. Once the test zone has been shown to have a smooth electric field with no rapid amplitude and phase changes or nulls the COMINT DF system can be installed.

There are a number of very important features evident in Figure 2.2. The source antenna always has an image in the ground plane (the range surface). There are always direct and reflected rays. These rays can add in or out of phase but this can be controlled if the transmit height h_t is set correctly. The test set-up in Figure 2.2 has all the features of a ground reflection range as discussed in detail in Reference [3]. For angles near-grazing incidence (which is the case here) the effective phase centre of the source is on the ground directly below the bilog source antenna. The DF system must be tilted forward by about 2.86 degrees on the elevation axis for the azimuth plane on its horizon to be correctly aligned with the test range measurement planes. Normally the axis of the bilog antenna is set parallel to the range surface.

For the ground reflection range the source height is a function of wavelength (i.e. frequency). It can be shown ([2] and [3]) that the transmit and receive antenna heights for the most uniform electric field distribution in the vertical plane are related by

$$h_t = \frac{\lambda R}{4 h_r} \qquad (2.1)$$

where

h_t = height of bilog axis

λ = wavelength (m) = 300/f

f = frequency in MHz

R = range length = 200 m

h_r = height at centre of AUT = $h_p + h_c$

h_p = height of azimuth turntable = 8.5 m

h_c = height above azimuth positioner to centre of DF system (nominally = 1.5 m)

NOTE: There is no source tower at the 200 m point on the VHF/UHF range. The source antenna is normally mounted on a tripod or other fixture.

With R and h_r fixed the shortest wavelength (highest frequency) defines h_t. At 3 GHz, λ = 0.1 m which gives h_t = 500 mm for the parameters shown above. This height turns out to match the vertical extent of the CBL6143 which is 970 mm high. The closest the CBL6143 can be placed to the ground for vertical polarization is half of its height unless it is tilted forward. The axis (boom) of the CBL6143 is placed parallel to the range surface at a height of 500 mm to achieve optimum field distribution in the vertical plane at 3 GHz. The horizontal field distribution is given by the H-plane pattern of the CBL6143 which is very broad. For measurements up to 6 GHz, the optimum height is about 250 mm.

Equation 2.1 assumes that the reflection coefficient from the ground is -1, which is the case for angles near grazing. At a test height of 10 m and a test distance of 200 m the grazing angle is about 2.9˚. The height h_t in Equation 2.1 is adjusted to have one half wavelength of path distance between R_D the direct path and R_R the reflected path. This gives the most uniform field distribution in the vertical plane. It can be shown ([2] and [3]) that the normalised electric field in the vertical plane is given by

$$E_n(h) = \sin\frac{\pi}{2}\frac{h}{hr} \qquad (2.2)$$

where h is the height above ground.

For the ground reflection range the height h_t is adjusted to create the in-phase condition at the centre of the test height h_r for each frequency of operation. For the in-phase condition the direct and reflected rays add to give a peak value of 2 if the magnitude of the reflection coefficient is 1. The half wavelength condition is shown schematically in Figure 2.3. Equation 2.2 is expressed in dB in Equation 2.3. In Figure 2.4 the total field is shown for h_t and 3 h_t. The first maximum is much wider than the second maximum for 3 h_t. There is a source height in between h_t and 3 h_t at 2 h_t where the direct and reflected rays subtract and there is a null in the centre of the test aperture. This is shown in Figure 2.5. Such a null in elevation creates a test field which is totally unsuitable for DF system (or other antenna) testing.

Equation 2.3 is used to evaluate the field taper.

$$E_n(h)(dB) = 20\log\sin\frac{\pi}{2}\frac{h}{hr} \qquad (2.3)$$

For the VHF/UHF range the source height is not adjusted for each frequency but kept fixed at 0.5 m as for 3 GHz. At lower frequencies the peak position shifts upwards at the receive position but the receive height h_r is still fixed at 10 m. This means that the DF system is no longer in a uniform test field.

For a 1 m high DF system centered on the 10 m receive height the amplitude taper between 9.5 and 10.5 m is only -0.027 dB at 3 GHz with the peak centered at 10 m. This is clearly evident from Figure 2.4 where the $h/h_r = 1$ part of the pattern is applicable..

To find the location h_m of the maximum of the elevation field for fixed transmit height h_t we rewrite Equation 2.1 (with h_m for h_r) as

$$h_m = \frac{\lambda R}{4 h_t} \qquad (2.4)$$

At 500 MHz we find h_m to be 60 m. The 10 m high fixed receive height is well below this and the 1 m high DF system sits on the slope of the elevation field distribution at 0.167 on the horizontal axis of Figure 2.4. The amplitude at 9.5 m is now -12.2 dB and at 10.5 m it is -11.3 dB which gives a 0.9 dB vertical taper across the DF antenna centered at 10 m. The test field is about 11.8 dB less at the centre of the DF system compared to the peak which is at 60 m above ground. At 100 MHz h_m is 300 m, and the amplitude at 9.5 m is -26.1 dB and at 10.5 m it is -25.2 dB Again there is a 0.9 dB taper but the field at the centre of the 1 m aperture has decreased by a further 14 dB from the 500 MHz case. The field taper is within a dB because at 200 m test distance the 1 m high DF antenna subtends only about 0.3˚. For a 2 m high DF system the taper increases to 1.7 dB. The azimuth field is set almost entirely by the azimuth (i.e. the H-plane) beamwidth of the bilog or other source antenna. This half power beamwidth is typically more than 100˚ and there is very little azimuth taper.

As the frequency decreases there are still direct and reflected rays and the range still functions as a ground-reflection range. Below 500 MHz with the fixed transmit and receive heights and the fixed test distance the electric field in the test area gets an increasing taper. This is seen in Figure 2.4 where the test field is in the region where h/h_r lies between 0.2 and 0. At these frequencies a ground wave is also launched. This ground wave uses the range surface as a guiding structure. Figure 2.6(a) shows a vertically polarized ground wave on a perfect conductor and Figure 2.6(b)) shows the ground wave on an imperfect conductor such as the soil of the range surface. Note that on the imperfect conductor the electric field is not perfectly vertical and has a field component parallel to the range surface near the ground. The test field is now made up by the vector addition of a direct wave, a reflected wave and a ground wave. When the field in Figure 2.4 is low, the ground wave may start to dominate. The purely vertical polarization can be lost depending on the summation of all the field components. In extremely compact DF arrays the mutual coupling between the elements introduces inherent horizontal polarization into the nominally vertically polarized DF array. Unless the source antenna is configured in exactly the same way for each set of measurements it can become difficult to achieve repeatable measurements from day-to-day or more particularly over many months. Depending on the soil conditions (wet, dry, very dry) the total field created by the three waves can have slightly variable polarization.

For these compact DF arrays it is often easier to use vertically polarized whips or conical monopoles fed with the outer conductor of the coaxial cable attached to a wire mesh screen (chicken wire) placed on the ground. The centre conductor of the feeding cable is connected to the whip or monopole. This arrangement launches a surface wave which does not have the other two components. This procedure proved extremely effective for measuring an ultra-compact DF system (500 mm in diameter) operating from 300 kHz to 30 MHz where a vertically polarized whip antenna was used as source, 30 MHz to 100 MHz where a vertically polarized caged rod monopole was used as source and 100 MHz to 3 GHz where the bilog was used. Even in the 100 to 500 MHz frequency range the caged rod monopole gave better polarization purity. These measurements were made on the microwave range which was operated as a HF/VHF/UHF range.

2.2.2 Testing E- and H-plane patterns of individual antennas

The DF systems discussed up till now are vertically polarized and they are measured in azimuth and at conical cuts at selected angles in the elevation plane. When measurements are required out of the horizontal plane, the elevation axis is tilted forward or backwards and azimuth cuts are taken by rotating the upper azimuth turntable at the desired elevation angles – this results in the conical cuts. Because the DF systems are relatively small, only a small portion of the elevation test field is used in these measurements. At a particular elevation all the elements of the DF antenna are immersed in almost the same field. The only proviso is that there must not be a null or deep dip in the elevation field. This can be assessed by probing the field distribution.

The VHF/UHF range (and the microwave range) is suitable for measuring relatively large antennas in the 20 to 1 000 MHz frequency range. They can be log periodic dipole array antennas or blade antennas mounted on metallic ground planes. For these antennas full azimuth and elevation plane patterns are required. For the LPDA the E-plane is the plane containing the dipole elements and the H-plane is at right angles to this. Thus, if the LPDA is set for vertical polarization the E-plane is the elevation plane and the H-plane is the azimuth plane.

Figure 2.7 shows a schematic drawing of a 20 to 1 000 MHz LPDA mounted on a fibreglass pipe which is mounted on the upper azimuth turntable of the receive positioner. The LPDA is tilted downwards towards the LPDA source on the ground about 40 m away. This LPDA source is normally a conventional LPDA covering 20 to 1 000 MHz. The E-plane of the source is in the vertical plane. The E-plane of the LPDA has a null at about 90˚ from the peak of its E-plane pattern. This null is pointed at the specular reflection point on the ground. This means that the reflected wave is greatly reduced in amplitude and the test field is due almost entirely to the direct wave from the source LPDA. The LPDA under test is now rotated using the azimuth turntable to take an H-plane pattern. Note that apart from setting the axis of the AUT to look at the source (a depression angle of about 17 degrees for a receive height of 12 m to the centre of the AUT at a test distance of 40 m), the elevation axis is not used to make a pattern cut. This procedure can introduce undesired effects in the patterns as is discussed later. To reduce the volume swept out in the test zone the LPDA under test is mounted near its centre if the LPDA is large. A 20 to 1 000 MHz LPDA is about 7.5 m wide at the longest element and 7.5 m long.

To make an E-plane cut the LPDA under test is rotated through 90˚ on the fibre glass pipe and the elements set in the horizontal plane. The source LPDA is also set for horizontal polarization and its height h and angle A are adjusted so that the active region of the LPDA adds in phase with the active region of the image in the range surface. This is illustrated in Figure 2.8. The E-plane pattern is now made by rotating the upper azimuth axis. This procedure works extremely well because the nulls in the E-plane patterns are measured correctly and are not degraded by reflections from the surface of the range.

2.2.3 Ground reflection range using compact source antennas

The test range configuration described in Section 2.2.1 can be used to measure the patterns and gain of individual antennas (e.g. LPDAs) over wide frequency bands. The range set-up can be made on the microwave and VHF/UHF ranges. The following discussion is for a particular test configuration to measure a 100 to 1 000 MHz LPDA on the microwave range.

Figure 2.9 shows the test range lay-out. The LPDA under test is mounted on a fibre glass mast on top of the az/el/az positioner of the microwave range. The geometrical parameters for this configuration were:

h_r = 14.5 m

R = 180 m

The optimum source height h_t is determined from Equation 2.1 for the highest frequency of 1 GHz. We find

h_t = 0.93 m

and the depression angle $\alpha = 4.6°$ if we take the effective source height (source plus image) to be on the ground at 180 m distance.

All the required interconnections are shown in Table 2.1. The VNA is configured to make a S_{21} forward transmission measurement.

Table 2.1 Interconnections for VHF/UHF antenna measurements

Item number	Description
VNA	Agilent E 5071 B, S_{21} measurement
Tx1	Transmit coaxial cable from port 1
RF – Fibre	RF – optical fibre Optical Zonu
OF1	Optical fibre line 200 m long
Fibre – RF	Optical fibre – RF Optical Zonu
Tx2	Transmit cable to power amplifier
Power amplifier	Amplifier Research Corp. Model 10 W 1000 C
Tx3	Transmit cable to source antenna
Source antenna	ETS Lindgren 3142 D
Reference antenna	Schaffner CBL 6143
Rx1	Receive cable from AUT to rotary joint
Rj1	Rotary joint in upper az turntable
Rx2	Cable from rotary joint to positioner
Rx3	Cable to step attenuator
Step attenuator	110 dB step attenuator
Rx4	Test cable to port 2

The 110 dB step attenuator is included to establish the dynamic range of the measurements in the 20 to 1 000 MHz frequency range. The set-up parameters for the test instrumentation are shown in Table 2.2.

Table 2.2 Set-up parameters for test equipment

VNA Agilent E 5071 B	Measure IF Bandwidth Averaging Output power	: S_{21} : 100 Hz : 16 : 0 dB m
ARC 10 W 1000 C	Gain	: Set for mid range

For testing the dynamic range the source antenna was the ETS Lindgren 3142 D and the AUT was the Schaffner CBL 6143. Both antennas were set for vertical polarization using a spirit level. Figure 2.10 shows the source antenna on its tripod with the antenna axis set at a height of 0.93 m. The AUT is shown on its fibre glass mast on the test positioner in Figure 2.11. The S_{21} response on the VNA was calibrated as a 'THRU' measurement response. This results in a horizontal trace at the 0 dB level on the screen of the Agilent VNA E 5071 B. The 110 dB step attenuator was then used to insert 10 dB step attenuation in steps from 10 to 60 dB. Each trace was allowed to stabilize and the data was captured.

Figure 2.12 shows the dynamic range from 20 to 1 000 MHz. From 80 MHz up, 50 dB of dynamic range is achieved with about ± 1 dB of noise at the -50 dB level. At -60 dB the noise is about ± 2 dB. This dynamic range is adequate for most applications. Antennas such as LPDAs, Yagis, blades, base station panels, omni-directional antennas can be measured with good accuracy.

Below 80 MHz the dynamic range degrades, being only about 20 to 30 dB at 20 MHz. This loss in gain occurs because the gains of both the source and receive antennas drop from about 0 dBi at 80 MHz to -26 dBi at 26 MHz. There is also some signal loss because the height of the source antenna is not optimum at the lower frequencies. The dynamic range below 80 MHz can be improved by increasing the transmit power. The ARC 10 W 1000 C was set for gain at the mid range, the maximum output power is 10 WCW at full gain. Alternately a source antenna with higher gain (e.g. a full-scale LPDA with typically 2 to 6 dBi gain) could be used. This will give an immediate improvement of more than 20 dB. For some applications the dynamic range of 30 dB in the 20 to 80 MHz band may be adequate.

Figure 2.13 shows the ARC 10 W 1000 C power amplifier at the source position together with the power supply for the optical transceiver which is shown in Figure 2.14. The optical transceiver is a full duplex unit operating from 10 kHz to 3 GHz.

