USER MANUAL
FOR THE SLANT RANGE OF THE NATR
AT PAARDEFONTEIN

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for

GEROTEK

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

What is now referred to as the slant range was originally a part of the microwave range. This is shown in Figure 1.1 which gives an overall view of the microwave range.

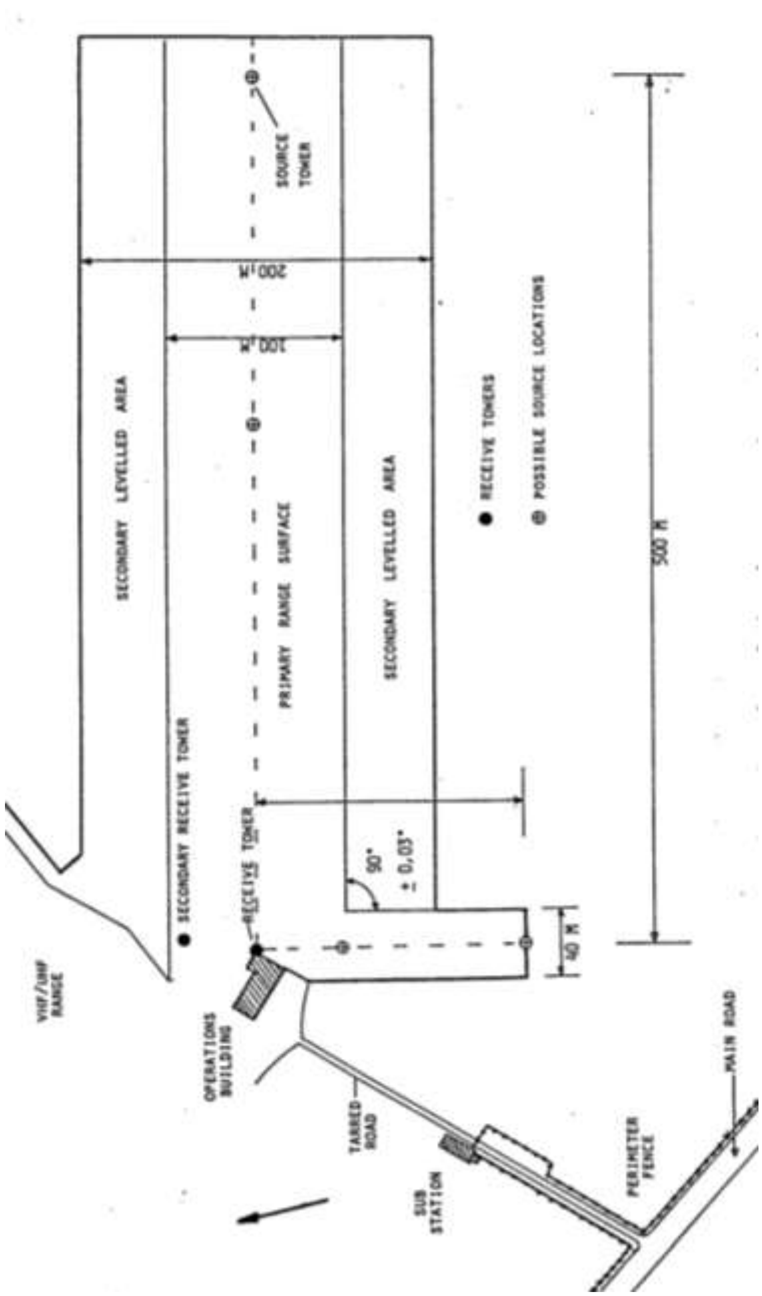
North of the operations building at about 42 m distance a secondary receive tower is indicated. This tower was a 5 m tall high strength tower for a heavy duty azimuth only positioner. The intention was that azimuth only tests of large radar antennas could be done using this receiver tower. This arrangement could use source antennas at 500 m, 3 000 m and 7 000 m (the latter two source positions being off-site and requiring custom set-ups). The main purpose was to do comparative tests (e.g. before and after repair/ modification tests) and not absolute measurements. This tower was used in the 1980s for the intended purpose but since then the intended function has fallen away.

Subsequently this tower has been equipped with a remote controlled polarization positioner which has manual adjustments for the azimuth and elevation axes. In this configuration a source antenna can be attached to the polarization positioner and pointed at the main receive tower at the operations building.

There are increasing requirements to make measurements on antennas for personal communications (wireless, LAN, WiFi, etc.). These antennas are usually physically quite small and have moderate gains (10 to 25 dBi). They operate in the 2.4 to 7 GHz frequency range with higher frequencies to 18 GHz also coming into use. There are smaller GSM 900/ GSM 1800/ UMTS base station antennas (say up to 1.2 m long) operating in the 860 MHz to 2.2 GHz frequency range. These smaller antennas do not need to be measured on the 500 m ground-reflection range. It will increase operational efficiency of the NATR if wideband set-ups can be configured to cover the 860 MHz to 18 GHz frequency range with a maximum of two source dishes.

This user manual discusses how the slant range operates and how it should be configured to obtain the desired test field. The size and frequency of the antennas able to be tested and measurement accuracies for sidelobes and gain are presented. Special requirements for axial ratio measurements are also presented.

Figure 1.1 Plan view of the microwave antenna test range of the NATR showing the secondary receive tower which is now the source tower for the slant range



2. TEST RANGE CONFIGURATION

2.1 Test range geometry

The slant range is a variant of the elevated range which is described first. An elevated range, as the name suggests, uses source and receive towers which are high enough above the ground to reduce or eliminate reflections from the ground (range surface). This is in contrast to the ground reflection range which uses the reflection to create the test field. The heights of the towers must be such that the source antenna does not illuminate the ground with significant power compared to the main beam which points at the antenna under test (AUT). When large test distances are required, the towers become prohibitively high and these long ranges are often installed on hills with a deep valley in between.

Figure 2.1(a) shows the geometry for the elevated range. The source tower h_t and receiver tower h_r are generally about the same height. The AUT has a diameter D and the source antenna uses the peak of its main beam with subtended angle α to illuminate the dish. By selecting the directivity of the source antenna (effectively the source diameter d) one can point the first null of the source pattern at the base of the receive tower (this first null is at angle α_h). The major advantage of the elevated range over the ground reflection range is that provided the ground reflections are small, a single source height h_t is required for all frequencies. For the ground reflection range the source height is a function of wavelength (i.e. frequency) because the heights are related by

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

Technically, for each frequency there is a new source height. Depending on the size of the AUT, the precise height need not be achieved for all frequencies. For a detailed discussion see "User manual for the microwave range of the NATR at Paardefontein", Report Gerotek 01/2010.

The slant range is a modification of the elevated range where the test distance is limited, Figure 2.1(b). By placing the source antenna at or near the ground, the specular reflection point between the towers is brought closer to the source antenna. This effectively moves the specular point further off the peak of the main beam of the source antenna, reducing the ground reflection. The slant range in Figure 2.1(b) has a 30 m tower which is inconveniently high for the NATR. An alternative configuration is discussed in the next section.

2.2 Basic operation of the slant range

The main receive tower of the microwave range has a three axis (azimuth/ elevation/ azimuth) positioner. The lower azimuth positioner can be rotated through the required angle (about 90°) to place the elevation axis at right angles to the line of sight to the 5 m tower. All these adjustments can be made using a bore sighting laser.

Figure 2.2 shows a side view of the slant range at the NATR. The slant range distance from the source dish to the centre of the antenna under test (AUT) is about 43 m. The top of the receive pedestal is 11.2 m above ground and a short tower (1.5 m high) is shown onto which antennas can be attached. The depression angle from the centre of the test zone (11.2 + 1.5 = 12.7 m) to the axis of the polarization positioner is about 10.2°. This depression angle can be applied using the elevation axis of the three axis positioner. This allows the boresight of the AUT to be aligned with the polarization axis of the source polarization positioner. A bore sighting laser is used to exactly line up the axes. Azimuth pattern cuts are then made by rotating the upper azimuth turntable onto which the AUT is mounted via the short mounting tower.

Reflections from the range surface can affect the measured patterns of the AUT. This is particularly true for elevation patterns when the elevation axis of the positioner on the receive tower is used to measure the elevation patterns. A typical GSM 1800/ UMTS base station panel antenna is about 1.2 m high and 150 mm wide. These antennas have a narrow elevation pattern with shaped sidelobes in elevation. The azimuth pattern is relatively wide with about 60° beam width.

The possible effects of measuring this type of antenna using the elevation axis are illustrated by the following example. Suppose the nominal sidelobe levels of the source and test antennas are 20 dB below the peaks of the main beams. The range surface has a reflection coefficient and scatters energy and there may be a 10 dB reduction of the reflected wave. Under these conditions the extraneous signal level will be approximately 50 dB below the direct path signal in the case where the peak of the main beam of the AUT points at the peak of the source antenna. Figure 2.3 presents two useful graphs which can be used to determine the amplitude error in the measured amplitude pattern.

The right hand curve in Figure 2.3 shows that at the -50 dB level the error at the peak of the main beam will be less than 0.03 dB. However, if the elevation axis of the positioner is tilted forward to make the elevation cut the peak of the main beam will point at the reflection point on the range and the -20 dB sidelobe will point out the source antenna. Under these conditions the level of the extraneous signal received on the main beam of the AUT will only be 10 dB below the signal received on the -20 dB sidelobe. The left hand graph of Figure 2.3 shows that the measurement error on the sidelobe will be between -3.3 and 2.4 dB. The extraneous reflection can add out of phase (the -3.3 dB) or in phase (+2.4 dB).

This clearly illustrates that pointing the main beam of the AUT down at the range surface of the slant range is not good practice. The operational use of the slant range requires that this cannot happen. The AUT must be installed on a test jig on the receive tower such that the AUT can be rotated through 90° about its axis. The source antenna must then also be rotated through 90° to match the AUT polarization. The elevation cut is now measured by rotating the upper azimuth turntable as if an azimuth pattern is being measured.

This procedure works extremely well and the operator must keep track of the polarization settings. For example, a typical GSM 1800/ UMTS antenna is slant 45° polarized. With the antenna mounted as for conventional operation the V polarization is aligned parallel to the long axis of the AUT and the H polarization is transverse to the length. When the AUT is rotated through 90° to make the elevation cut the source antenna is set to H polarization which is now the actual V polarization for the AUT.

