Antenna Boresighting

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CONTENTS

COMMENT

The difficulty of discussing the practical aspects of boresighting in general terms has been circumvented by writing two parallel sections - one pertaining to antennas with a fixed mechanical reference and one pertaining to antennas with adjustable optical - mechanical references.

The reader is advised to concentrate first on the section that pertains most specifically to his particular antenna boresight problem. Either of Sections I or II may be read without prior knowledge of the other; they are partially repetitive when discussing overlapping material.

Those antennas whose boresight reference is defined by touch points on the mounting structure are covered in Section I; those antennas having boresight telescopes are covered in Section II.

SECTION I-A
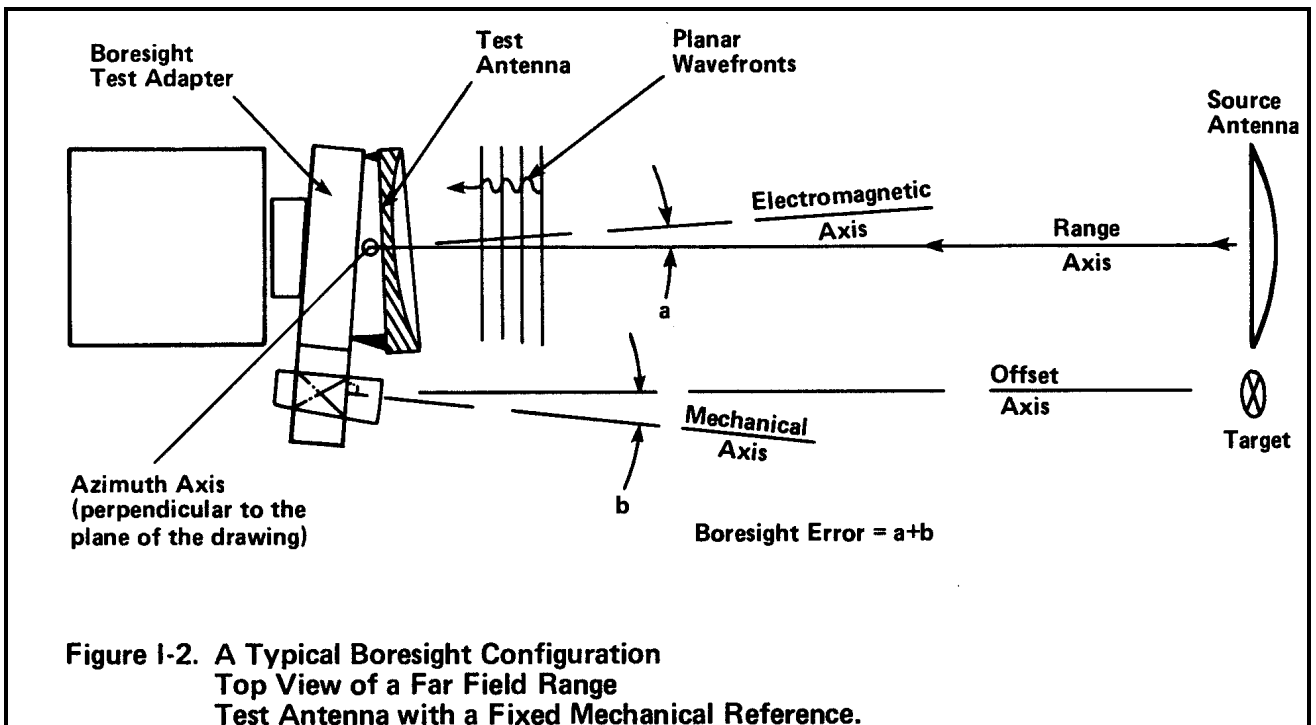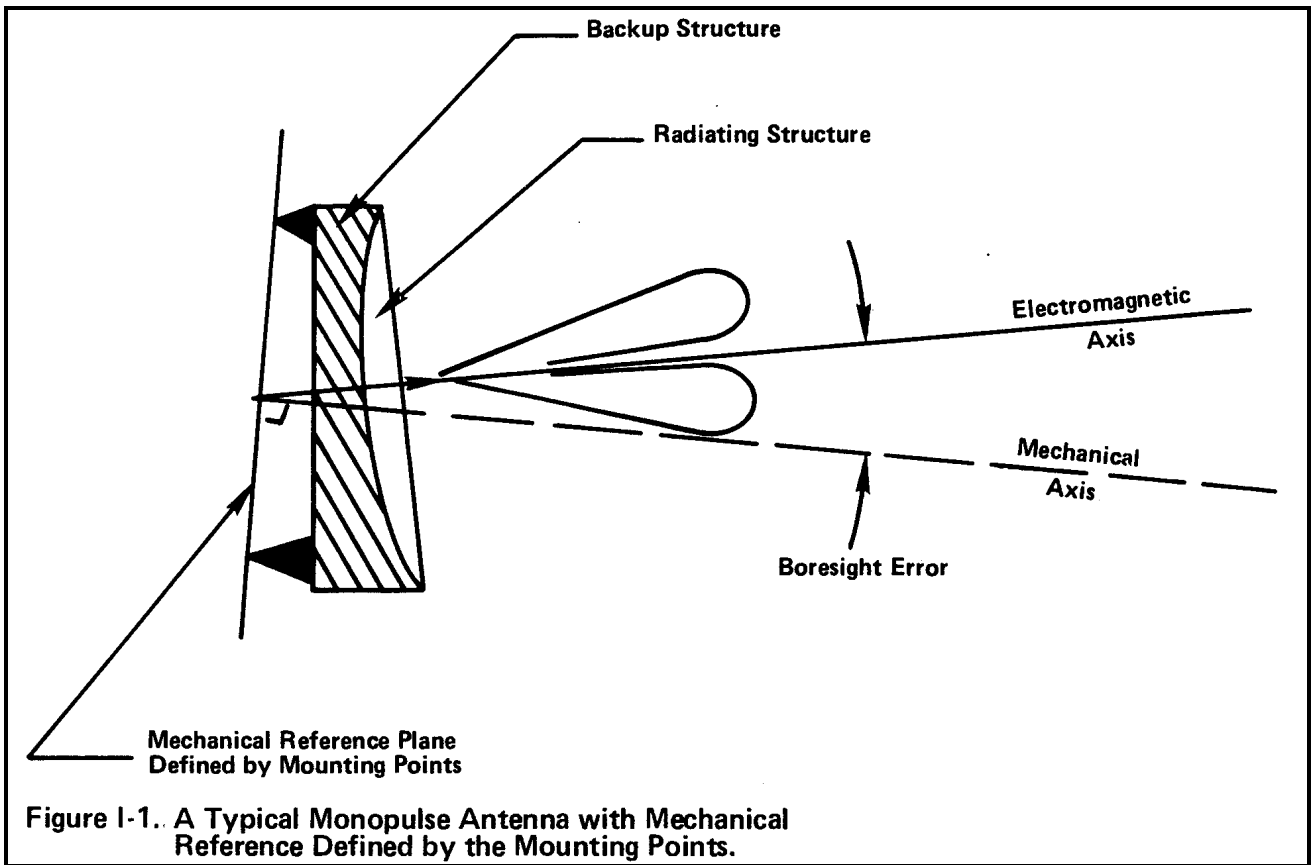# BORESIGHTING ANTENNAS HAVING A FIXED MECHANICAL REFERENCE