Figure 2.1 Plan view of VHF/UHF range showing basic layout

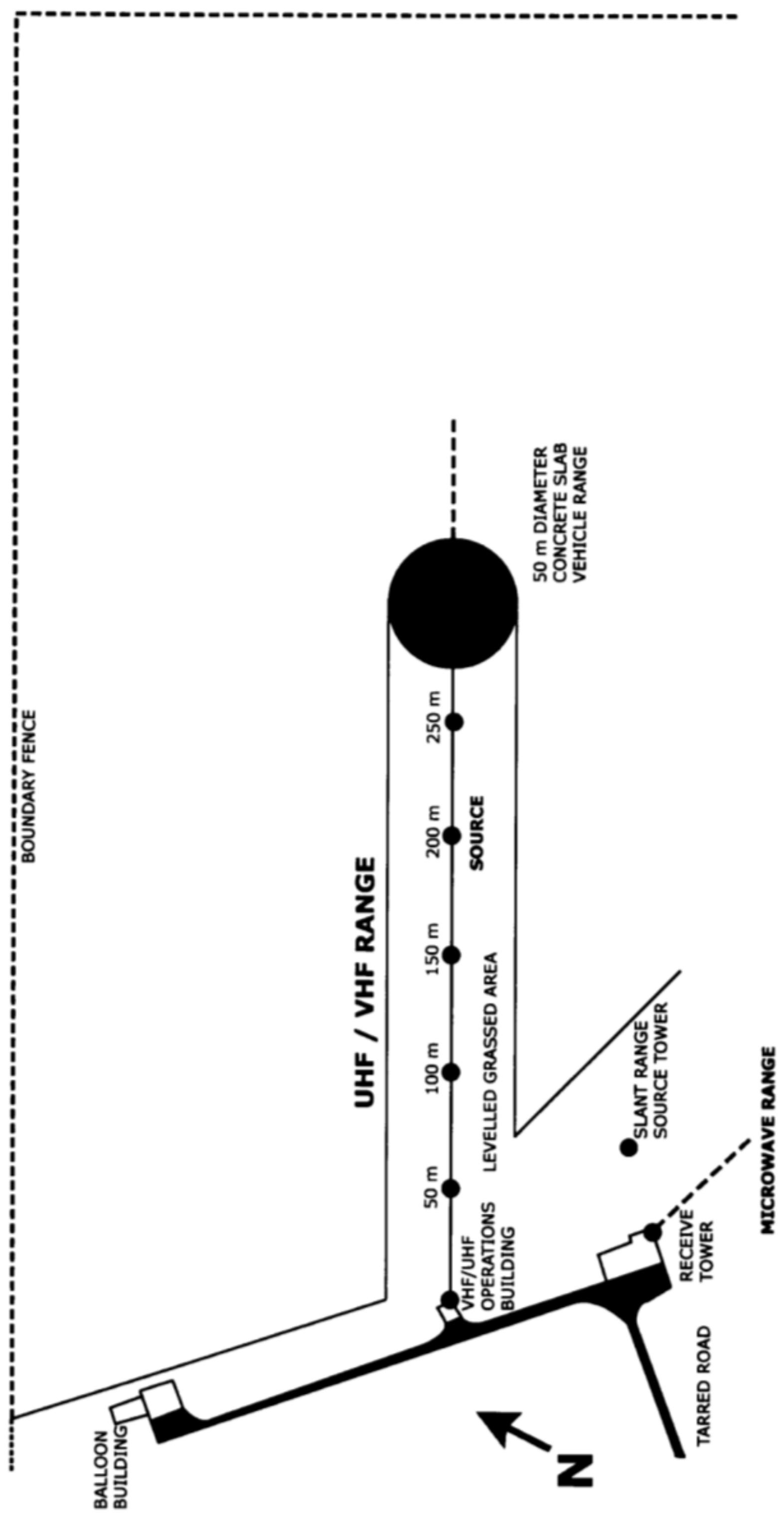


Figure 2.2 **VHF/UHF measurements using a LPDA antenna as the transmit antenna (note that the image of the source is always present)**

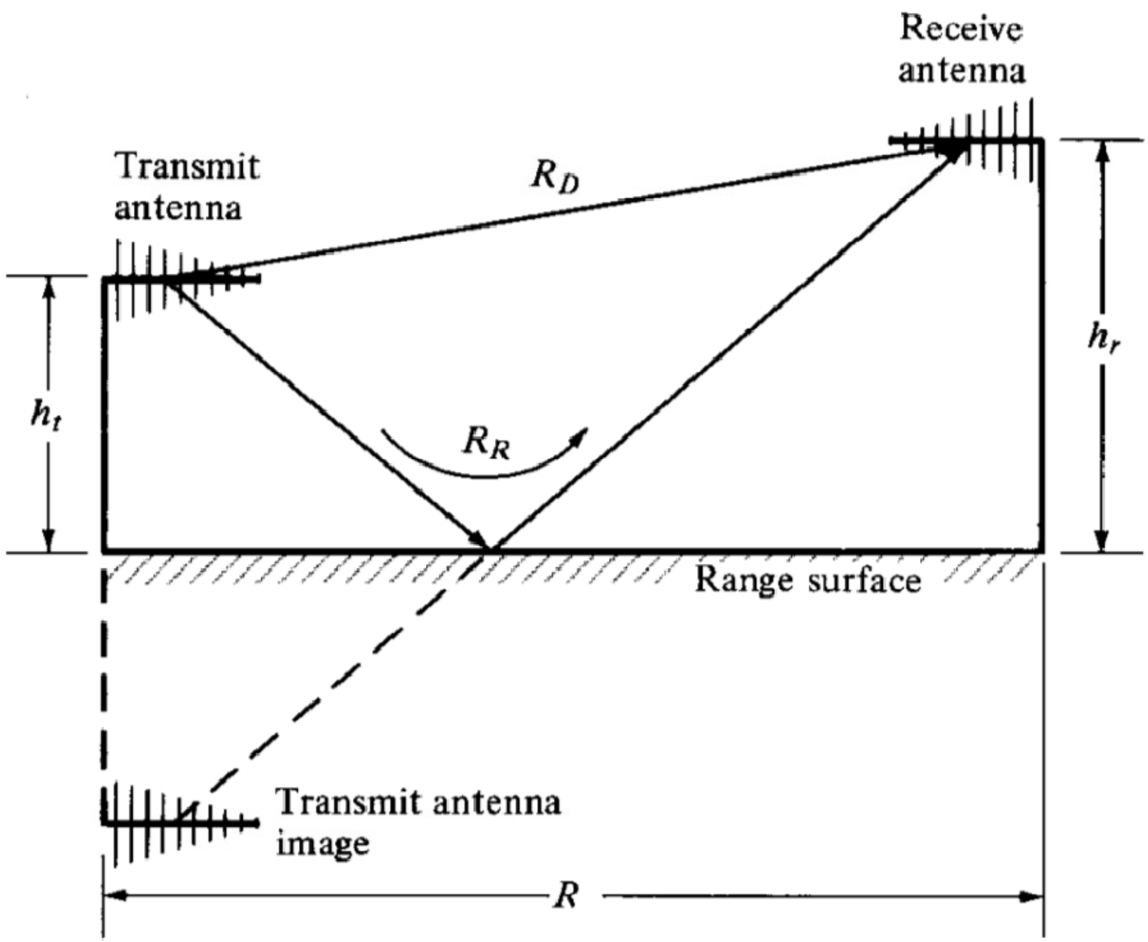


Figure 2.3 **Half wavelength condition to get best elevation field distribution at 3 GHz, (b) vertical field distribution when source is at optimum height and three times the optimum height**

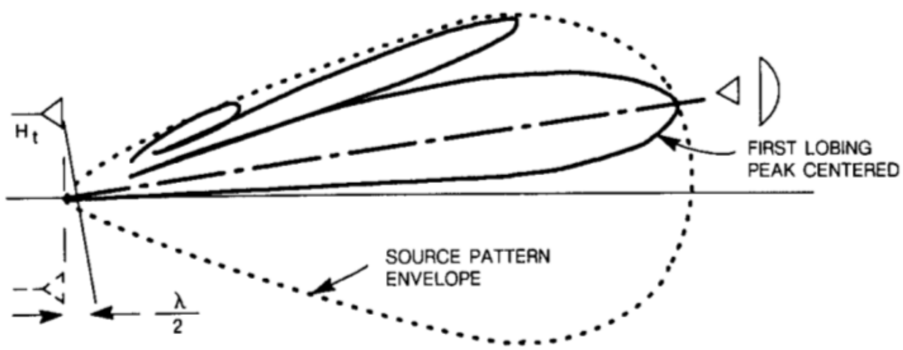


Figure 2.4 **Vertical field distribution when source is at optimum height and three times the optimum height (0 on the horizontal axis is on the ground)**

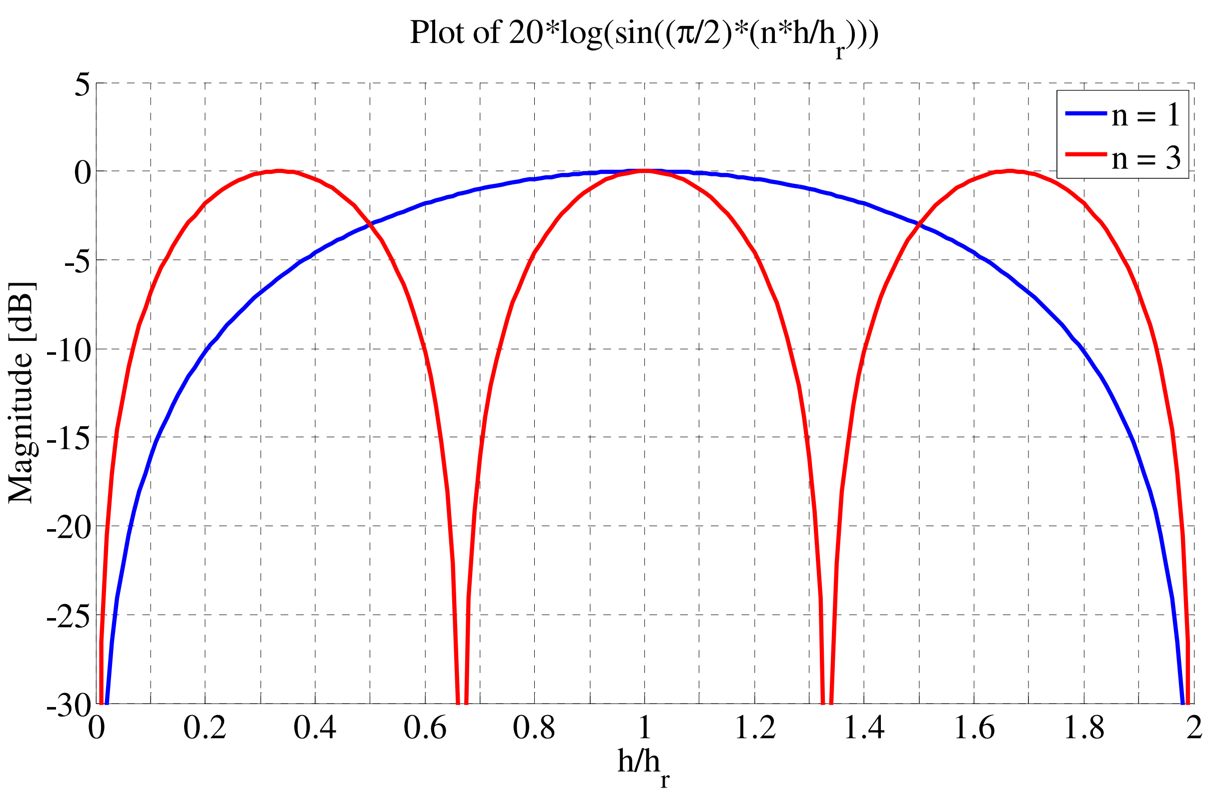


Figure 2.5 **Vertical field distribution when source is at height for cancellation between the direct and reflected rays (1 on the horizontal axis is at the centre of the test zone)**

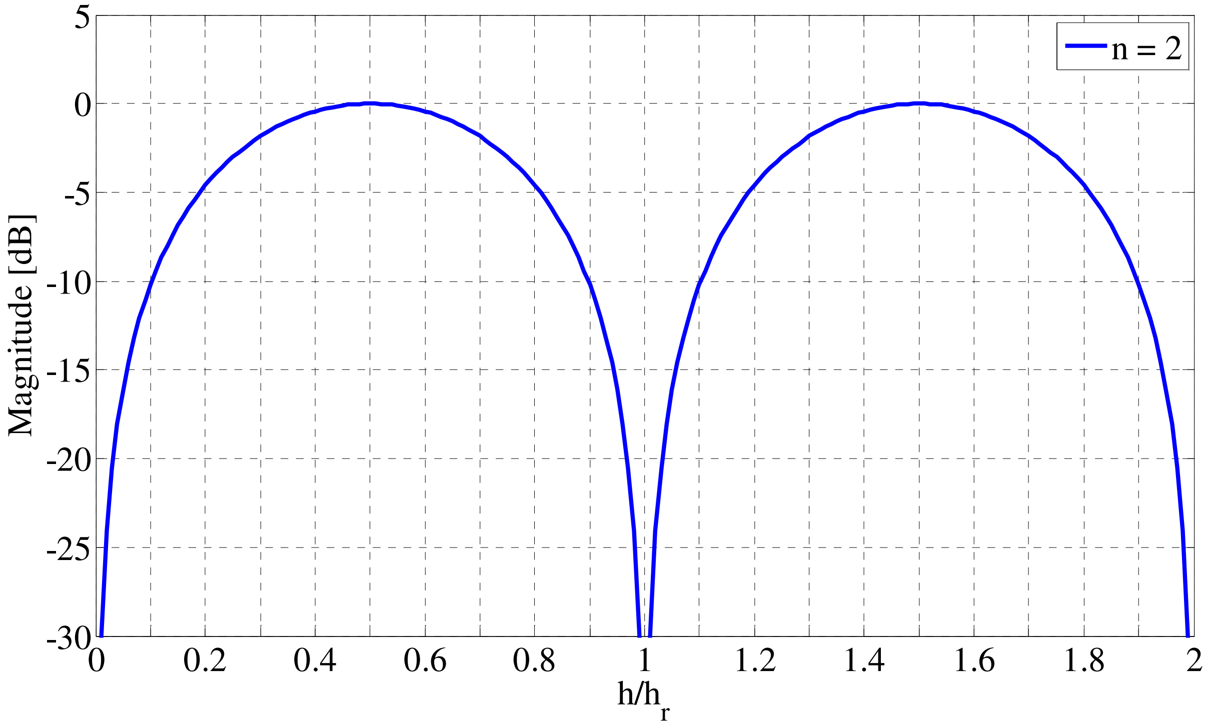


Figure 2.6 **Ground wave (a) on a perfect conductor and (b) on an imperfect conductor (e.g. real soil); note that there is a horizontal component of the electric field in (b)**