An alternative procedure is to tilt the AUT upwards so that the lower half of the elevation pattern is measured. Then the AUT is rotated through 180° and the antenna tilted up again to measure the other half of the elevation pattern. These patterns must then be given the required elevation offset angle to obtain the final pattern.

NOTE: It must be stressed that the above discussion does not apply to the ground-reflection range. In this range the height of the source antenna is adjusted to use the reflected wave to create the test field with the direct wave. At 500 m range the source and its image effectively create a single source with its phase centre at the base of the tower. There is only one half wavelength between the distance from the source and its image to the test zone. The source and image cannot be resolved (i.e. seen as separate sources) by the AUT. Thus elevation plane patterns of radar antennas can be tested on the ground-reflection range even when the main beam points downwards to the range surface. The only proviso is that there should not be extraneous reflecting sources on the range (e.g. a truck or other vehicle). The half wavelength criterion is not met on the slant range (or any other typical elevated range).

The ground reflection can disturb the test field and the reflection from the ground should be minimised by reducing the illumination of the reflection area near point A in Figure 2.2. This can be achieved in several ways. The chief are:

2.2.1 Reduce the beamwidth and sidelobes of the source dish. This is generally done by increasing the dish diameter. However, the 0.25 dB amplitude taper requirement limits the dish diameter (See Tables 3.2 and 3.3).

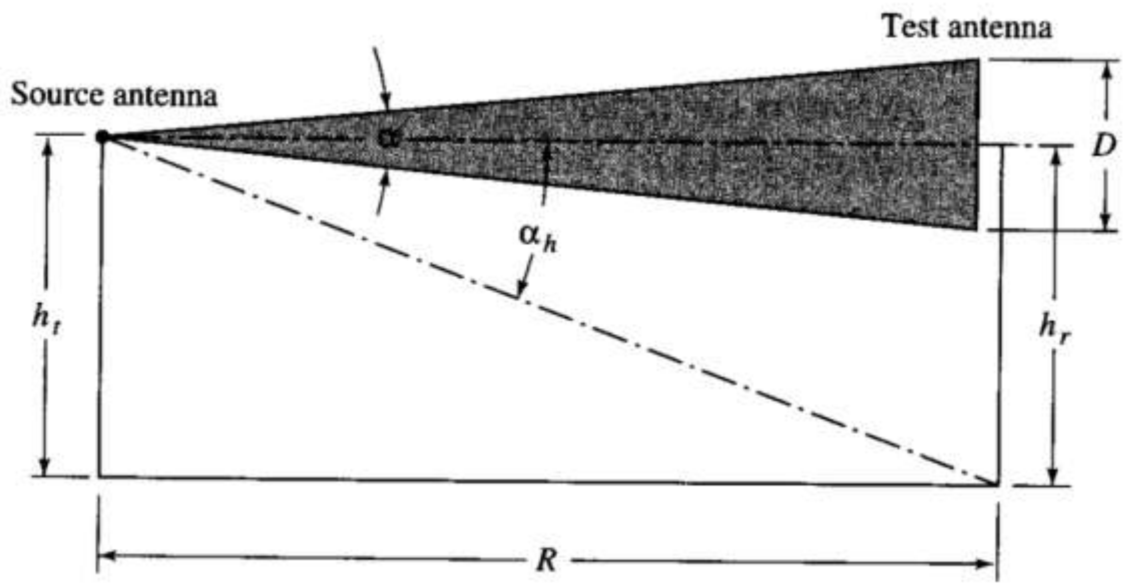
2.2.2 Diffraction fences can be erected near the specular reflection point A in Figure 3.2. Design of diffraction fences is discussed in reference [4].

2.2.3 Place microwave absorber near the specular point A. The ground reflection occurs over an area near point A which is about 12 m fom the edge of the 5 m source tower . This can be seen in Figure 3.2 which shows reflection points around A for rays gitting the top and the bottom of a 3 000 mm high test height. This means that an area about 2-3 m wide and 5-6 m long should be covered. The precise area depends on the source dish diameter and its beam widths.

NOTE: The STATIC RCS test range is at the end of its useable life. There are a large number of weatherproof wedge absorber blocks at the STATIC range. These blocks are 300 mm wide x 600 mm long x 300 mm high and should provide 20 to 30 dB reflection reduction from 1 GHz upwards. Such reflection reduction will greatly improve the performance of the slant range. This is particularly important when circularly polarized patterns and axial ratio are to be measured. The reflection coefficients for V and H incident polarizations at point A are not the same and this can impact the axial ratio measurements.

Figure 2.1 **(a) Geometry of elevated range**
(b) Slant range with source antenna near the ground

(a)



(b)

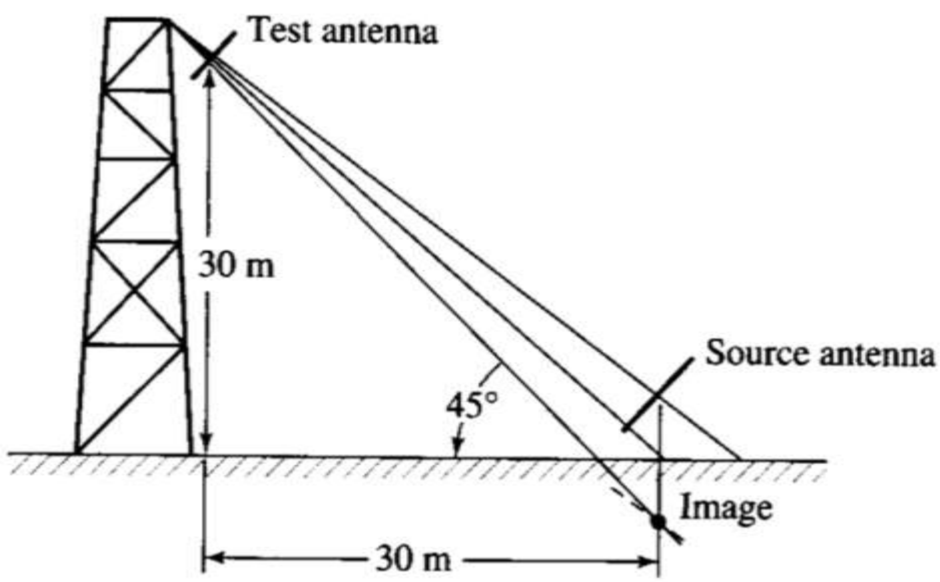


Figure 2.2 Side view of 43 m long slant range

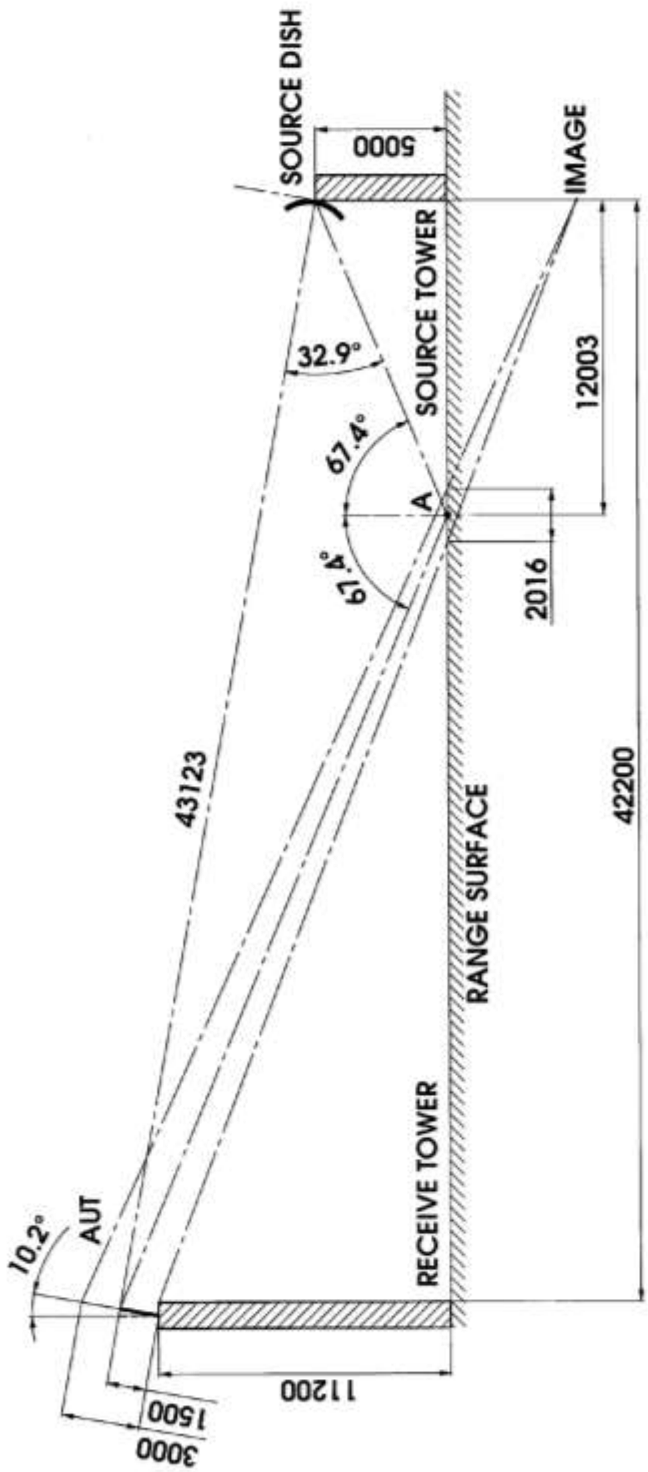
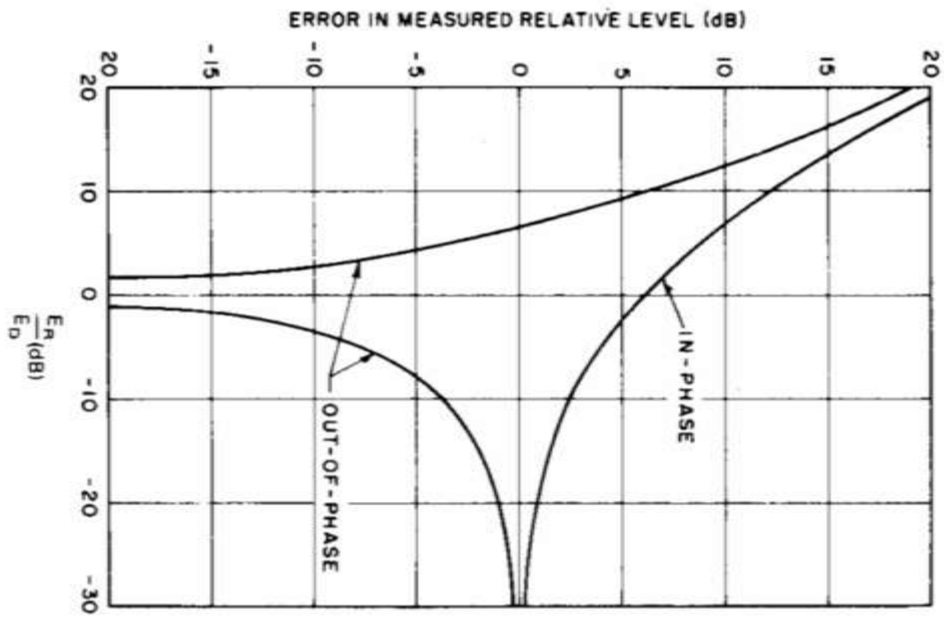
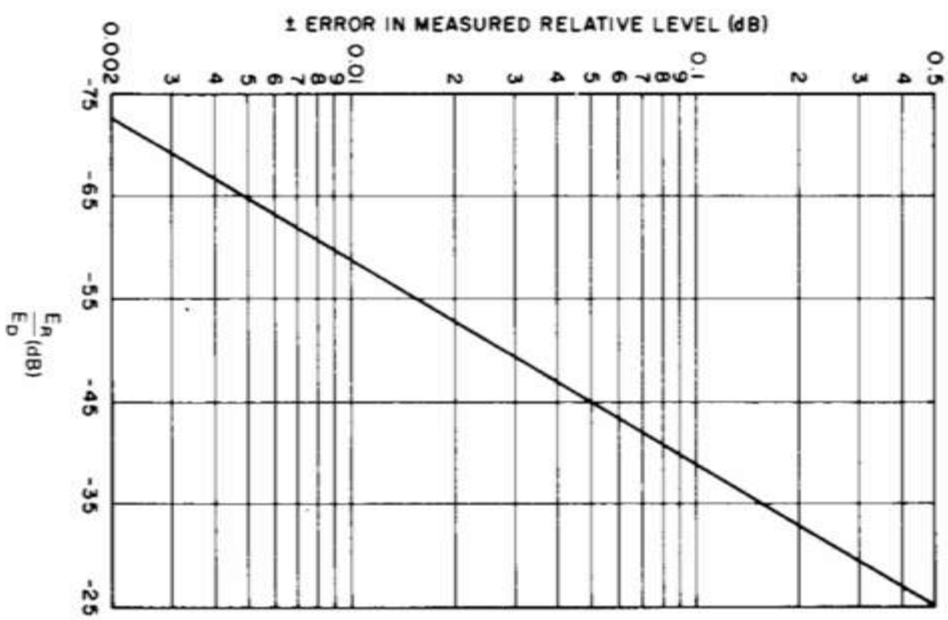