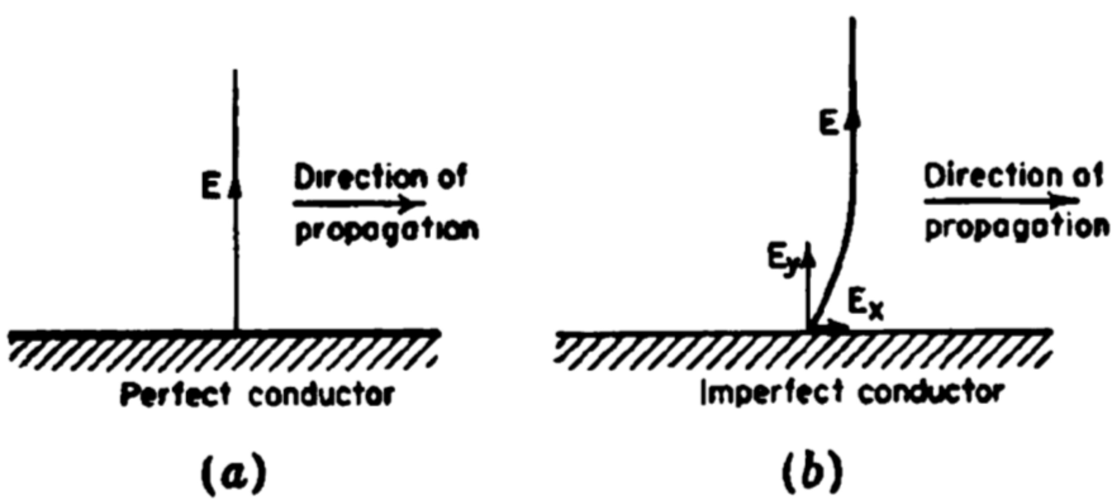


Figure 2.7 LPDA source set up to measure H-plane patterns of test LPDA using upper azimuth rotator of test positioner

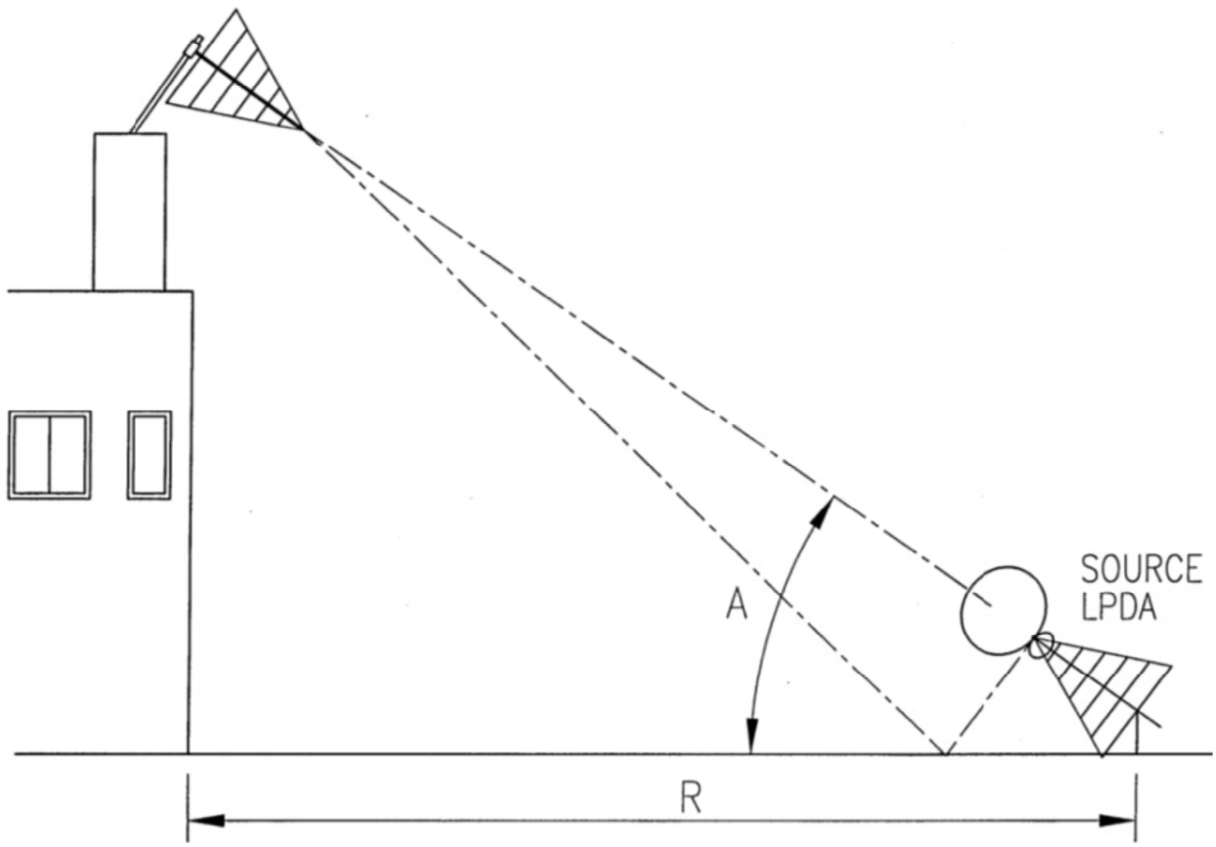


Figure 2.8 LPDA source set up to measure E-plane patterns of test LPDA using upper azimuth rotator of test positioner

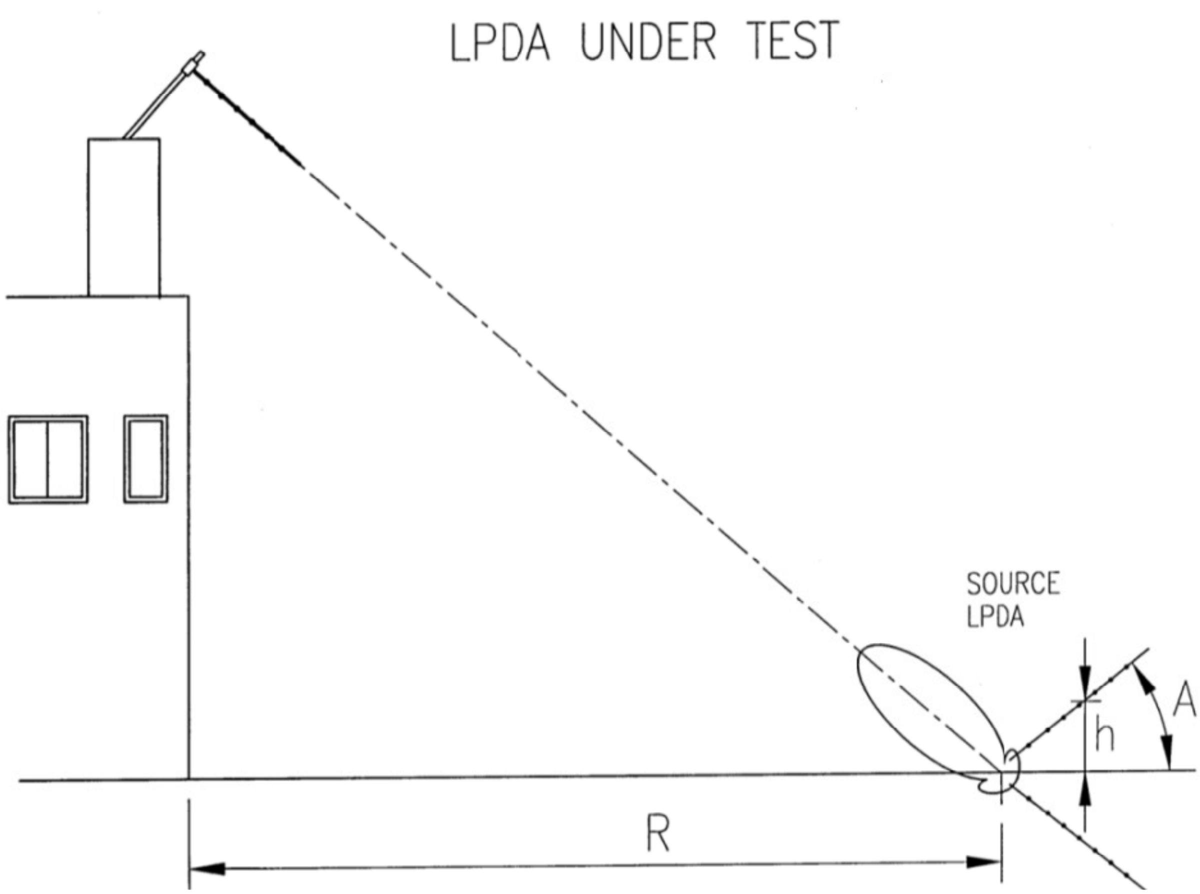


Figure 2.9 VHF/UHF test range layout with compact source antenna set to optimise ground reflection at highest required frequency

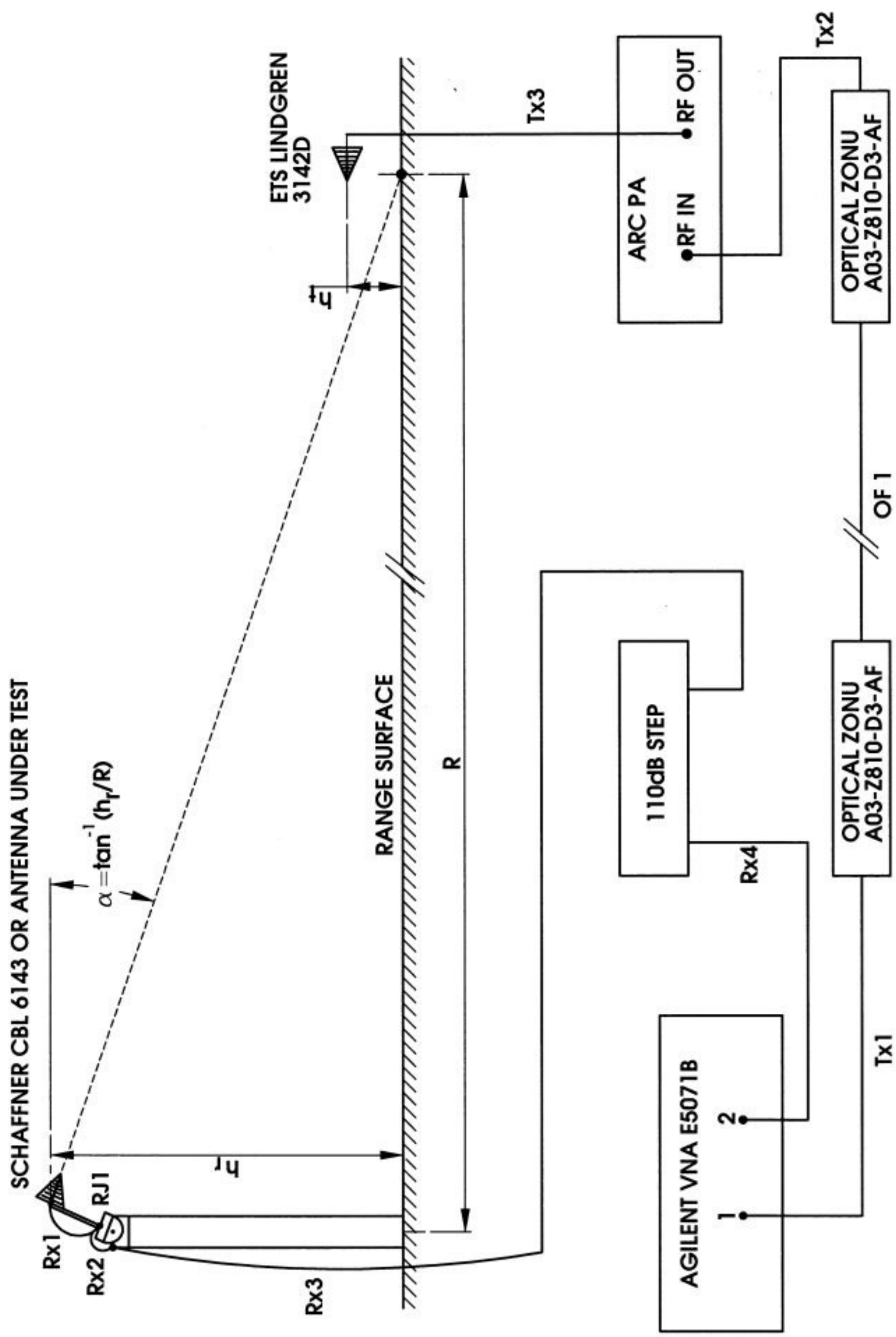


Figure 2.10 ETS Lindgren model 3142D set for vertical polarization at optimum height for 1 GHz

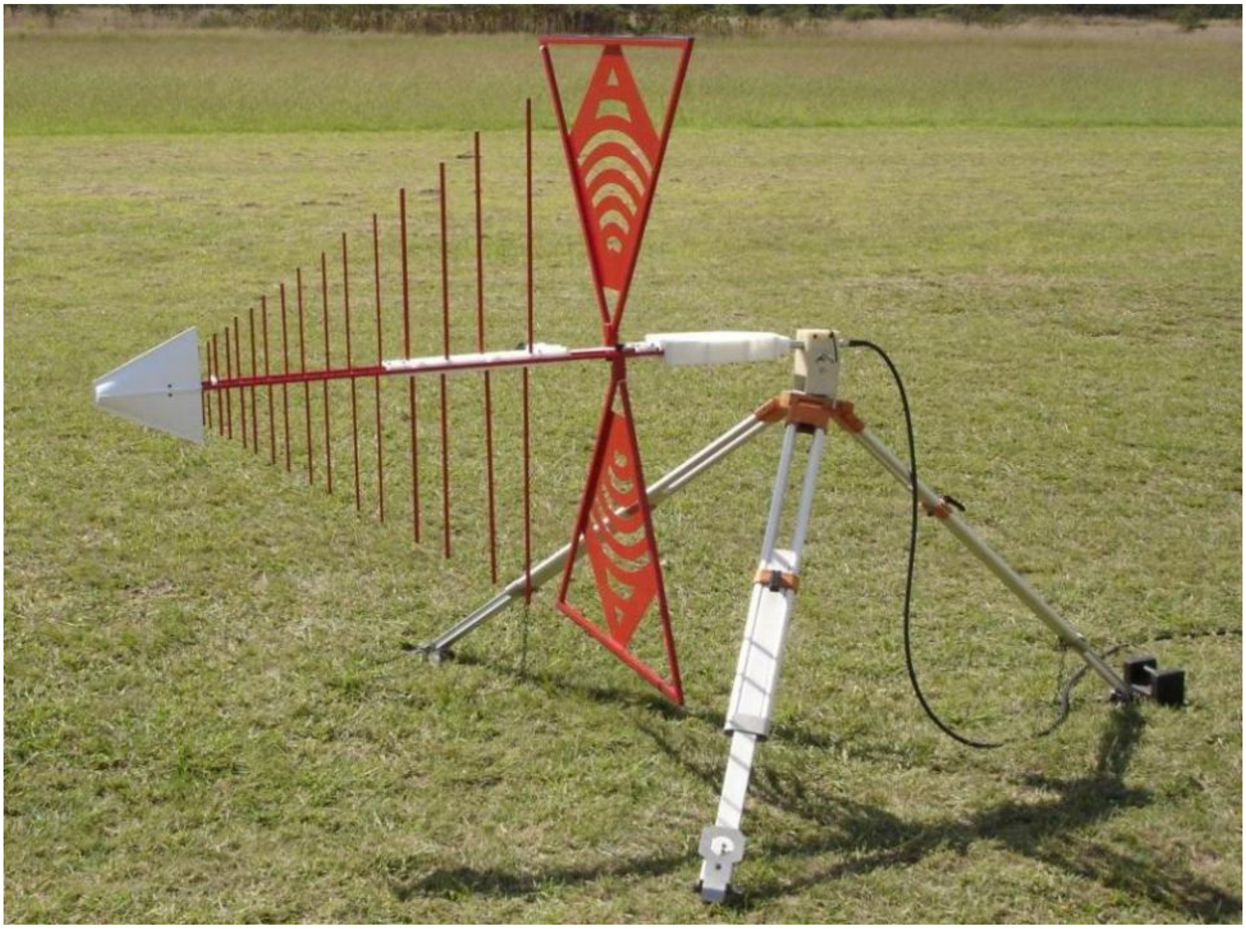


Figure 2.11 Schaffner model CBL 6143 mounted for vertical polarization on the test positioner of the Microwave Range