Figure 2.3 Error in measured relative level as a function of extraneous reflection with indicated level compared to the direct signal





3. SIZE OF ANTENNAS AS A FUNCTION OF FREQUENCY

3.1 Positioner capability

The three axis positioner of the main receive tower has a mechanical specification for a vertical load of 10 000 lb (4 545 kg) and a bending moment of 10 000 lb.ft (13 533 Nm). This positioner is mainly used to measure large radar antennas (5 m in diameter or more) and it is unlikely that any of the antennas to be measured at 43 m range will exceed these specifications. The positioner is not a 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 [4]. The commonly employed far-field criterion gives the range length as

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

where

R = test range = 43 m

D = largest dimension of AUT (m)

λ = wavelength (m).

This equation sets the diameters of the antennas to be measured.

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 range should be greater than 10 wavelengths [1]. 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 range 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 43 m test range this means the largest wavelength is 4.3 m which is a frequency of 69.8 MHz. Thus at the normal microwave frequencies above 500 MHz, inductive coupling is not a factor.

3.2.3 Longitudinal amplitude taper

For reflector antennas the aperture (diameter) of the dish is the main parameter. 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 ≥ 10 L. At 43 m range this gives L ≤ 4.3 m which clearly is not a problem. At shorter ranges (e.g. anechoic chambers) this condition may be difficult to achieve.

3.2.4 Antenna diameters and gain at 43 m range

From the foregoing it is clear that the far-field phase criterion places the most stringent requirement for testing reflector antennas. We can deduce the largest linear dimension D of the reflector from Equation 3.1 as

$$D \leq \sqrt{\frac{1}{2} R \lambda} \qquad (3.4)$$

These diameters can be used to calculate the typical gains and beam widths of antennas to be tested at 43 m range. The gain for a circular dish of diameter D is given by

$$G = \frac{4\pi}{\lambda^2} A_e \qquad (3.5)$$

where A_e is the effective aperture (area) of the dish. This is related to the physical aperture A_p by

$$A_e = \in_{ap} A_p \qquad (3.6)$$

for a well-designed reflector antenna $\in_{ap}$ = 0.65. Thus

$$G = 0.65\left(\frac{\pi D}{\lambda}\right)^2 \quad (3.7)$$

The 3 dB (half power beamwidth) of a circular aperture can be approximated by

$$\theta_{hp} = 70° / (D/\lambda) \quad (3.8)$$

Equations 3.4, 3.7 and 3.8 are used to set up Table 3.1 which gives the maximum diameters, gain and beamwidth of reflector antennas which can be measured with small errors at a test distance of 43 m on the microwave range.

Table 3.1 Diameter, gain and half power beamwidth at various frequencies for 43 m test range

Frequency (GHz)	Diameter D (mm)	Gain (dBi)	3 dB BW (deg)
0.5	3 592	23.6	11.7
1	2 540	26.6	8.3
2	1 795	29.6	5.8
3	1 466	31.4	4.7
5	1 136	33.6	3.7
10	803	36.5	2.6
18	598	39.0	1.9
26	498	40.7	1.6
40	402	42.8	1.3

Note: 1. The table shows the largest antennas which can be measured at the far-field range of Equation 3.1.

3.3 Requirements for source dish

Table 3.1 presents the diameters (or for a linear antenna, the largest length) which can be measured at the far-field range of $2D^2/\lambda$. The range distance (43 m) sets the phase criterion. The directivity of the source dish sets the amplitude taper over the test zone. In the absence of reflections the source dish need only have symmetrical beamwidths which meet the generally accepted criterion of 0.25 dB taper over the test aperture. This criterion is sometimes relaxed to 0.5 dB depending on the types of measurements.

It can be shown that the diameter d of the source dish must satisfy

$$d \leq 0.74\, D \quad (3.9)$$

where D is the diameter of the AUT to meet the 0.25 dB amplitude taper requirement.

In addition, the source dish must have narrow enough beamwidths to keep the illumination of the range surface low. The selection of the source antenna can be done theoretically or by examining the patterns of actual source antennas. Recall that one of the main reasons for selecting the slant range is the fact that wide band measurements can be made in a single test set up. A wide band source antenna will be ideal since the source antennas need not be interchanged during a measurement program. Wide band source dishes are discussed in the next section.

3.3.1 1-18 GHz parabolic dish

Gerotek has acquired a 600 mm diameter prime focus reflector antenna with a 1-18 GHz feed antenna. In order to cover the full 1-18 GHz frequency range in a single antenna, this source antenna must have a wide enough beamwidth at 18 GHz to meet the 0.25 (or 0.5) dB amplitude taper criterion. In addition, at 1 GHz the beamwidth must be narrow enough not to illuminate the range surface too strongly.

Measured patterns exist for this antenna and they are used to look at the illumination of the range surface. A 0.25 dB amplitude taper at the far-field distance of $2D^2/\lambda$ introduces a gain measurement error of only 0.15 dB (see Table 6.1). The 0.25 dB beamwidth is α and at a distance of 43 m subtends a test zone of diameter D (0.25) given by

$$D\,(0.25) = 43 \tan \alpha \tag{3.10}$$

The measured 0.25 dB beamwidths, test zone diameters D (0.25) and far-field diameters D are shown in Table 3.2.

Table 3.2 0.25 dB BW, test zone diameters at the 0.25 dB level and the far-field diameter at sample frequencies for a 0.6 m dish

Frequency (GHz)	0.25 dB BW (Deg)	D (0.25) (mm)	D (mm)
1.0	8.20	6 196	2 540
1.5	5.36	4 034	2 074
2.0	4.55	3 422	1 795
3.0	2.95	2 216	1 466
5.0	1.71	1 284	1 136
7.5	1.17	878	927
10.0	0.88	660	803
12.5	0.74	555	718
15.0	0.64	480	656
18.0	0,60	450	598

Notes:
1. The far-field diameter in column 4 sets the largest antenna in the test zone up to about 7.5 GHz, thereafter the 0.25 dB criterion applies.
2. The reflections from the range surface will restrict the lowest frequency of operation in the 1-18 GHz frequency range.

3.3.2 0.5-3 GHz parabolic dish

A 0.5 - 3 GHz etched printed circuit board log periodic dipole array (LPDA) antenna was manufactured in about 1990 and installed in the 3 m (10 ft) diameter scientific reflector model 22-10A. This was used as a wide band source dish on the 500 m long microwave range. The LPDA antenna was focussed in this reflector. Detailed patterns are not available for this antenna but it is suitable for use on the slant range. This antenna is five times larger than the 1-18 GHz reflector for which 0.25 dB beamwidths are available. With the 5:1 scale, a frequency of 0.5 GHz for the 3 m reflector corresponds to 2.5 GHz in the 600 mm diameter reflector.