Figure 2.12 Measured dynamic range from 20 to 1 000 MHz at 180 m for ETS Lindgren model 3142D as source antenna and Schaffner model CBL 6143 as AUT (note degraded dynamic range below 80 MHz)

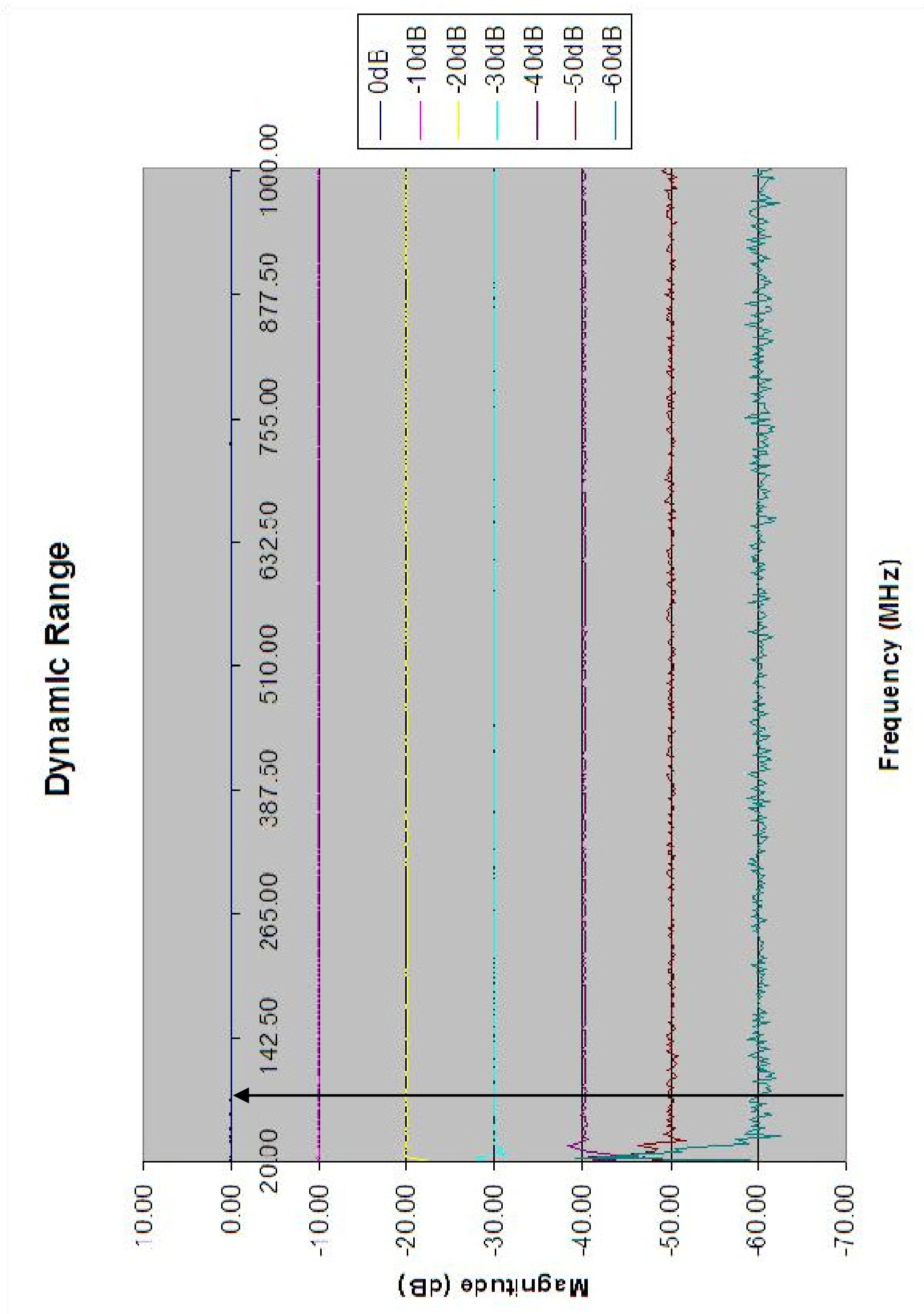


Figure 2.13 Amplifier Research Corporation model 10W1000C power amplifier and DC power supply for optical transceiver

Figure 2.14 Optical fibre to RF transducer at source end of the range providing RF input power to the power amplifier

3. SIZE OF ANTENNAS AS A FUNCTION OF FREQUENCY

3.1 Positioner capability

The VHF/UHF range has a Scientific Atlanta model 54150A azimuth/ elevation (az/ el) positioner mounted on the N – E corner of the operations building directly above the equipment room. The azimuth over elevation positioner has a mechanical specification for a vertical load of 2 500 lb (1 136 kg) and a bending moment of 2 500 lb.ft (3 388 N m). This positioner is mainly used to measure antennas and DF systems and it is unlikely that any of the antennas to be measured on the VHF/UHF range will exceed these specifications. The positioner generally is not the limitation on the antenna sizes.

3.2 Range distance requirements

3.2.1 Phase taper

Antennas are normally tested at some finite range where the incident field approximates a plane wave [3] and [4]. The commonly employed far-field criterion gives the range length as

$$R \geq \frac{2D^2}{\lambda} \tag{3.1}$$

where

R = test distance = 200 m

D = largest dimension of AUT (m)

λ = wavelength (m).

This equation sets the physical size of the antennas which can be measured. The DF systems measured on the VHF/UHF range are generally very small and this phase taper criterion is normally not a problem.

3.2.2 Inductive coupling

In addition to the far-field criterion we must also limit the inductive coupling. Here the commonly accepted criterion is that the test distance should be greater than 10 wavelengths [3] and [4]. Inductive coupling is more of a factor at the lower frequencies. The ratio of the amplitude of the inductive field E_i to the radiated field E_r from the source antenna at distance R is given by:

$$E_i / E_r = \lambda / (2\pi R) \tag{3.2}$$

If $R > 10\lambda$ then $20 \log (E_i / E_r) < -36$ dB.

At 200 m test range this means the largest wavelength is 20 m which is a frequency of 15 MHz. Thus at the normal VHF/UHF frequencies above 15 MHz, inductive coupling is not a factor. Below 15 MHz somewhat larger inductive coupling is accepted for practical reasons, even doubling the range distance only reduces the frequency to 7.5 MHz.

3.2.3 Longitudinal amplitude taper

For DF antenna systems the diameter of the antenna assembly is the main parameter. These diameters are quite small (1 to 2 m and at 200 m longitudinal amplitude taper is not a problem). However, there are end-fire antennas (Yagis, log periodic dipole arrays, end-fire arrays) which have significant length L. In this case the taper along the length of the antenna must be limited to about 1 dB. If the centre of the antenna is at R, the front of the antenna will be L/2 closer to the source and the rear of the antenna L/2 further away. The amplitude taper A over the length of the antenna is:

$$A = 20 \log \frac{R + L/2}{R - L/2} \qquad (3.3)$$

To achieve the 1 dB limit we need $R \geq 10$ L. At 200 m range this gives $L \leq 20$ m which clearly is not a problem. For the nominally 40 m test distance for LPDAs as in Figures 2.7 and 2.8 this implies that $L \leq 4$ m. The active region of a LPDA is shorter than its total length and so even for a 7.5 m long 20 to 1 000 MHz LPDA longitudinal amplitude taper is not significant. At shorter ranges (e.g. anechoic chambers) this condition may be difficult to achieve.

4. MEASUREMENT OF GAIN

4.1 Linearly polarized gain

The procedure outlined in this section is applicable to individual antenna elements. For integrated DF systems there are normally amplifiers and other RF components integrated behind the antenna elements and by using this procedure the 'integrated system gain' will be measured. When there are amplifiers in the receiver chain, the operator must ensure that the input drive levels of the VNA as specified by the equipment manufacturer are not exceeded and that the VNA is used in the linear region of its dynamic range and not driven into compression.

The most commonly used procedure for gain measurement on the VHF/UHF range is the gain transfer method [4]. The gain of the antenna under test (AUT) is measured by comparing the received power on the AUT with that received on a reference antenna of known gain. This reference antenna is often called a "standard gain" antenna (SGA). At the microwave range these gain standards are normally horn antennas but on the VHF/UHF range the gain reference antennas are active monopoles, dipoles, LPDAs and bilog antennas.

The SGA is first connected to the receiver via a stable coaxial cable and the SGA is peaked in azimuth and elevation. The polarization of the source must also be aligned with that of the SGA. The antenna under test (AUT) is then connected via the same test cable (See schematic in Figure 4.1(a)). If the same test cable cannot be used, the difference in losses between the cables must be measured and taken into account. Ideally the SGA must be installed and measured as close as possible to the actual position where the DF system or AUT will be located. This endures that the two measurements are made in the same test field. This is particularly important if the test field has amplitude taper or ripples in the elevation plane which exceeds 1 dB.

The difference in received power (P_T) on the test antenna and that on the standard antenna (P_S) represents the difference in gain.

$$(G_T)_{dBi} = (G_S)_{dBi} + 10 \log\left(\frac{P_T}{P_S}\right) \qquad (4.1)$$

which can be written as

$$G\ (AUT, dBi) = G\ (Ref, dBi) + D\ (dB) \qquad (4.2)$$

where D = dB difference between the reference and the AUT. If the reference lies below the AUT, the gain of the AUT is higher than the reference antenna.

The gain of the reference antenna is normally provided by the supplier as a table or graph of gain versus frequency. The gain values for horn antennas in the microwave frequency band are quoted to a typical accuracy of ± 0.25 dB. For the reference antennas on the VHF/UHF range the typical accuracy is often about ± 0.5 dB.

Ideally, both the AUT and the reference antenna must be well matched. If not, there will be VSWR mismatch errors which should be taken into account []. The reference antennas usually have good VSWR and the AUT is measured without VSWR correction since this gives the operational or realized gain in the 50 ohm coaxial system. For many applications a 6 dB or a 10 dB attenuator is placed on the test cable directly behind the AUT or SGA output connector. This improves the match to the receiver and reduces small amplitude ripples in the gain measurement caused by VSWR interactions in the AUT/SGA, test cable/ receiver chain. As a side benefit the potential static damage to the VNA receivers is decreased.

Many of the source and reference antennas used on the VHF/UHF range were developed for EMI/EMC testing. Some of the suppliers do not provide gain curves but rather supply the antenna factor (AF) as a function of frequency. The antenna factor relates the incident electric field to the voltage received on a matched transmission line as follows:

$$AF = E/V_r \qquad (4.3)$$

where

AF = antenna factor (1/m)

E = electric field (V/m)

V_r = received voltage (V)

For a 50 ohm system (as is most often the case at the NATR) it can be shown that the reference antenna gain can be deduced from its AF by

$$G\ (\text{dBi}) = 20 \log f\ (\text{MHz}) - AF - 29.78 \qquad (4.4)$$

The known antenna factor of a reference antenna can be used with the measured voltage in the receiver to deduce the incident electric field strength. Many systems have a sensitivity requirement for specified field strength. When doing the field strength measurement the measured relative loss of any cables connecting the reference antenna to the receiver must be taken into account. The cables must be stable in terms of amplitude to make repeatable measurements.

In some situations it is not possible to remove the AUT from the test positioner and then to put the SGA in its place. This occurs mainly when the AUT is either very large or very heavy and needs a crane to place it in position. In such cases, depending on the type of gain reference antenna, the AUT can be adapted to mount the SGA close to the actual position. This is shown in Figure 4.1(b) where an active HF monopole reference antenna is mounted on top of a COMINT DF system using a custom interface made of a length of PVC pipe [5]. The gain reference data can be taken and the reference antenna removed for the measurement of the system under test. With this arrangement it is relatively easy to repeat gain or incident field strength tests at any time during the measurement programme.

4.2 Circularly polarized gain

Below 500 MHz the measurement of circularly polarized gain on the VHF/UHF range will require custom test set-ups. This may require special source antennas with more directional patterns than the LPDAs and bilog antenna typically used. When the grazing angle is small (angle of incidence near 90˚) the reflection coefficients for both horizontal and vertical source polarizations have a magnitude of about 1.0 and a phase of 180°. The near grazing condition is achieved at the longer test ranges, e.g. at 200 m with a receive height of 10 m the grazing angle is 2.86˚. However, as the range length is decreased or the receive height is increased the grazing angle increases and the magnitude and phase of the reflection coefficient for vertical polarization can vary rapidly. The minimum reflection for vertical polarization occurs at the 'pseudo-Brewster angle' and the phase of the reflection coefficient changes rapidly from about -180° to 0° as one passes through the pseudo Brewster angle [6]. Depending on the soil conditions and the frequency, the magnitude of the V polarized reflection coefficient is about 0.24 at 12.5˚ Brewster angle for 12 MHz and 0.06 at a Brewster angle of 15° for 100 MHz. The magnitude and phase of the reflection coefficient for H polarization are well behaved and show only small changes as the grazing angle increases from 0° to 10°. With rapidly varying V polarization reflection coefficient over frequency, measurements of circularly polarized antennas are difficult. These are not standard measurements and are not easily done on a general purpose facility. Above 500 MHz the microwave range or the slant range can be used. The principles of measuring circularly polarized gain apply and are discussed below.