Table 3.3 0.25 dB BW, test zone diameters at the 0.25 dB level and the far-field diameter at sample frequencies for a 3 m dish

Frequency (GHz)	0.25 dB BW (Deg)	D (0.25) (mm)	D (mm)
0.5	3.64	2 735	3 592
1.0	1.71	1284	2 540
1.5	1.17	878	2 074
2.0	0.88	660	1 795
2.5	0.74	555	1 606
3.0	0.64	480	1 466

Note: 1. The size of the antenna in the test zone is determined by the 0.25 dB taper and not the far-field requirement.

4. MEASUREMENT OF GAIN

4.1 Linearly polarized gain

The most commonly used procedure for gain measurement on the slant range is the gain transfer method [1]. Here 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.

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 change in losses between the cables must be measured and taken into account. For large antennas under test, the gain reference antenna is often mounted on the back of the AUT. The AUT and the SG horn are then connected via a switch which can be controlled from the operations room. All interconnecting cables must have the same losses or the relative losses must be taken into account. Absorber is often used to reduce reflections off the AUT into the SGA (See Figure 4.1(b)).

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 are quoted to a typical accuracy of ± 0.25 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 [1]. The reference antennas usually have good VSWR and the AUT is measured without VSWR correction since this gives the operational or realised 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.

4.2 Circularly polarized gain

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 [1]:

$$G(dBci) = 10 \log (g_v + g_h) \qquad (4.3)$$

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.

If the V and H polarization partial gains have nearly the same dBi values (say within 2 dB), the CP gain can be approximated by adding 3 dB to the dB average of the V and H linear gains.

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

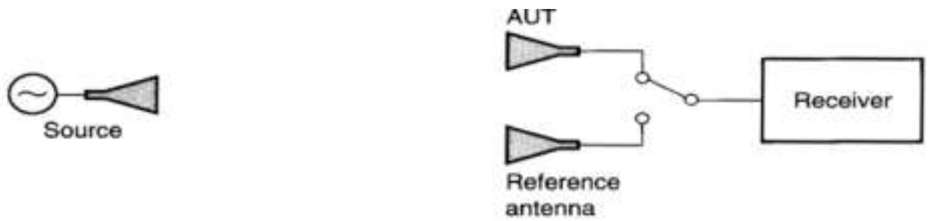
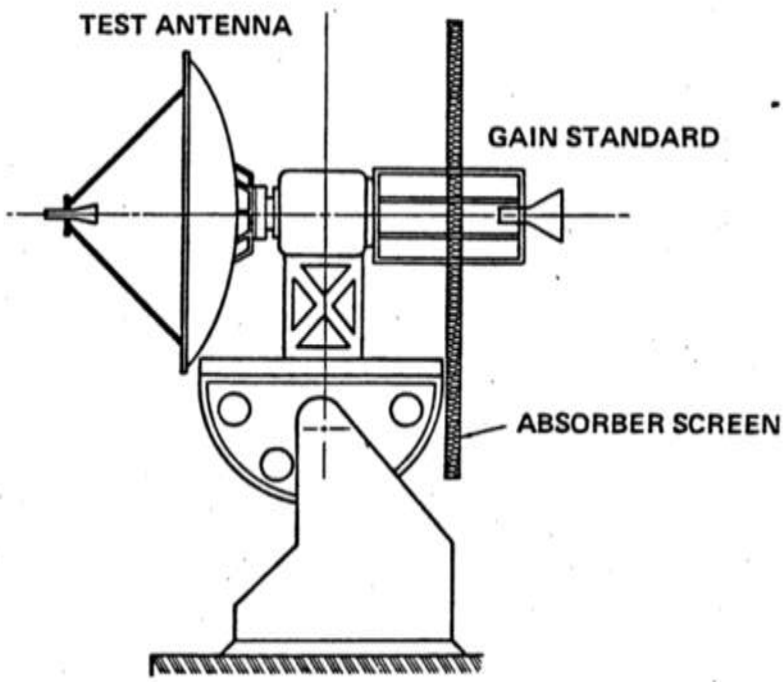


Figure 4.1(b) Test set-up showing AUT and gain reference mounted back-to-back (note absorber to eliminate reflections into gain standard)



5. POLARIZATION

Many antennas are linearly polarized (V, H or slant 45°). Satellite communications antennas, electronic warfare antennas and data relay antennas are often circularly polarized.

5.1 Linear polarization

The ground slant range can make excellent linear cross polarization measurements.

The ability to make linear cross polarization measurements depend almost entirely on the cross polarization of the source dish over the 0.25 dB beam width which illuminated the AUT. Linearly polarized measurements can be influenced by the undesired reflections from the range surface. These errors should be minimised as discussed in Section 2.2.

If cross-polarizations better than 25 dB down from the co-polarized response are to be made, the cross-polarization response of the range must be made. This follows a similar procedure to that followed in reference [3]. Since the antennas to be measured on the slant range are relatively small, only the area typically occupied by the antennas to be tested needs to be probed. A field probe is basically a small test antenna (horn, dipole or LPDA) attached to a polarization positioner attached to a beam mounted on the receive tower positioner. This is shown schematically in Figure 5.1. The co-polarized response is first measured for the source antenna set for V polarization to match the V polarization of the probe antenna. This is then repeated by turning the source to H polarization. The probe antenna is then set for H polarization and the co-polarized response measured. Finally with the probe set for H polarization, the source is rotated to V polarization.

The measured cross-polarization VH and HV should be more than 30 dB below the co-polarized responses VV and HH. The actual cross-polarized response sets the level of cross-polarization which can be measured for the AUT.

5.2 Circular polarization and axial ratio

Many commonly used antennas are linearly polarized. Linear polarization means that the tip of the E-field vector moves in a plane containing the E-field and the direction of propagation. There are some communications antennas which are circularly polarized. For a circularly polarized wave the tip of the electric field vector moves on a circle. This is illustrated in Figure 5.2 which shows linear, circular and elliptical polarizations. The special case of circular polarization requires two linear E-field components at right angles to each other and a 90° phase difference between the two components.

If the two fields at right angles do not have equal amplitudes and 90° phase shift we get elliptical polarization as shown in Figure 5.3. The dB ratio of the major to minor axes of the polarization ellipse is the axial ratio given by

$$AR = 20\log\frac{OA}{OB} \qquad (5.1)$$

An axial ratio of 0 dB represents a perfectly CP wave, while 20 dB or more gives a nearly linearly polarized wave. Circularly polarized communications antennas often have a requirement for the AR to be less than 1 dB. Figure 5.3 shows how good the amplitude tracking and the 90° phase shift must be to achieve various axial ratios.

Axial ratio pattern measurements can be done on the slant range. One way to make such pattern measurements is to spin the linearly polarized source rapidly about its axis while the AUT rotates slowly in azimuth or elevation. This results in a series of amplitude ripples in the patterns. The peak-to-peak ripples in dB give the AR. Figure 5.4 illustrates this procedure.

As will be seen in Section 6.3.2, circularly polarized measurements are much more sensitive to extraneous reflections than linearly polarized measurements. Figure 5.5 shows the effects of a single extraneous reflection on the measured axial ratio of a perfectly circularly polarized antenna (axial ratio = 0 dB).

Figure 5.5(b) shows an elevated range set-up which applies equally well to the slant range. Here the source antenna is circularly polarized and the receive antenna is linearly polarized. By reciprocity, the same results are true for a circularly polarized AUT and a linearly polarized source. The upper part, Figure 5.5(a), shows the impact of the ratio of the reflected ray to the direct ray in dB on the axial ratio of a perfect CP antenna (0 dB axial ratio). With -20 dB reflection the 0 dB axial ratio will be measured at about 1.8 dB. To measure to an accuracy of 0.5 dB, extraneous reflections must be at least 30 dB down.

The above discussion not only applies to reflections from the range surface but also reflections from test jigs and mounting structures. A poorly designed test jig and the test positioner itself can degrade the axial ratio measurements. Axial ratio measurements require extreme care by the user. In some cases it may be possible to use the "time-gating" function of a vector network analyser (VNA) to gate out the undesired range reflection. Such measurements need to be done using the instructions in the equipment manual supplied with the VNA. In many cases antenna measurements are not described in the manual and the users must devise their own techniques.

Figure 5.1 Schematic diagram of field probe which has automated movement of horn antenna used as the field probe