To support the above discussion, the Microwave Range was configured as described in Section 2.2.3 and a calibration was done from 250 to 500 MHz with the source antenna (ETS Lindgren 3142D) and the receive antenna (Schaffner CBL 6143) set for vertical polarization (this is called V-V). Both antennas were then rotated 90° to horizontal polarization (H-H). The H-H response was typically 2.5 dB above the V-V response. This difference is due to the differences in the ground reflection coefficients for the V and H polarizations. Using the data from [6] we obtain reflection coefficients for V polarization of 0.5 and 0.95 for H polarization at a grazing angle of about 5°. The net V-polarized field is the sum of the direct and ground reflected waves, similarly for the net H-polarized field. The input power to the source antenna remains the same during the measurements. Using a normalized value of 1 V/m for the direct filed, the V-polarized field in the test zone is 1.5 V/m while that for the H-polarized field is 1.95 V/m. This implies that the H-H field should be 2.3 dB higher than the V-V field in the test zone. This is in close agreement with the 2.5 dB which was measured. Such a difference will result in a range-induced measurement error in the axial ratio of the same size, i.e. 2.5dB. This error will also be present in the gain measurement. The magnitude of the error will be specific to the range configuration selected and accurate measurements may require longer test distances (smaller grazing angle) or time domain gating. Time domain gating implies that there is sufficient resolution to identify the direct and reflected signals; this is often not possible.

Gain measurements for circularly or elliptically polarized antennas are complicated because the gain reference antennas are usually linearly polarized. That is, no simple equivalent procedure to the gain transfer method described in Paragraph 4.1 is available because of the lack of commercially available circularly polarized reference antennas. For custom applications (normally narrow band, less than 30% bandwidth) some users manufacture and calibrate their own standard gain circularly polarized antennas. This is impractical on a general purpose test range.

Circularly polarized (CP) gain is usually measured using linearly polarized gain reference antennas. These are the same reference antennas used for the linear gain. The use of linearly polarized reference antennas is valid because the total power in the elliptically polarized wave can be separated into two orthogonal linear polarizations.

The gain calibration is done as before for vertical polarization between the source antenna and the SGA. The elliptically polarized AUT is then installed and the "partial gain" for V polarization measured. The source antenna is then rotated to horizontal polarization and the partial gain for H polarization is measured. V and H gains are calculated using Equation 4.2.

The circularly polarized gain is then computed from the partial gains for the orthogonal linear polarizations (normally V and H polarizations) as follows [4]:

$$G\ (dBci) = 10 \log (g_v + g_h) \tag{4.5}$$

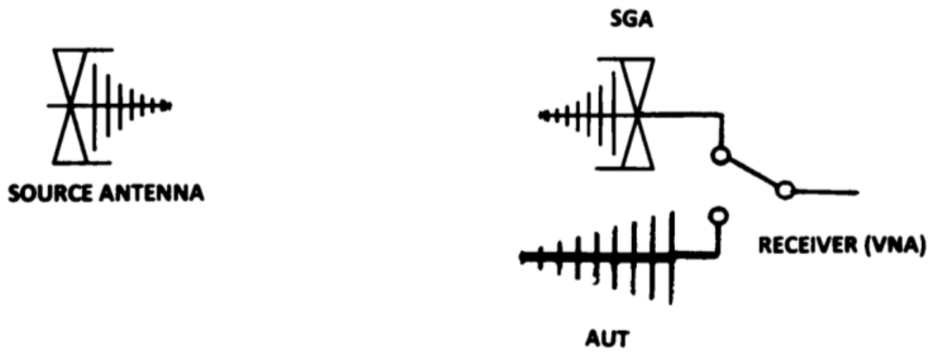
where

g_v = V polarized gain in numbers (not dBi)

g_h = H polarized gain in numbers (not dBi)

The linear gains are normally given as dBi relative to a linearly polarized isotropic antenna (often written as dBli). The circularly polarized gain is then expressed as dBci, dB relative to a circularly polarized isotropic antenna.

Figure 4.1 (a) Schematic showing successive connection of AUT and gain reference to receiver via a switch



(b) Test set-up showing AUT with HF gain reference mounted on top of the AUT

5. MEASUREMENT ACCURACY CONSIDERATIONS

5.1 Field probe measurements

The VHF/UHF range and the microwave range (operating in a VHF/UHF mode) are used to measure the pattern and gain performance of individual antennas (e.g. LPDA antennas, blade antennas on ground planes, omni-directional antennas, etc.). Some of these antennas cover extremely wide frequency ranges, for example LPDA antennas covering 20 to 1 000 MHz and blade antennas covering 25 to 500 MHz each in a single band. COMINT DF systems cover similar bands. These antennas and systems are normally linearly polarized. Ideally, for a time efficient measurement programme a single test set up is required that will cover the entire operating band of the antenna under test. The vector network analysers and gain reference antennas cover these frequency bands and so the main limitation is the source antenna configuration.

The COMINT antennas are tested as described in Section 2.2.1. Figures 2.2, 2.7 and 2.8 show various wide band test configurations designed to establish a uniform test field in the vertical plane. The ground reflection and the surface wave are used in Figure 2.2. In Figure 2.6 an attempt is made to eliminate the ground reflection by pointing the null of the E-plane pattern of the LPDA source antenna at the specular reflection point (the mirror reflection point) on the ground. This creates a vertically polarized field in the test zone. For a horizontally polarized test field, the LPDA source antenna is set for horizontal polarization and the phase centre movement of the LPDA antenna is used to achieve a ground-arrayed pattern which is nearly independent of frequency. The main determinant of the measurement accuracy is the taper in the test field and whether there are significant amplitude ripples in this test field.

The most reliable and accurate way to determine the field quality is to make field probe measurements. The NATR has a 5.5 m long field probe which consists of a high stiffness aluminium H-beam along which moves a probe carriage which has a polarization rotator and a pulley mechanism to move the probe antenna automatically. This is shown schematically in Figure 5.1 where the probe carriage is set for probing the field in the vertical plane. The probe antenna is normally a wide band resistively matched dipole or a bilog antenna. The field must be probed (measured) at a sufficient number of frequencies in the band to ensure that there are no frequencies in the band where the test field has undesired variations. It is a time-consuming process to mount the field probe and execute the measurements. What is often done is to mount a probe antenna on a PVC pipe on the test positioner; the pipe is long enough to extend beyond the physical extent of the antenna to be tested. The PVC pipe has around five fixed mounting locations along its length. The probe antenna is installed at the centre of the pipe and a swept-frequency response is taken at the centre of the test zone for a sufficient number of frequencies (say 101 or 201 frequency points). This is repeated for two positions above and two positions below the centre point. The amplitude taper over height can then be determined at each frequency. This procedure is very useful for compact COMINT DF arrays which are only 1 or 2 m high.

5.2 Measurement of large LPDA antennas

For large LPDA antennas (4 to 7.5 m wide at the longest dipoles) full field probes using the probe carriage of figure 5.1 should be done. However, when there are only a few antennas to be tested, an alternate procedure which relies on the expected received power as a function of frequency can be used. The received power is directly proportional to the gains of the source and receive antennas, the propagation path loss and the total cable losses in the transmit/receive chains. The path loss slope is known and the cable losses are measured with the VNA. These losses create a combined loss slope over frequency. For VHF LPDA antennas the gains are nearly constant with frequency (say, 6 to 8 dBi) and the gains have very small impact on the loss slopes. With the range configured as in Figures 2.7 or 2.8, measure the received signal on the reference LPDA using the VNA. Superimpose the expected loss slope with frequency on the measured data. If there are cyclical dips in the received power which deviate significantly from the loss slope adjust the height and/or inclination angle of the LPDA until the received power dips move out of the desired frequency range and the measured slope starts to match the expected slope. Under this condition the test field is optimised and the patterns and gain of the LPDA under test can be measured.

Figure 5.2 shows the results of this process. The reference antenna was the Scientific Atlanta Model 26-0.1 (0.1 to 1 GHz) LPDA antenna. Its relative power response is shown as the thick line. The source antenna was an American Electronics Laboratory (AEL) LPDA. The test antenna was a prototype 80 to 500 MHz LPDA (its received power response is shown by the thin line). Both the reference and test antennas follow the cable + path loss slope closely (typically to better than 1 dB) over the entire frequency range. If the source set up is incorrect a relatively wide dip in received power 10 to 15 dB deep appears in the 355 to 555 MHz frequency range. The Model 26-0.1 cuts off rapidly at 100 MHz while the test antenna cuts off at 80 MHz. The relative powers for the two antennas track each other closely showing that the gains of the two antennas are nearly the same.

There are five arrows on the plot of Figure 5.2 marking distinct features which belong to the individual LPDAs. Arrows 1, 2 and 5 indicate sharp dips in received power over narrow frequency bands which are present on both antennas. These features are known as 'boom resonance phenomena' which sometimes occur because of slight asymmetries in construction [7]. Because the dips are present on both the antennas under test the dips are a property of the source antenna. Arrows 3 and 4 show dips which are present only on the Model 26-0.1and as such are a property of this antenna (actually an undesired effect). Proper termination of the LPDA boom is required to eliminate these resonances. This swept frequency technique is a powerful tool to evaluate the performance of LPDA antennas. If patterns and gain are measured at 50 MHz intervals these resonance dips will probably be missed.

Figure 5.3 shows the E-plane pattern of a 80 to 600 MHz LPDA antenna measured using the test configuration in Figure 2.8. There is a high level of pattern symmetry and the deep nulls in the E-plane pattern are evident at 90° and 270°. Such deep nulls cannot be measured when the LPDA is set for vertical polarization on the test pedestal and the LPDA is tilted forward and backward to make the E-plane cut. Extraneous reflections from the range surface will fill in the nulls. Note that the pattern meets exactly at the same dB value (-18 dB) at + and - 180° which is the same data point but actually spaced 360°. There is no closing error. The measurements were made with a rotary joint in the azimuth positioner and the test cable was not wrapped as the positioner turned through 360°. The H-plane pattern (see Figure 5.4) was measured using the arrangement in Figure 2.7 where the LPDA is set for vertical polarization and the H-plane cut is made using the upper azimuth positioner. The pattern has all the features of a typical LPDA H-plane pattern. The trace is 'noisy' in the angular sector from 120° to 200°. This is not a sensitivity or a dynamic range problem, the 40 dB deep null in Figure 5.3 is not noisy at all. This is an indication of extraneous interference where a strong vertically polarized VHF FM signal breaks through the VNA receiver and is not suppressed. These measurements were made using an older generation VNA (Hewlett Packard 8753B) which does not have the extraneous signal rejection capability of the more modern VNAs. Even these VNAs can be susceptible to strong extraneous signals and the user must be aware that the output power of the VNA should be increased to maximum and that the band width should be reduced. Smaller band width increases the measurement time but much smoother and cleaner patterns are measured and one does not subsequently have to explain this type of pattern oddity to the customer.

Blade antennas have deep nulls at 90° above the horizon, these nulls and the high elevation coverage elevation plane patterns can only be measured to good accuracy with the blade ground plane set vertical and the blade at right angles to this. The source is set for horizontal polarization as in Figure 2.8 and the E-plane cut (in this case this is the elevation cut) is made by rotating the azimuth positioner.

5.3 Measurement of a COMINT DF system

COMINT DF systems can be measured on the VHF/UHF and microwave ranges. Depending on the number of RF channels there may be many RF cables which must come down the receive tower. A particular system had 11 RF cables, a fibre-optic control cable and a power cable coming down the mast. There are no RF rotary joints with 10 or more channels so the cables must wrap around the mast as the upper azimuth positioner turns. To limit the wrapping effect the cables are bunched together and supported in such a way that there is only about 180° rotation in the clockwise direction and 180° rotation in the counter clockwise direction. This limits the torsion on the cables which can be problematic for phase measurements to 3 GHz. The positioner always rotates from - 180° to + 180° while the data is being gathered. At the end of a 360° pattern cut, the positioner rotates back to -180° to start the next cut. There are hard limit switches which turn off the electrical power to the motors to prevent rotations greater than + and - 200°. The limits can also be set as soft limits in the measurement software. Both these actions improve the measurement repeatability. There is another beneficial effect in that the backlash in the turntable gears is always the same. For high accuracy systems the backlash can be problematic if data is taken sequentially in clockwise and then counter clockwise rotations.

Because the test cables cannot pass down the centre of the positioned (no rotary joints), they are draped down the back of the positioner and held in place. In addition, ferrite cores are added to suppress the currents which will run on the outer conductors of the coaxial cables. Figure 5.5 shows a typical azimuth pattern with a closing error (upper plot) caused by motion of the cables and currents coupling to the positioner, the lower plot shows the effects of the ferrite cores which remove the closing error. Figure 5.6 shows a typical set up with ferrite cores and the cable grouping taped to the positioner. DF measurements are equally sensitive to non-closing errors and large RMS accuracy errors can result if the cables are not configured in as near identical ways when the DF system is calibrated and subsequently used to do DF with the corrected data from the calibration sequence.

5.4 Measurement of LPDAs using compact source antennas

The test configuration described in Section 2.2.3 can be used to measure the E- and H-plane patterns of LPDAs, blades and other antennas over broad frequency ranges. The test set-up as depicted in Figure 2.9 was made and the patterns of the Schaffner CBL 6143 bilog antenna were measured over the 100 to 1 000 MHz frequency range. The E-place patterns are measured with the source and AUT set for horizontal polarization. The H-plane patterns are made with the source and AUT set for vertical polarization as shown in Figures 2.10 and 2.11.

The E-plane patterns at 100 and 1 000 MHz are shown in Figures 5.7(a) and 5.7(b). At 100 MHz the pattern of the bilog resembles that of a dipole except the nulls are filled in. This is so because the triangular part of the antenna is the basic radiating element below about 150 MHz. At 1 000 MHz (Figure 5.7(b)) the pattern is that of a well-behaved LPDA as is expected.

The H-plane patterns at 100 and 1 000 MHz are shown in Figures 5.8(a) and 5.8(b). At 100 MHz the H-plane pattern is nearly omni-directional as we expect for a vertically polarized dipole. The elements of the LPDA have some action as directors thereby giving some forward radiation. At 1 000 MHz the pattern is typical of a LPDA with the Schaffner design parameters. It is clear the good antenna pattern measurements can be made over wide frequency ranges using the compact source antenna in a ground reflection mode.