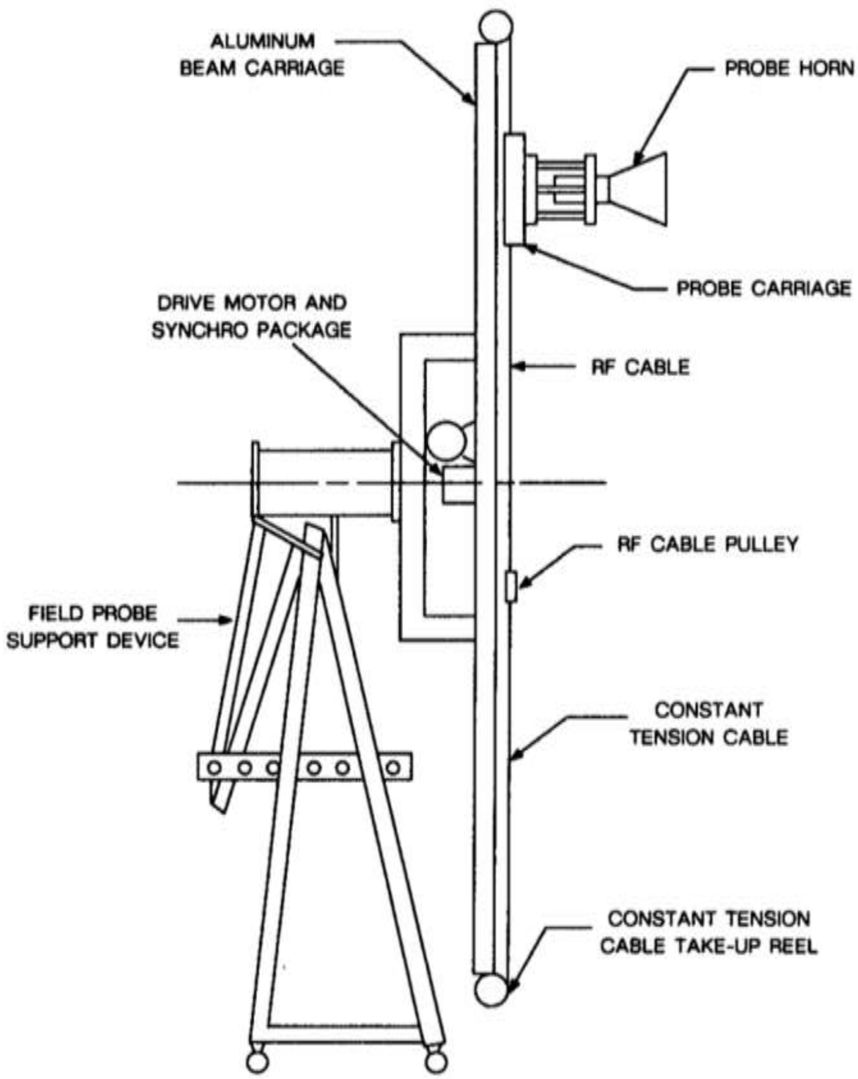


Figure 5.2 Schematic diagrams for linear, circular and elliptical polarizations

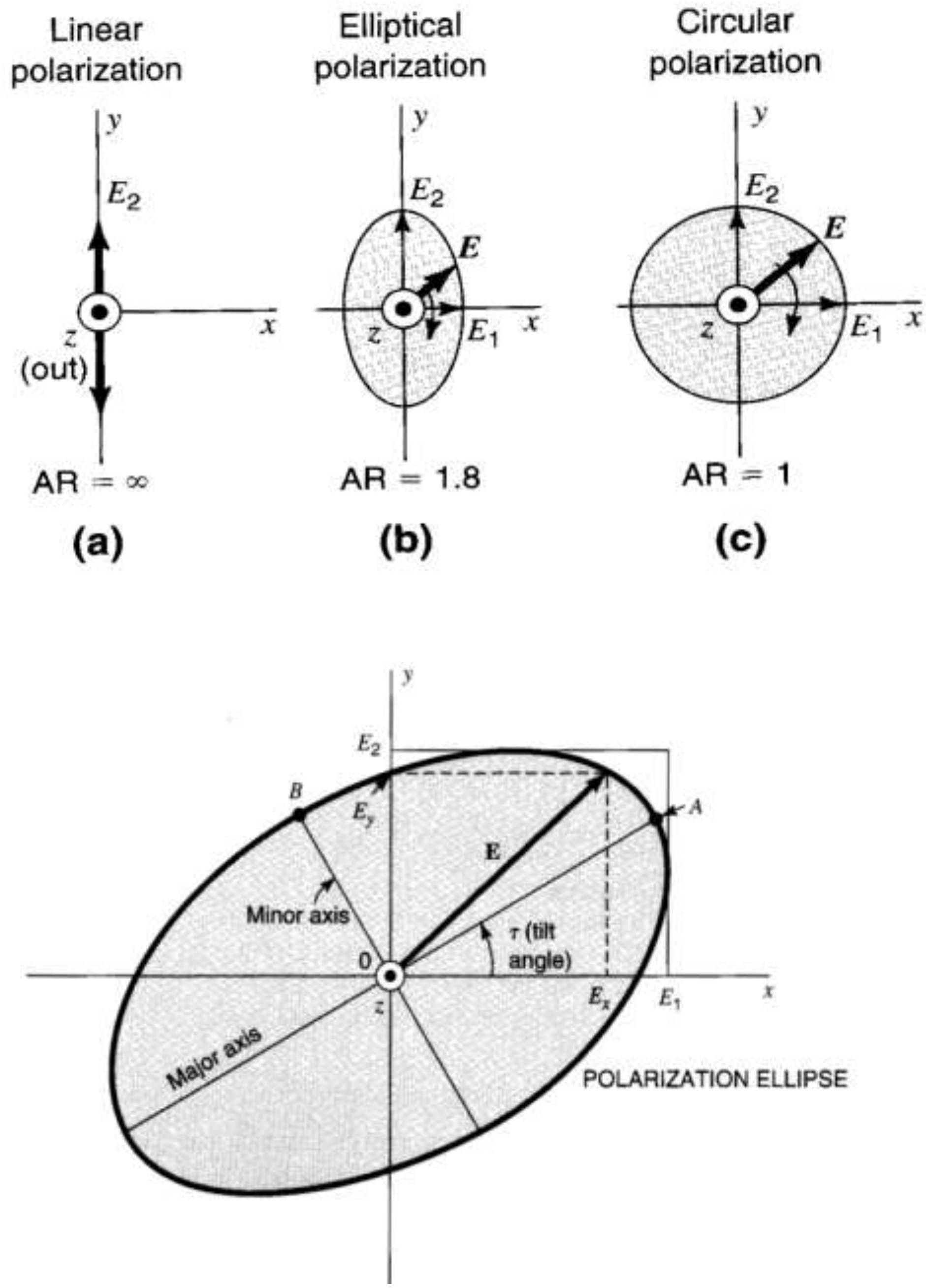


Figure 5.3 Amplitude and phase errors to achieve a specified axial ratio

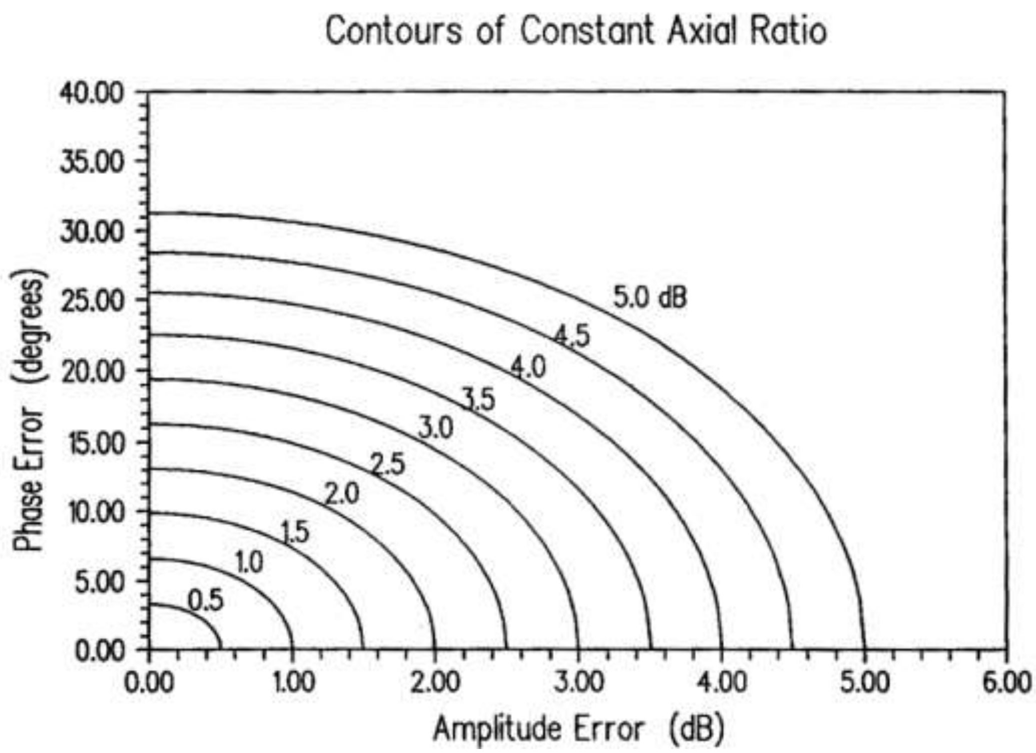
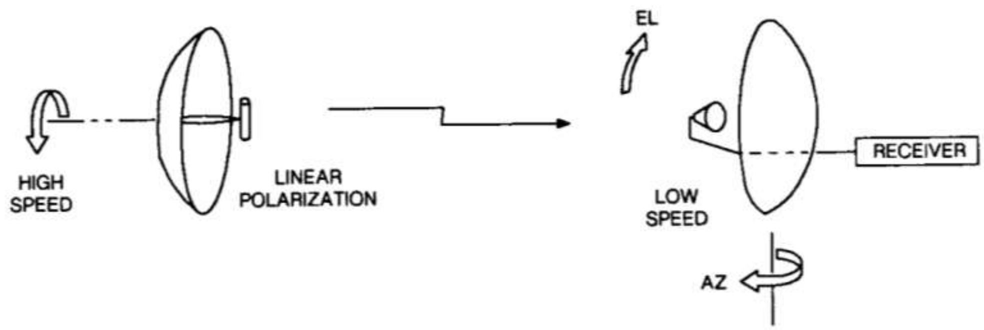


Figure 5.4 Procedure for measuring CP with a linearly polarized spinning dish, and typical response (peak-to-peak ripple in dB = AR at that angle)



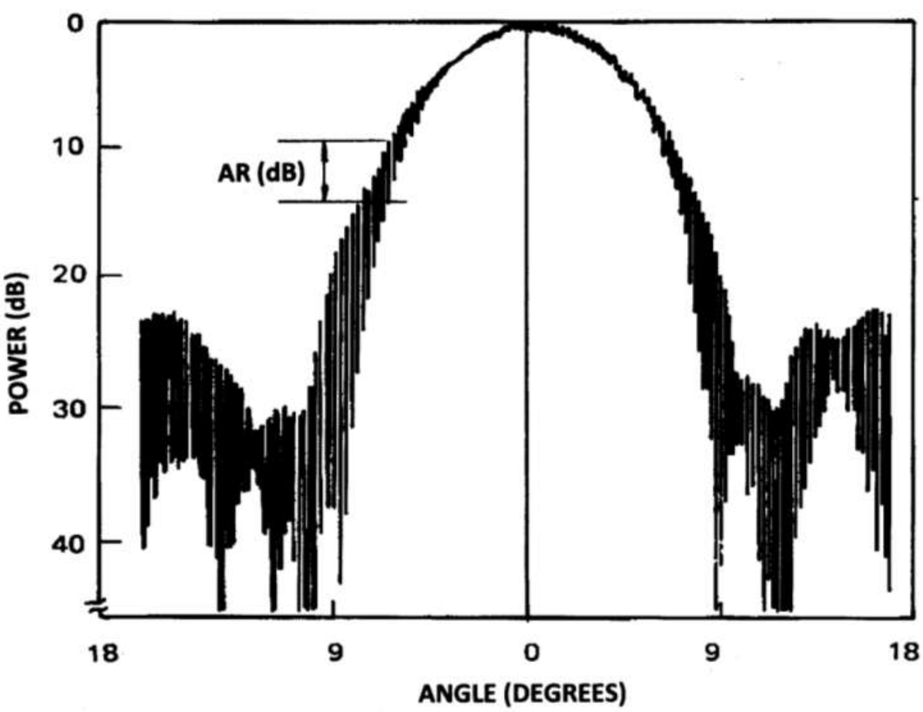
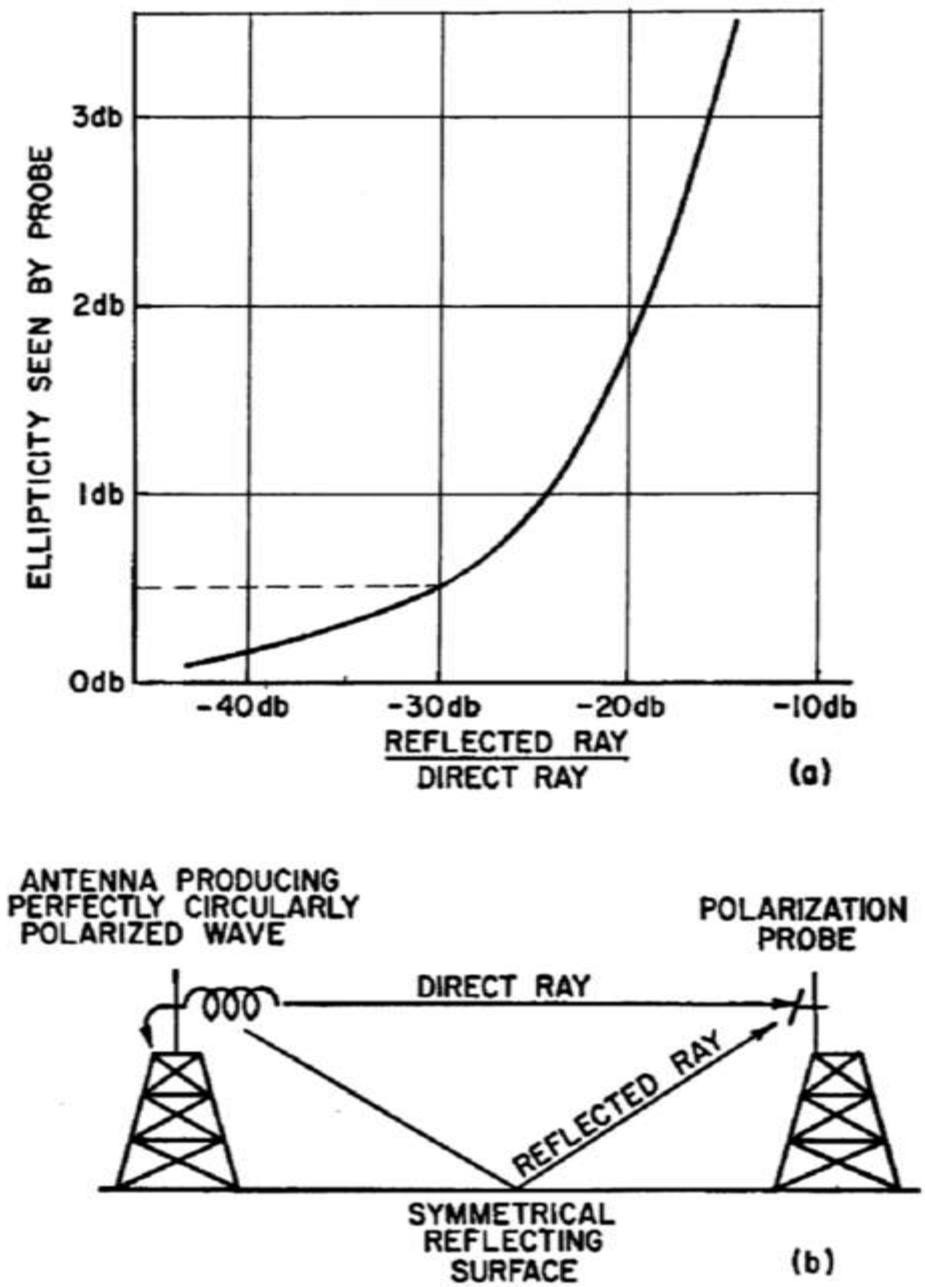


Figure 5.5 **(a) Result of measuring a 0 dB axial ratio antenna in the presence of an extraneous reflection, (b) circularly polarized antenna with linearly polarized probe**



6. MEASUREMENT ERRORS

The accuracy of gain and pattern measurements depends on how closely the antenna range conforms to establishment of a uniform plane wave over the test antenna. The slant range tries to eliminate the ground reflection to establish the test field. Undesired reflections can come from trees, fences, buildings, etc. and they cause ripple in the test field. The polarization purity of the source antennas and the reference antennas can also impact the final gain measurements.

Test equipment stability, linearity and dynamic range used to be major potential sources of error. However, with the advent of modern vector network analysers the contributions of the test equipment to measurement errors are now very small. A potential source of error which cannot be calibrated out in the measurement set-up relates to unstable or poor quality coaxial cables or other means to connect the AUT and SGA to the test equipment. The operator must ensure that the test cables make stable and repeatable connections. Poor connector attachment can be a major source of error.

Most low-loss coaxial cables are stable under bending (flexing) provided the minimum bend radius requirements are not exceeded. A major problem with coaxial cables both in amplitude and phase transmission occurs when the cable is twisted along its length (torsion). When interchanging the test cable between the AUT and SGA there should be a minimum of twisting and bending when moving the cable from one antenna to the other. The VSWR (reflection coefficient) and insertion loss of all test cables should be checked before any measurement programme. Any defective (or "suspicious") cables should be replaced at the start of the measurements.

This section will address test range induced errors in gain and pattern measurements. Instrumentation errors are covered in the equipment manuals provided by their suppliers. Extraneous interference caused by transmitters which are not part of the NATR must be treated on a per case basis.

6.1 Pattern measurements

In Section 2, the amplitude taper over the test zone was designed to be in the region of 0.25 to 0.5 dB. The far-field phase criterion of Equation 3.1 provides a phase taper over the aperture of 22.5°. The illuminating field on the test aperture is thus not uniform in phase and amplitude as in the true far-field. The non-ideal test field introduces measurement errors in the sidelobes and the gain. While the amplitude and phase tapers act together to give the nett results, it is easier to discuss them separately.

6.1.1 Effect of phase taper on sidelobes

Extensive work has been done to quantify the effects of finite test ranges on the measured sidelobes [4], [6] and [7]. Figure 6.1 shows calculated antenna patterns for a circular parabolic dish of diameter D wavelengths. The horizontal axis is in terms of $(D/\lambda)\sin\theta$ where θ is the azimuth angle. In this sense the patterns are "universal" antenna patterns which can be applied to any circular aperture. The patterns are shown at ∞ range, $2D^2/\lambda$ and $4D^2/\lambda$. The nominal infinite range first sidelobe is -28 dB down from the peak. At range $4D^2/\lambda$ this first sidelobe has increased by a few tenths of a dB and the first null is slightly filled in. Note that the second and third sidelobes and second and third nulls are unaffected. This is an extremely important result which is discussed in detail in [6].

The results in Figure 6.1 and those presented in [6] show that by measuring at finite test range, the first sidelobe is affected first. The other sidelobes remain unaffected until the first sidelobe makes a shoulder and starts to blend into the main beam. Then the second sidelobe starts to increase leaving the third unaffected, and so on. Patterns similar to Figure 6.1 have been computed for various sidelobe levels and test ranges, however these are not easy to use since many patterns must be inspected to decide on the sidelobe increase. Reference [7] has developed a useful graph which allows the increase in the first sidelobe to be read off directly for various first sidelobe levels and test ranges. This is shown in Figure 6.2.

The use of Figure 6.2 is illustrated by reference to a 927 mm wide antenna operating at 7.5 GHz. At R = 43 m the test range is $2D^2/\lambda$. The AUT has an actual first sidelobe of -20 dB. To achieve 1 dB accuracy project the -20 dB up to the 1 dB line and then across to the range distance which is $2D^2/\lambda$. The -20 dB first sidelobe will thus be measured as -19 dB.

What is also clear from Figure 6.2 is that the higher the accuracy required for a particular first sidelobe level the longer the test range must be. The lower the design first sidelobe the longer the range required to measure this sidelobe to a desired accuracy. In order to measure a 40 dB first sidelobe to an accuracy of 1 dB the test range must be $6D^2/\lambda$ or 129 m. Such ultra low sidelobes are difficult to achieve except by arrays and carefully designed offset reflectors.

The slant range at the NATR can be used to make excellent far-field measurements. The antenna diameters are smaller than for the 500 m microwave range. The user must be aware of the effects on sidelobe measurements as discussed in this section. The phase taper also has an impact on the gain which is discussed later.

6.1.2 Effect of amplitude taper on sidelobes

A symmetrically tapered amplitude distribution over the AUT as is achieved with the properly aligned slant range has effects on the measured sidelobes and gain. The taper in the incident field effectively reduces the edge taper on the AUT and thus reduces the gain and sidelobes by a predictable amount. Figure 6.3(a) shows the tapered field distribution over the aperture and the change in gain and sidelobe level. In this case the gain and all the sidelobes are reduced by a small amount. For a typical parabolic reflector with a 10 dB edge taper Figure 6.3(b) shows the gain and sidelobe reductions for various edge tapers. At the microwave range the taper for the largest antennas can be 0.5 dB but for smaller antennas the taper is typically less than 0.25 dB.