Figure 5.1 Linear field probe set for vertical plane

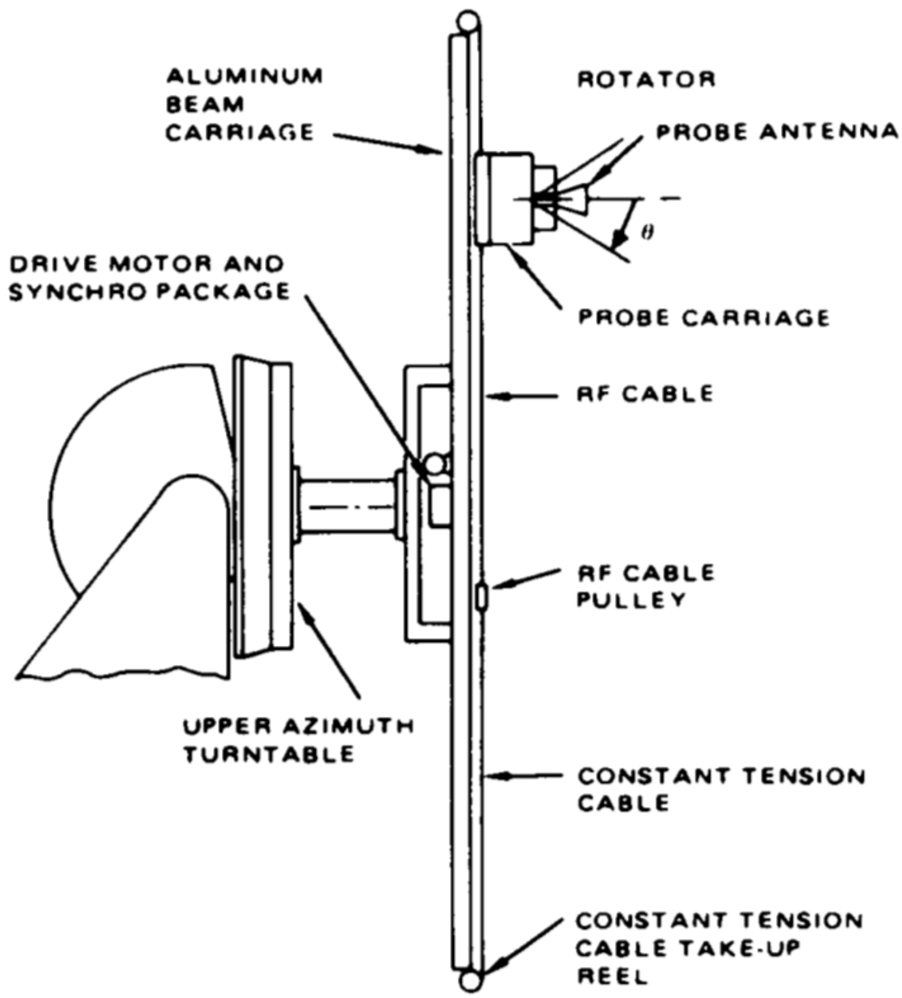


Figure 5.2 Expected received power between two LPDA antennas based on measured cable losses and predicted path loss slopes

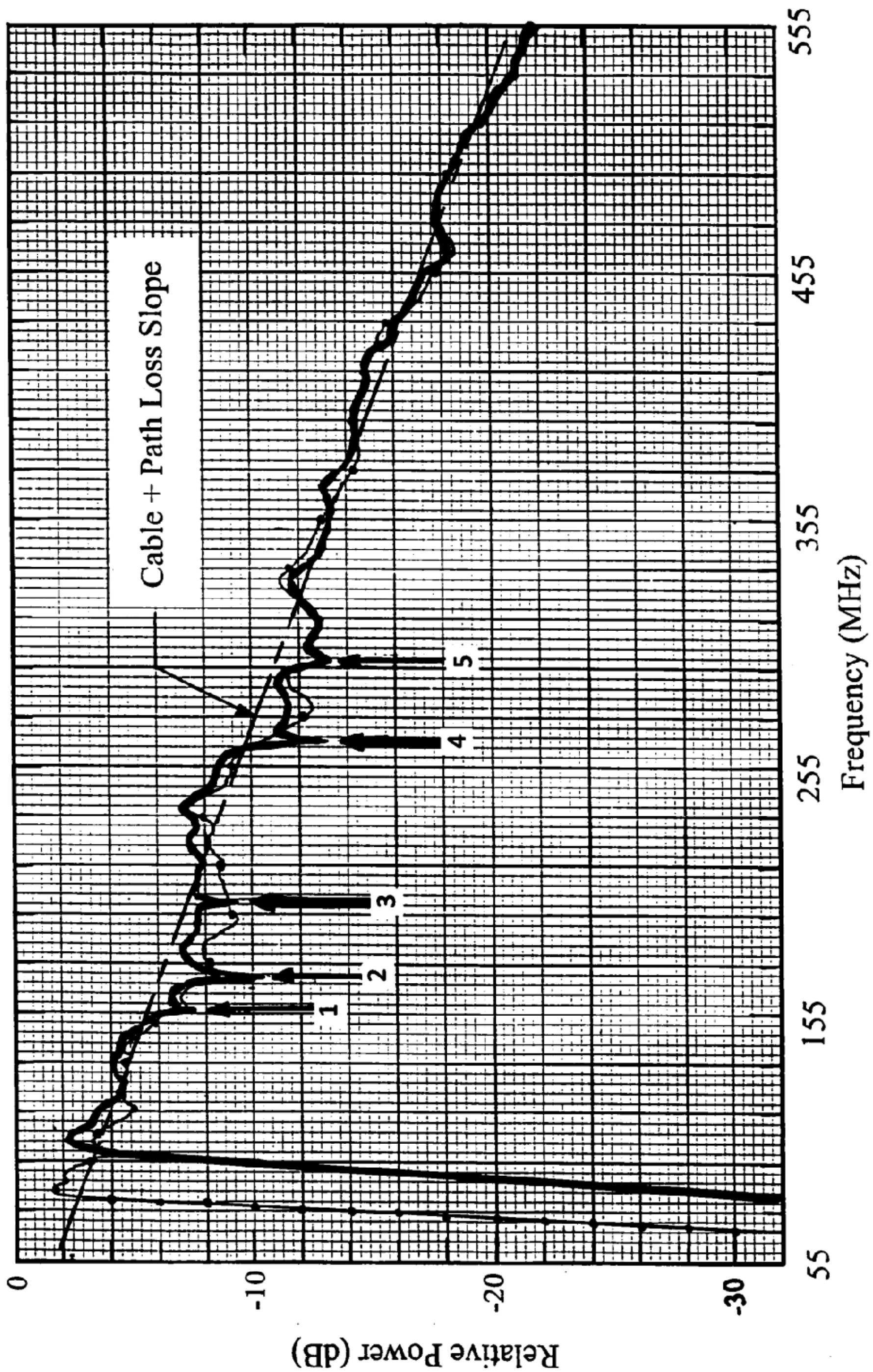


Figure 5.3 E-plane pattern of 80 to 600 MHz LPDA antenna measured at 100 MHz, note the 40 dB deep nulls at 90° and 270°

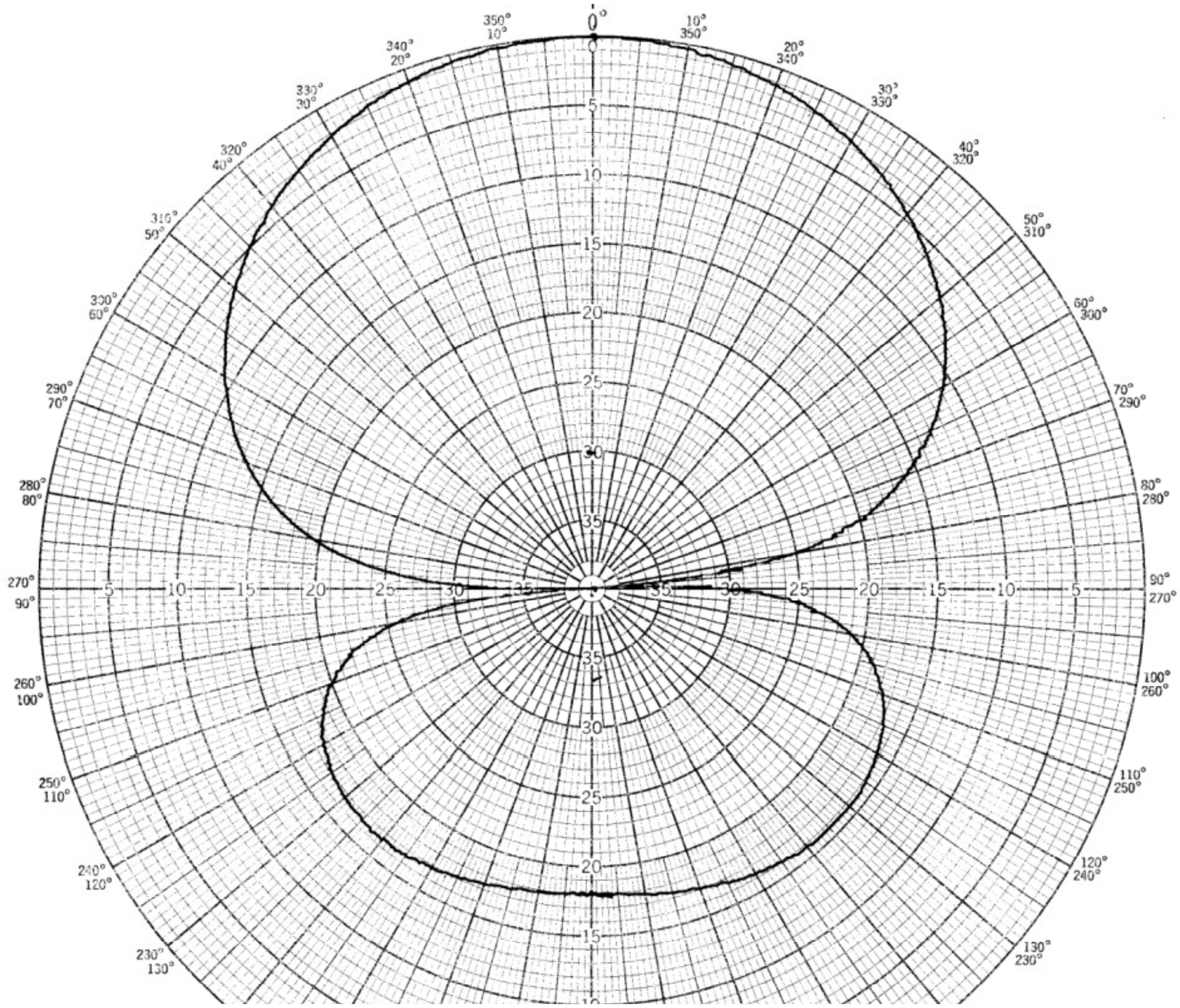


Figure 5.4 H-plane pattern of 80 to 600 MHz LPDA antenna measured at 100 MHz, note the noisy trace between 120° and 200°

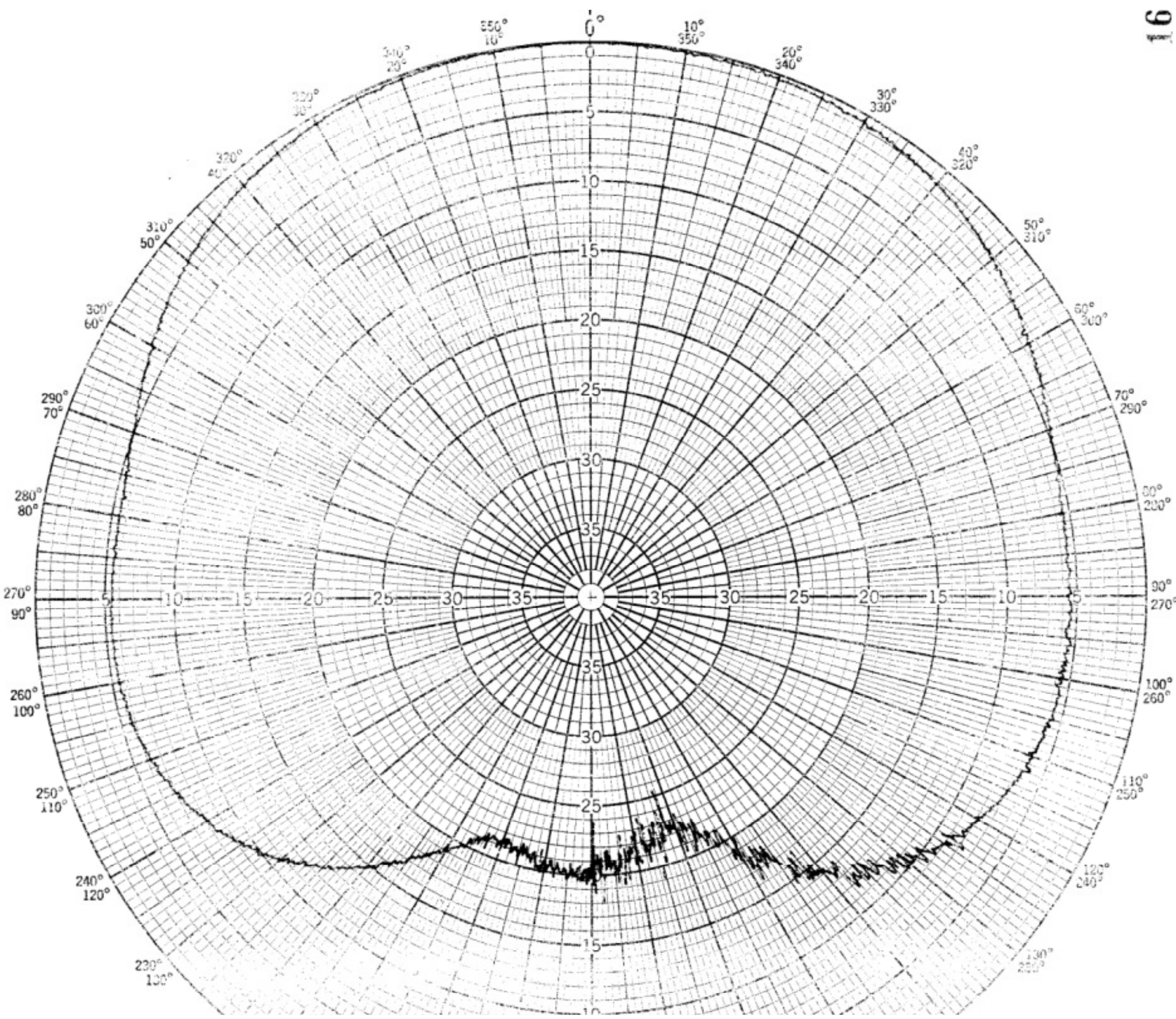
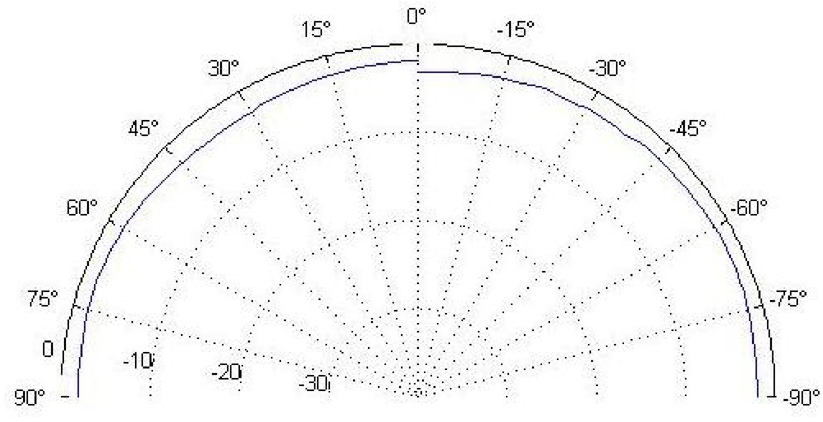