6.1.3 Effect of extraneous reflections

For the slant range, extraneous reflections include the ground reflection and reflections from nearby buildings, fences, test fixtures, etc. This is shown schematically in Figure 6.4 where the main beam of the AUT points at a reflecting object while the sidelobes point at the source. The direct signal is picked up on the sidelobe but the interfering reflection from the object is received on the main beam which may have 40 dB or more gain than the sidelobe being measured. The graph of Figure 6.5 can be used to estimate the impact on the measured sidelobe. The interfering signal could add in phase with the direct signal thereby increasing the measured sidelobe or out of phase which decreases the measured sidelobe.

For example, say the sidelobe in Figure 6.4 is at -40 dB relative to the main beam, if the reflected signal from the object is 65 dB down from the direct wave from the source, the sidelobe will be measured to an accuracy of 1 dB. However, if the reflection is 55 dB down the accuracy becomes 6 dB. The lower the sidelobes, the lower the extraneous reflections should be.

The operations building is set at an angle to the range axis and reflections generally scatter away from the test zone. It may be possible for undesired reflections to be received by the AUT via the antenna's own mounting fixtures on the receive tower. The user must ensure that this cannot happen.

6.2 Gain measurements

The measured gain is affected by the phase and amplitude tapers. A theoretical study could be done for any particular antenna but for a general purpose test range this is not practical. Extensive work was done by the authors of reference [4] to generate a useful look-up table which can be applied to typical parabolic reflector antennas. Table 6.1 shows a gain correction table. For amplitude and phase tapers the measured gain is lower than the actual gain by the dB values entered in the table. The dB values in the table can be added to the measured gain to get the far-field gain.

Table 6.1 Gain reduction factors relative to true far-field gain as a function of range length (phase taper) and amplitude taper of illuminating field computed for a 10 dB parabolic taper on the dish

Range Length (D^2/λ)	Decibel amplitude taper of illuminating field (sin (x)/(x))						
	0	0.5	.1	.15	.2	.25	.5
1	.204	.224	.246	.265	.286	.307	.404
2	.051	.071	.093	.112	.134	.154	.252
3	.023	.043	.065	.084	.105	.126	.224
4	.0127	.033	.055	.074	.096	.116	.214
5	.008	.029	.051	.070	.091	.111	.210
6	.006	.026	.048	.067	.089	.109	.207
7	.004	.025	.047	.066	.087	.107	.206
8	.003	.024	.046	.065	.086	.106	.205
9	.003	.023	.045	.064	.085	.106	.204
10	.002	.023	.045	.064	.085	.105	.204
∞	0	.020	.043	.062	.083	.103	.202

For 0 dB amplitude taper and ∞ test range, the correction factor is 0 dB. At a range of $2D^2/\lambda$ and 0.5 dB amplitude taper the correction factor is 0.25 dB. At the same range with 0.25 dB amplitude taper the correction is 0.15 dB. It is clear that the gain measurement errors are small when the microwave range is properly configured.

6.3 Polarization errors

It is generally assumed that the source and gain reference antennas are purely linearly polarized (i.e. an infinite axial ratio). The reference horns at the NATR have good linear polarization (35 to 40 dB axial ratio).

6.3.1 *Linearly polarized AUT*

Polarization errors for a linearly polarized source and AUT are discussed in [4]. If the test antenna is linearly polarized with an axial ratio of 25 dB, the error associated with using a range source antenna with finite axial ratio is given in Table 6.2.

Table 6.2 Errors in measured gain for a 25 dB axial ratio AUT and source antennas with various axial ratios.

Source antenna AR (dB)	Errors in measured gain	
	Same sense	Opposite sense
20	-0.035	0.063
25	-0.014	0.041
30	-0.002	0.003
35	0.005	0.022
40	0.009	0.019
45	0.011	0.016
50	0.012	0.015

Note: The linearly polarized antennas are effectively elliptically polarized with large axial ratio. The antennas can be either left or right elliptically polarized.

It is clear that the linearly polarized gain errors are extremely small even for 20 dB axial ratio source antennas.

6.3.2 *Circularly polarized AUT*

The discussion in [4] is for the measurement of circularly polarized gain using the partial gain method for linearly polarized source antennas (see Section 4.2). Equation 4.3 gives the circular gain for ideal linearly polarized source antenna (infinite axial ratio). The axial ratio and sense of polarization for the linearly polarized source antenna and the sense of polarization for the AUT must be known for compensation of the measured data. The errors in the measured CP gains are given in Table 6.3.

Table 6.3 Errors in measured circularly polarized gain of the AUT using source antennas with various axial ratios

Source antenna AR (dB)	Errors in measured CP gain	
	Same sense	Opposite sense
20	0.828	-0.915
25	0.475	0.505
30	0.270	0.279
35	0.153	0.156
40	0.086	0.109
45	0.049	0.049
50	0.027	0.028

Comparison of Tables 6.2 and 6.3 shows that the CP gain measurement is far more sensitive to the axial ratio of the source antenna. If the source is only linearly polarized to 20 dB axial ratio, the measurement errors are nearly ±1 dB for CP and only 0.06 dB for linear polarization. At 35 dB axial ratio the gain error is 0.15 dB. This emphasises the fact that excellent linear polarization is required in the test field when measuring circularly polarized antennas. The slant range must be evaluated to assess the CP errors.

Many electronic warfare and satellite communications systems use circularly polarized antennas. These antennas can be measured to good accuracy on the slant range depending on the size of the AUT. In these cases custom designed test set-ups may be required depending on the specified measurement accuracy.

Figure 6.1 Calculated antenna patterns illustrating the effects of quadratic phase errors encountered when measuring at the test ranges shown

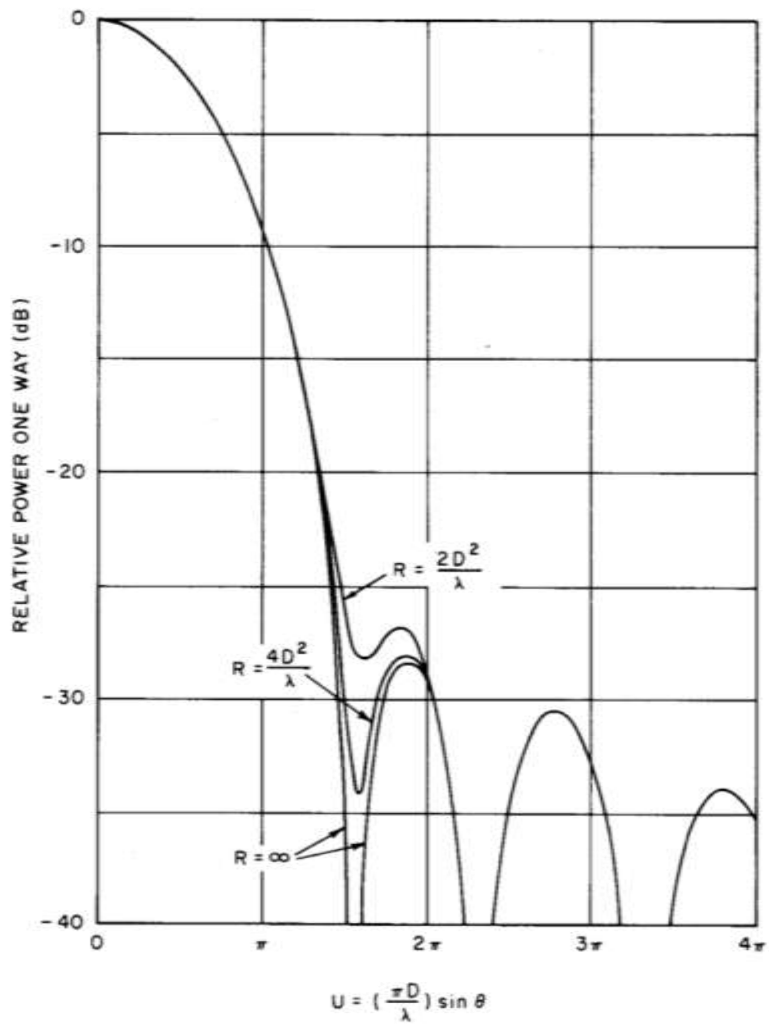


Figure 6.2 Range distance required for measuring the correct first sidelobe to the accuracy (error) stated on the straight lines

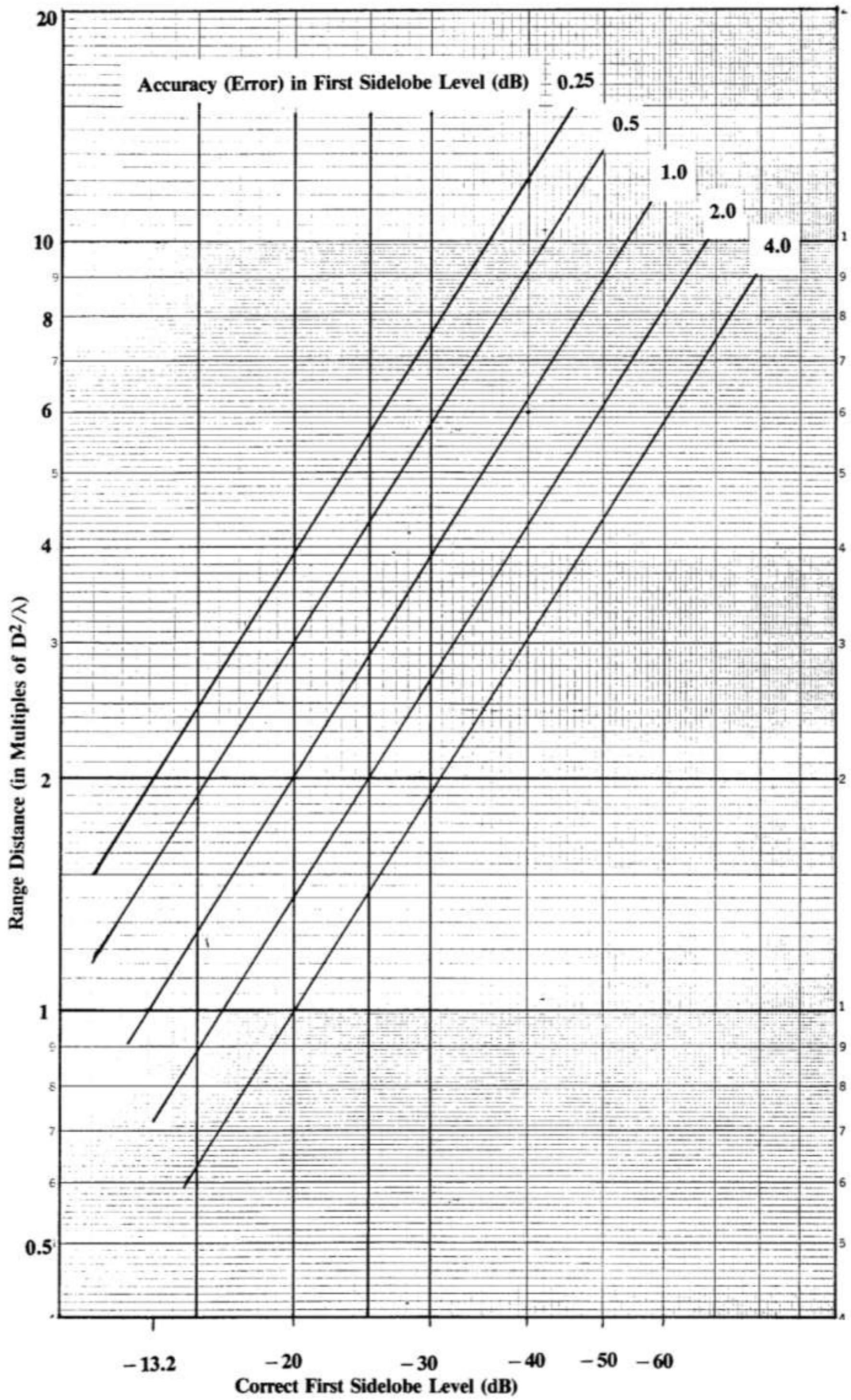
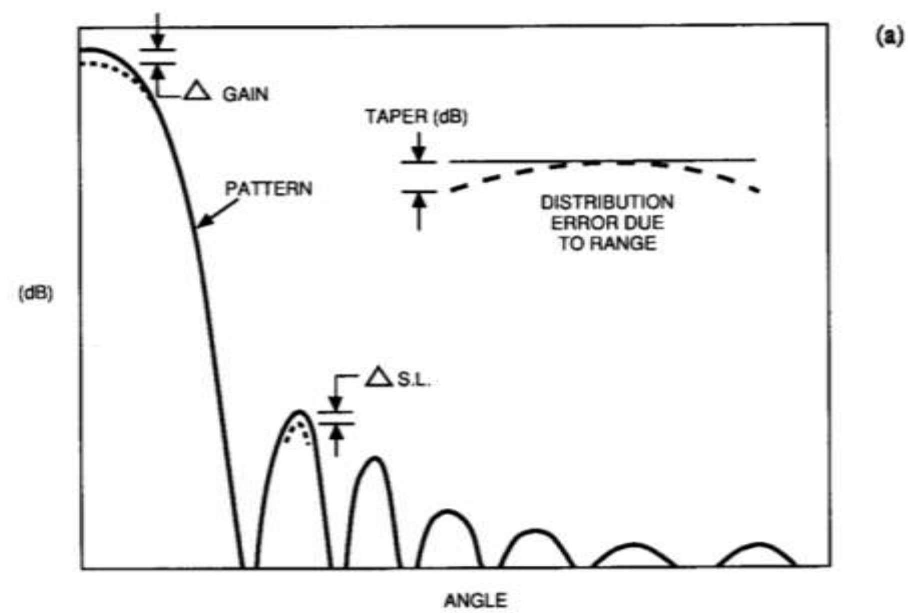


Figure 6.3 Effect of amplitude taper in the test field
(a) explanation of terms
(b) impact on gain and first and second sidelobes



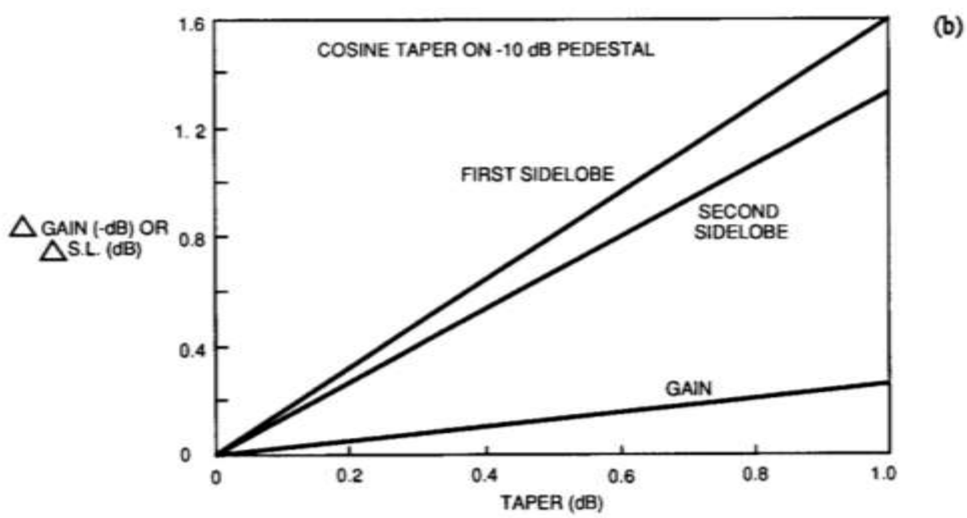


Figure 6.4 Diagram showing extraneous reflection entering main beam when sidelobe points at source

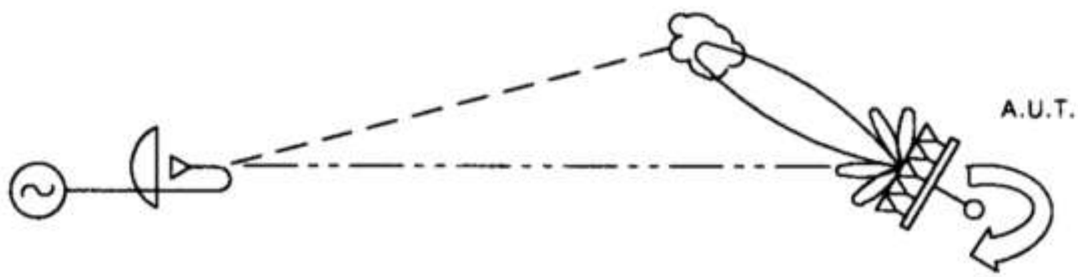
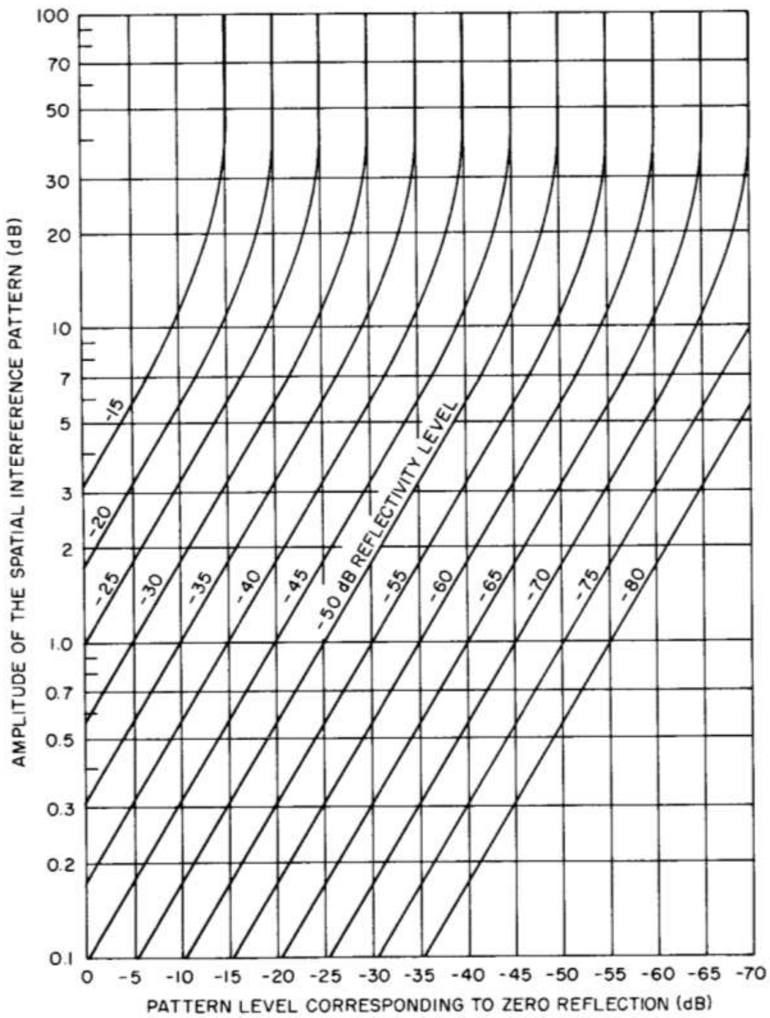


Figure 6.5 Amplitude of the spatial interference level for a given reflectivity level and antenna pattern level



7. CONCLUSION

This user guide has described the requirements for the operation of the 43 m slant range under controlled and well understood conditions. The largest diameter antennas for the 0.5 to 18 GHz frequency range have been derived based on the 0.25 dB test field amplitude taper and the $2D^2/\lambda$ far-field criteria. Linear and circular polarization measurements can be made but great care must be taken to set up the range for circular polarization. Pattern and gain measurement errors were discussed. Modern vector network analysers with sophisticated self-calibration capabilities have greatly reduced instrumentation errors.

It has been shown that the 43 m slant range can make accurate measurements on antennas which meet the $2D^2/\lambda$ and 0.25 dB criteria. Measurements can be made on antennas at test distances less than this requirement. At shorter test distances only the first (or possibly also the second) sidelobe will be in error. The impact on the gain measurement can be deduced from Table 6.1 when the test distance and amplitude taper are known.

Operation of the slant range can be simplified if microwave absorbing material is placed around the specular reflection area on the range surface. Such outdoor microwave absorber may be available from the STATIC RCS measurement range.

In consultation with Gerotek, the most important aspects of configuring the slant antenna test range and the typical measurement errors will be extracted from this user manual to create a "short-form guide" for users.

8. REFERENCES

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