Figure 5.5 Top: Closing error at 0 degrees on the omni-directional monitoring antenna at a particular frequency caused by wrapping of the test cable, and Bottom: no closing error at another frequency



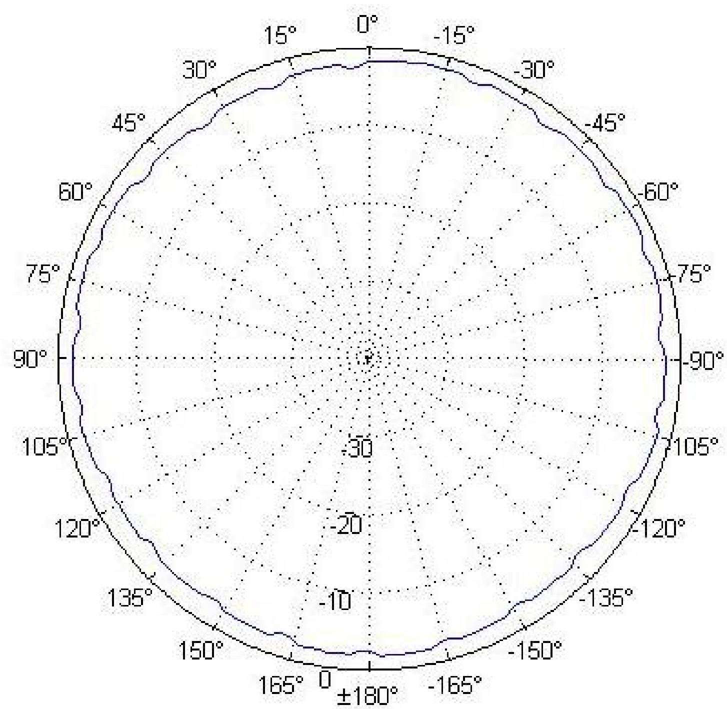


Figure 5.6 Receive cables with ferrite cores (upper photograph), cables and cores taped to positioner

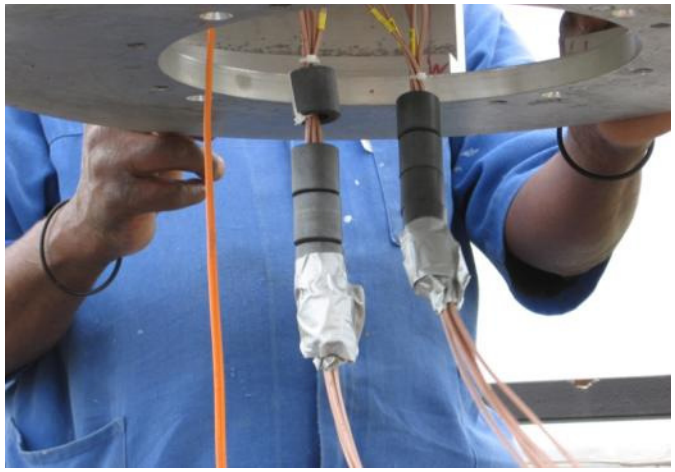
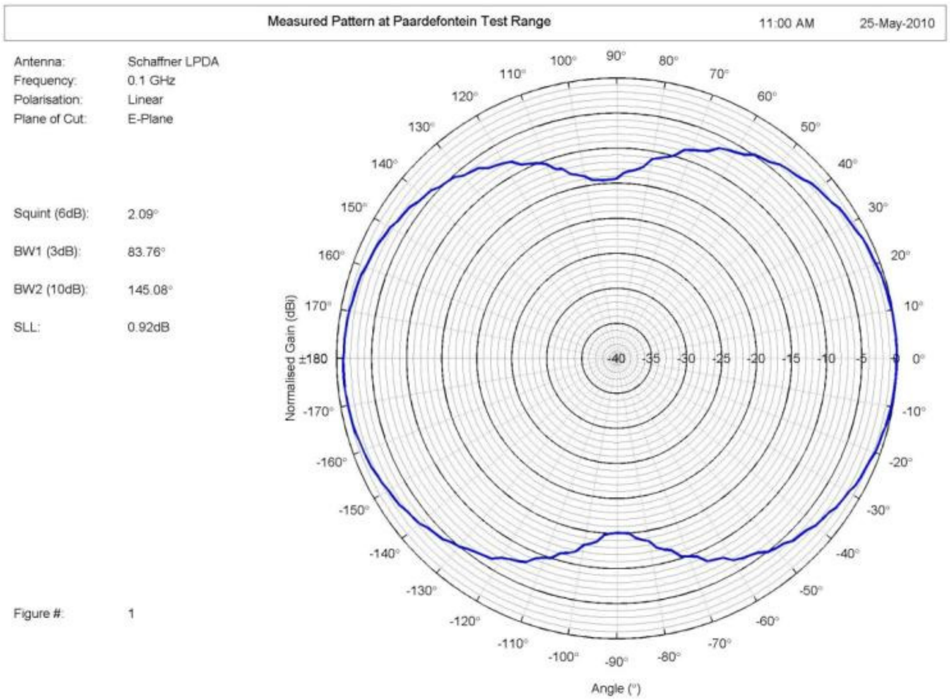


Figure 5.7 Measured E-plane patterns of Schaffner model CBL 6143 at (a) 100 MHz and (b) 1 000 MHz



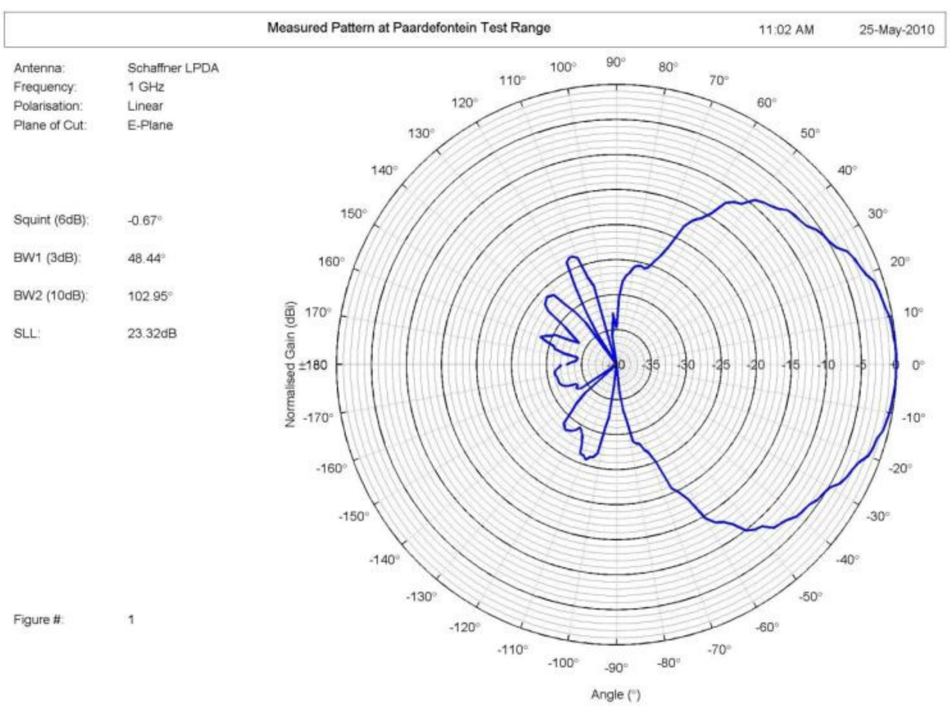
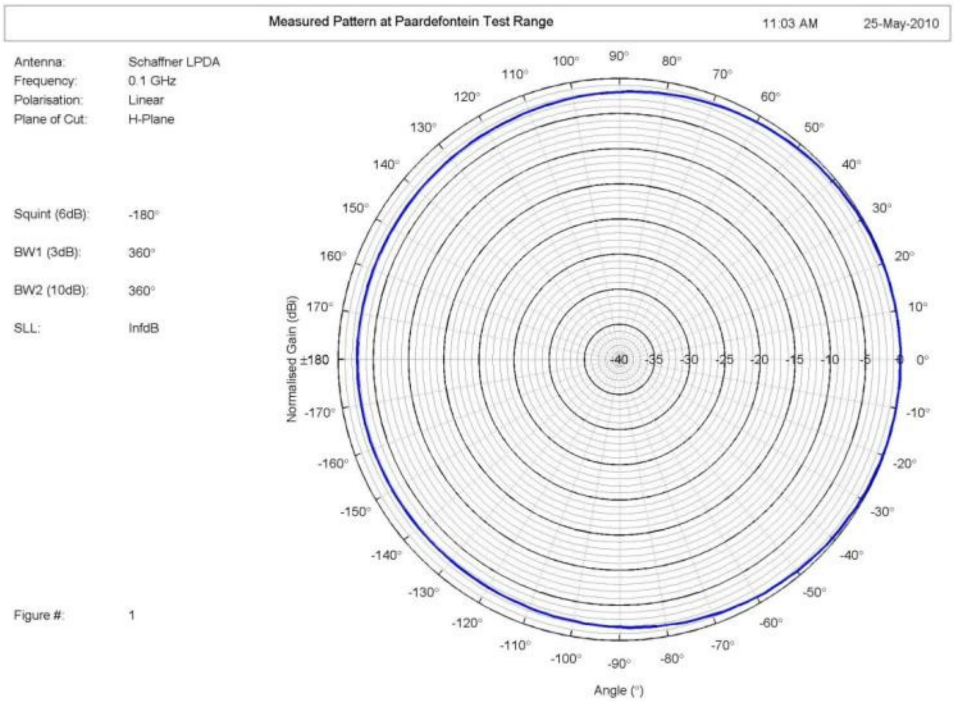
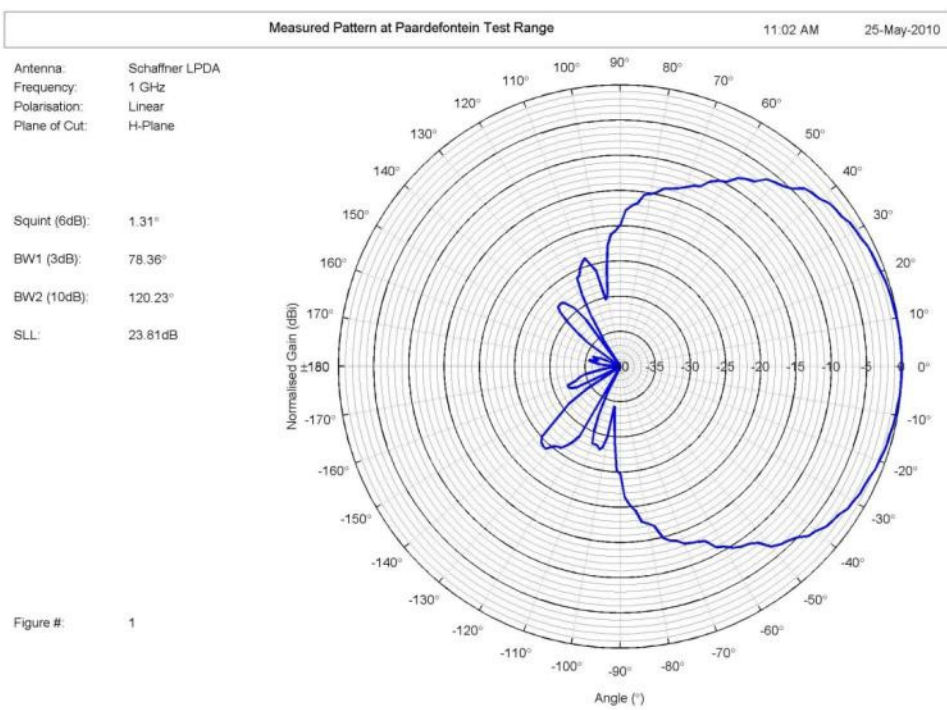


Figure 5.8 Measured H-plane patterns of Schaffner model CBL 6143 at (a) 100 MHz and (b) 1 000 MHz





6. CONCLUSION

This user manual has described the VHF/UHF range and the typical measurements currently made on this range. Emphasis is on measuring the DF accuracy of COMINT systems. These are generally very wide frequency band width systems requiring a very large number of calibration data points over frequency, azimuth angle, elevation angle and incident field strength. Most of the COMINT DF systems being tested currently are vertically polarized and this simplifies the measurement configurations.

From a measurement time point of view it is not practical to have more than 2 or 3 source antenna configurations. For the integrated DF systems, the VHF/UHF range is operated with wide band source antennas which are placed at fixed height above the range surface. This gives a combination of direct, reflected and ground waves which create the incident electric field in the test zone. Because the height of the source antenna is not adjusted as for a conventional ground reflection range, the test field is not always optimised and at the lower frequencies the test field can have significant taper. Because the vertical extent of the DF systems is generally quite small (1 to 2 m) the field taper in the vertical plane can be limited to typically around one dB. This is acceptable for the type of system tests required.

With sufficient care highly repeatable measurement set ups can be made. This is important because system calibration and customer acceptance tests can sometimes be months apart. The VHF/UHF range has proved to be ideal for these measurements and calibrations over frequencies extending from 300 kHz to 3 GHz.

In addition to the capability to make COMINT DF system measurements, the VHF/UHF range can make excellent pattern and gain measurements on large LPDA antennas in the 20 to 3 000 MHz frequency band. Full scale measurements can be done on 20 to 500 MHz blade antennas mounted on large ground planes. Caution must be exercised not to tilt the antennas forwards and backward to make elevation plane cuts, much better results are achieved by rotating the LPDA 90° about its axis, rotating the source polarization 90° and making what is effectively the elevation cut using the upper azimuth positioner. Two different source antenna configurations were presented for making measurements on individual antennas. The first configuration uses the pattern properties of a full-sized LPDA source antenna to obtain an acceptable test field. The other configuration exploits the properties of compact bilog antennas as source antennas by configuring what is effectively a ground reflection range. In this case the source height is held fixed over frequency ranges from 30 to 3 000 MHz, The fixed height is selected to place the peak of the test field (formed by the sum of the direct and reflected fields) at or near the centre of the test aperture at the highest frequency of operation. This height is calculated using Equation 2.1.

Special care must be taken when measuring circularly polarized antennas at frequencies below about 500 MHz using the ground reflection set up with the bilog antenna as the source antenna. Depending on the grazing angle, the V and H polarization ground reflection coefficients can be quite different. Rotating the source antenna from V to H polarization can introduce an axial ratio error of as much as 3 dB depending on the grazing angle. Above 500 MHz the 3 m dish can be used as the source antenna on the 500 m Microwave Range.

All the measurements described in this manual for the VHF/UHF Range can be carried out on the Microwave Range. The converse is not necessarily true – large radar antennas require the longer test distance, the heavy duty positioner and the tower with adjustable source height on the Microwave Range.

7. REFERENCES

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APPENDIX: GLOSSARY OF STANDARD ANTENNA TERMS

This glossary is an extract taken from the IEEE definitions and defines some of the most commonly used antenna terms (see IEEE Std. 149-1979, *Definition of terms for Antennas* for a complete listing). Consistent application of standard definitions will eliminate confusion relating to antenna specifications and interpretation of measured results.

Antenna efficiency of an aperture-type antenna. For an antenna with a specified planar aperture, the ratio of the maximum effective area of the antenna to the aperture area.

Aperture of an antenna. A surface, near or on an antenna, on which it is convenient to make assumptions regarding the field values for the purpose of computing fields at external points.
Note: The aperture is often taken as that portion of a plane surface near the antenna, perpendicular to the direction of maximum radiation, through which the major part of the radiation passes.

Aperture illumination. The field over the aperture as described by amplitude, phase and polarization distributions.

Axial ratio (of a polarization ellipse). The ratio of the major to minor axes of a polarization ellipse. The ratio varies from infinity to 1 as the polarization changes from linear to circular.

Beam. The major lobe of the radiation pattern.

Bistatic cross section. The scattering cross section in any specified direction other than back toward the source.

Cardinal plane. For an infinite planar array whose elements are arranged in a regular lattice, any plane of symmetry normal to the planar array and parallel to an edge of a lattice cell.

Circularly polarized field vector. At a point in space, a field vector whose extremity describes a circle as a function of time.
Note: Circular polarization may be viewed as a special case of elliptical polarization where the axial ratio has become equal to one.

Copolarization. The polarization that the antenna is intended to radiate or receive.

Cross polarization. In a specified plane containing the reference polarization ellipse, the polarization orthogonal to a specified reference polarization.
Note: The reference polarization usually is the copolarization. Two fields have orthogonal polarizations if their polarization ellipses have the same axial ratio, major axes at right angles, and opposite senses of rotation. If the reference polarization is right-handed circular, the cross polarization is left-handed circular, and vice versa.

Directivity (of an antenna) (in a given direction). The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.
Notes: (1) The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. (2) If the direction is not specified, the direction of maximum radiation intensity is implied.

Directivity, partial (of an antenna for a given polarization). In a given direction, that part of the radiation intensity corresponding to a given polarization divided by the total radiation intensity averaged over all directions.

Note: The (total) directivity of an antenna, in a specified direction, is the sum of the partial directivities for any two orthogonal polarizations.

Effective area of an antenna (in a given direction). In a given direction, the ratio of the available power at the terminals of a receiving antenna to the power flux density of a plane wave incident on the antenna from that direction, the wave being polarization-matched to the antenna.

Notes: (1) If the direction is not specified, the direction of maximum radiation intensity is implied. (2) The effective area of an antenna in a given direction is equal to the square of the operating wavelength times its gain in that direction divided by 4π.

Elliptically polarized field vector. At a point in space, a field vector whose extremity describes an ellipse as a function of time.

Note: Any single-frequency field vector is elliptically polarized if *elliptical* is understood in the wide sense as including circular and linear. Often, however, the expression is used in the strict sense meaning noncircular and nonlinear.

E plane, principal. For a linearly polarized antenna, the plane containing the electric field vector and the direction of maximum radiation.

Equivalent flat plate area of a scattering object. For a given scattering object, an area equal to 7the wavelength times the square root of the ratio of the monostatic cross section to 4π.

Note: A perfectly reflecting plate parallel to the incident wavefront and having this area, if it is large compared to the wavelength, will have approximately the same monostatic cross section as the object.

Far-field region. That region of the field of an antenna where the angular field distribution essentially is independent of the distance from a specified point in the antenna region.

Note: In free space, if the antenna has a maximum overall dimension, D, which is large compared to the wavelength, the far-field region commonly is taken to exist at distances greater than $2D^2/\lambda$ from the antenna, λ being the wavelength. The far-field patterns of certain antennas, such as multibeam reflector antennas, are sensitive to variations in phase over their apertures. For these antennas $2D^2/\lambda$ may be inadequate.

Fraunhofer region. The region in which the field of an antenna is focused.

Note: In the Fraunhofer region of an antenna focused at infinity, the values of the fields, when calculated from knowledge of the source distribution of an antenna, are sufficiently accurate when the quadratic phase terms (and higher order terms) are neglected.

Fresnel region. The region (or regions) adjacent to the region in which the field of antenna is focused (that is, just inside the Fraunhofer region).

Note: In the Fresnel region in space, the values of the fields, when calculated from knowledge of the source distribution of an antenna, are insufficiently accurate unless the quadratic phase terms are taken into account, but are sufficiently accurate if the quadratic phase terms are included.

Front-to-back ratio. For directional antennas, the ratio of the antenna's effectiveness toward the front to its effectiveness toward the back (often expressed as a dB value).

Gain, absolute (of an antenna) (in a given direction). The ratio of the radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.

Notes: (I) Gain does not include losses arising from impedance and polarization mismatches. (2) The radiation intensity corresponding to the isotropically radiated power is equal to the power accepted by the antenna divided by 4π. (3) If an antenna is without dissipative loss, then in any given direction, its gain is equal to its directivity. (4) If the direction is not specified, the direction of maximum radiation intensity is implied. (5) The term absolute gain is used in those instances where added emphasis is required to distinguish gain from relative gain; for example, absolute gain measurements.

Gain, partial (of an antenna for a given polarization). In a given direction, that part of the radiation intensity corresponding to a given polarization divided by the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.
Note: The (total) gain of an antenna, in a specified direction, is the sum of the partial gains for any two orthogonal polarizations.

H plane, principal. For a linearly polarized antenna, the plane containing the magnetic field vector and the direction of maximum radiation.

Intercardinal plane. Any plane that contains the intersection of two successive cardinal planes and is at an intermediate angular position.
Note: In practice, the intercardinal planes are located by dividing the angle between successive cardinal planes into equal parts. Often, it is sufficient to bisect the angle so that there is only one intercardinal plane between successive cardinal planes.

Isotropic radiator. A hypothetical, lossless antenna having equal radiation intensity in all directions.
Note: An isotropic radiator represents a convenient reference for expressing the directive properties of actual antennas.

Linearly polarized field vector. At a point in space, a field vector whose extremity describes a straight line segment as a function of time.
Note: Linear polarization may be viewed as a special case of elliptical polarization, where the axial ratio has become infinite.

Major lobe; main lobe. The radiation lobe containing the direction of maximum radiation.
Note: In certain antennas, such as multi-lobed or split-beam antennas, there may be more than one major lobe.

Mean sidelobe level. The average value of the relative power pattern of an antenna taken over a specified angular region, which excludes the main beam, the power pattern being relative to the peak of the main beam.

Minor lobe. Any radiation lobe except a major lobe. *See sidelobe*.

Monostatic cross section; backscattering cross section. The scattering cross section in the direction toward the source.
Note: Compare this term with the term *bistatic cross section*.

Near-field region. That part of space between the antenna and far-field region.
Note: In lossless media, the near-field may be further subdivided into reactive and radiating near-field regions.

Orthogonal polarization (with respect to a specified polarization). In a common plane of polarization, the polarization for which the inner product of the corresponding polarization vector and that of the specified polarization is equal to zero.
Notes: (I) The two orthogonal polarizations can be represented as two diametrical points on the Poincare sphere. (2) Two elliptically polarized fields having the same plane of polarization have

orthogonal polarizations if their polarization ellipses have the same axial ratio, major axes at right angles, and opposite senses of polarization.

Omnidirectional antenna. An antenna having an essentially non-directional pattern in azimuth and a directional pattern in elevation. The deviation from omni in the azimuth pattern is the difference between the maximum gain in the pattern (wherever it occurs in the pattern) and the minimum gain (wherever it occurs in the pattern) divided by two. This difference is expressed as a ± dB value.

Phase center. The location of a point associated with an antenna such that, if it is taken as the center of a sphere whose radius extends into the far-field, the phase of a given field component over the surface of the radiation sphere is essentially constant, at least over that portion of the surface where the radiation is significant.

Note: Some antennas do not have a unique phase center.

Plane of polarization. A plane containing the polarization ellipse.

Note: For a plane wave in an isotropic medium, the plane of polarization is taken to be normal to the direction of propagation.

Polarization efficiency; polarization mismatch factor. The ratio of the power received by an antenna from a given plane wave of arbitrary polarization to the power that would be received by the same antenna from a plane wave of the same power flux density and direction of propagation, whose state of polarization has been adjusted for a maximum received power.

Note: The polarization efficiency is equal to the magnitude of the inner product of the polarization vector describing the receiving polarization of the antenna and the polarization vector of the plane wave incident at the antenna.

Polarization pattern (of an antenna). (1) The spatial distribution of the polarizations of a field vector excited by an antenna taken over its radiation sphere. (2) The response of a given antenna to a linearly polarized plane wave incident from a given direction and whose direction of a polarization is rotating about an axis parallel to its propagation vector; the response being plotted as a function of the angle that the direction of polarization makes with a given reference direction.

Polarization, receiving (of an antenna). That polarization of a plane wave, incident from a given direction and having a given power flux density, which results in maximum available power at the antenna terminals.

Polarization of a wave (radiated by an antenna in a specified direction). In a specified direction from an antenna and at a point in its far field, the polarization of the (locally) plane wave which is used to represent the radiated wave at that point.

Principal half-power beamwidths. For a pattern whose major lobe has a half-power contour which is essentially elliptical, the half-power beamwidths in the two pattern cuts that contain the major and minor axes of the ellipse respectively.

Radar cross section. For a given scattering object, upon which a plane wave is incident, that portion of the scattering cross section corresponding to a specified polarization component of the scattered wave. *See scattering cross section*.

Radiation efficiency. The ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter.

Radiation intensity. In a given direction, the power radiated from an antenna per unit solid angle.

Radiation pattern; antenna pattern. The spatial distribution of a quantity which characterizes the electromagnetic field generated by an antenna.

Note: When the amplitude or relative amplitude of a specified component of the electric field vector is plotted graphically, it is called an *amplitude pattern*, *field pattern*, or *voltage pattern*. When the square of the amplitude or relative amplitude is plotted, it is called a *power pattern*.

Radiation pattern cut. Any path on a surface over which a radiation pattern is obtained.

Note: For far-field patterns the surface is that of the radiation sphere.

For this case the path formed by the locus of points for which θ is a specified constant and Φ is a variable is called a *conical cut*. The path formed by the locus of points for which Φ is a specified constant and θ is a variable is called a *great circle cut*. The conical cut with θ equal to 90° is also a great circle cut. A spiral path which begins at the north pole (θ = 0°) and ends at the south pole (θ = 180°) is called a *spiral cut*.

Radiation resistance. The ratio of the power radiated by an antenna to the square of the rms antenna current referred to a specified point.

Note: The total power radiated is equal to the power accepted by the antenna minus the power dissipated in the antenna.

Realized gain. The gain of an antenna reduced by the losses due to the mismatch of the antenna input impedance to a specified impedance.

Note: The realized gain does not include losses due to polarization mismatch between two antennas in a complete system.

Realized gain, partial (of an antenna for a given polarization). The partial gain of an antenna for a given polarization reduced by the loss due to the mismatch of the antenna input impedance to a specified impedance.

Scattering cross section. For a scattering object and an incident plane wave of a given frequency, polarization, and direction, an area which, when multiplied by the power flux density of the incident wave, would yield sufficient power that could produce by isotropic radiation the same radiation intensity as that in a given direction from the scattering object. *See monostatic cross section*, *bistatic cross section* and *radar cross section*.

Note: The scattering cross section is equal to 4π times the ratio of the radiation intensity of the scattered wave in a specified direction to the power flux density of the incident plane wave.

Sense of polarization. For an elliptical or circularly polarized field vector, the sense of rotation of the extremity of the field vector when its origin is fixed.

Note: When the plane of polarization is viewed from a specified side, if the extremity of the field vector rotates clockwise [counterclockwise], the sense is right-handed [left-handed]. For a plane wave, the plane of polarization shall be viewed looking in the direction of propagation.

Shoulder lobe; vestigial lobe. A radiation lobe which has merged with the major lobe, thus causing the major lobe to have a distortion which is shoulder-like in appearance when displayed graphically.

Sidelobe. A radiation lobe in any direction other than that of the major lobe. *See mean side lobe level* and *minor lobe*.

Squint. A condition in which a specified axis of an antenna, such as the direction of maximum directivity or of a directional null, departs slightly from a specified reference axis.

Notes: (1) Squint is often the undesired result of a defect in the antenna; but, in certain cases, squint is intentionally designed in order to satisfy an operational requirement. (2) The reference axis is often taken to be the mechanically defined axis of the antenna; for example, the axis of a paraboloidal reflector.

Standard [reference] directivity. The maximum directivity from a planar aperture of area *A*, or from a line source of length *L*, when excited with a uniform amplitude, equiphase distribution.

State of polarization; polarization state (of a plane wave [field vector]). At a given point in space, the condition of the polarization of a plane wave [field vector] as described by the axial ratio, tilt angle, and sense of polarization.

Tilt angle (of a polarization ellipse). When the plane of polarization is viewed from a specified side, the angle measured clockwise from a reference line to the major axis of the ellipse.

Note: For a plane wave, the plane of polarization shall be viewed looking in the direction of propagation.

Vestigial lobe. *See shoulder lobe*.

Figure A.1 Pattern properties for antennas