An antenna is boresighted by making a measurement of the angular correspondence between a mechanical reference on the structure of the antenna and an electromagnetic reference defined by a unique point on the amplitude pattern of the antenna. Once this is done, the axis system with which the pattern is measured can be referred to the axis system on which the antenna is mounted.

To get a more definite idea of these terms, consider the antenna illustrated in Figure I-1. This shows a monopulse antenna that has a null point on its pattern which defines the electromagnetic axis of the antenna. The antenna shown mounts by use of touch points on the rear of the frame that forms its backup structure. These touch points lie in a plane and the normal to this plane defines a mechanical reference direction or "mechanical axis" that is fixed to the antenna. The antenna is said to be "boresighted" when the electromagnetic axis and the mechanical axis are parallel. The angular discrepancy between the electromagnetic axis and the mechanical axis is called the "boresight error"; a "boresight measurement" is a measurement of this angle.

To understand how the boresight error might be measured, consider the illustration in Figure I-2. This shows a far-field range with a source antenna illuminating the antenna under test with planar wavefronts. The axis of the range is defined by the line joining the center of the source antenna and the azimuth axis of the test positioner on which the antenna under test is mounted. The range axis is normal to the planar wavefronts. To enable the mechanical reference of the test antenna to be defined optically, a boresight test adapter is used. This is a flat plate together with a telescope that has been prealigned to have its optical axis normal to the plane of the flat. The range has been set up with a target that is offset from the source antenna by the same distance that the telescope is offset from the azimuth axis. When the optical axis of the telescope intersects the center of the target it is parallel to the range axis.

The boresight error is measured by noting the angle through which the azimuth axis rotates as the antenna is reoriented from the position in which the optical axis of the telescope intersects the target to the position in which the null of the pattern appears at the port of the antenna. The null of the pattern occurs when the electromagnetic axis of the antenna is coincident with the range axis; at this position the electromagnetic axis is normal to the wavefronts illuminating the antenna.

In order to cause the antenna to be boresighted, one of two kinds of changes must be made in the antenna itself: either the radiating structure must be altered to move the position of the electromagnetic axis relative to the backup structure or the mechanical

Figure I-1. A Typical Monopulse Antenna with Mechanical
Reference Defined by the Mounting Points.

Figure I-2. A Typical Boresight Configuration
Top View of a Far Field Range
Test Antenna with a Fixed Mechanical Reference.

reference plane must be altered to move the mechanical axis relative to the radiating structure. In general, one might conceive of a variety of possible ways to make the electromagnetic and mechanical axes to be parallel. For example, on a reflector antenna the feed can be moved in the focal plane of the reflector to cause the electromagnetic axis to shift relative to the backup structure; or, the mounting points could be modified to define a new mechanical reference plane whose normal is parallel to the electromagnetic axis.

Thus, a typical boresight procedure is carried out in three steps. First, the angular discrepancy between the electromagnetic axis and the mechanical axis is measured by reading the angle(s) through which the antenna is moved in going from the optical zero to the electromagnetic null. Then an adjustment is performed to bring the electromagnetic and mechanical axes into parallelism. Finally the measurement of the first step is repeated to verify the accuracy of the adjustment. It is sometimes necessary to repeat these three steps and iteratively seek the optimum point. The critical step, however, is the measurement.

In general an antenna pattern is a two-parameter function - that is, it is the received amplitude as a function of the two angles of a spherical coordinate system. The illustrated example discussed above took account of one angle only - azimuth. In practical situations one must work with two angles, usually azimuth and elevation. To first order, the adjustments are independent and orthogonal so that no complexity is introduced by including the second angle; it is simply a matter of repeating measurements for the second axis. The discussion to follow illustrates a technique for boresighting on a Compact Range. Only one axis will be illustrated for simplicity, but the approach also applies to the practical case.

SECTION I-B
BORESIGHTING ON A COMPACT RANGE FOR ANTENNAS HAVING A FIXED MECHANICAL REFERENCE

The nature of the boresight procedure for a Compact Range differs from that for a far field range because of an essential difference between the far field range and the Compact Range: on a far field range the range axis is defined optically by the visual line joining the rotation center of the test positioner and the center of the source antenna. On a Compact Range there is no inherent optical definition of the wavefront normal. In order to circumvent the difficulty a boresight procedure has been devised which utilizes the polarization axis of the test positioner to relate the mechanical and electromagnetic axes of the test antenna. This procedure can also be implemented on an outdoor range; when used it eliminates the need to set up a visual target at the source antenna.

The equipment required for boresighting on a Compact Range is illustrated schematically in Figure I-3. It consists of a boresight test adapter which interfaces between the polarization axis and the test antenna, an adjustable spindle mirror, and an autocollimator with an adjustable mount. The autocollimator mounts on a stand directly behind the test positioner near the rear wall of the room.
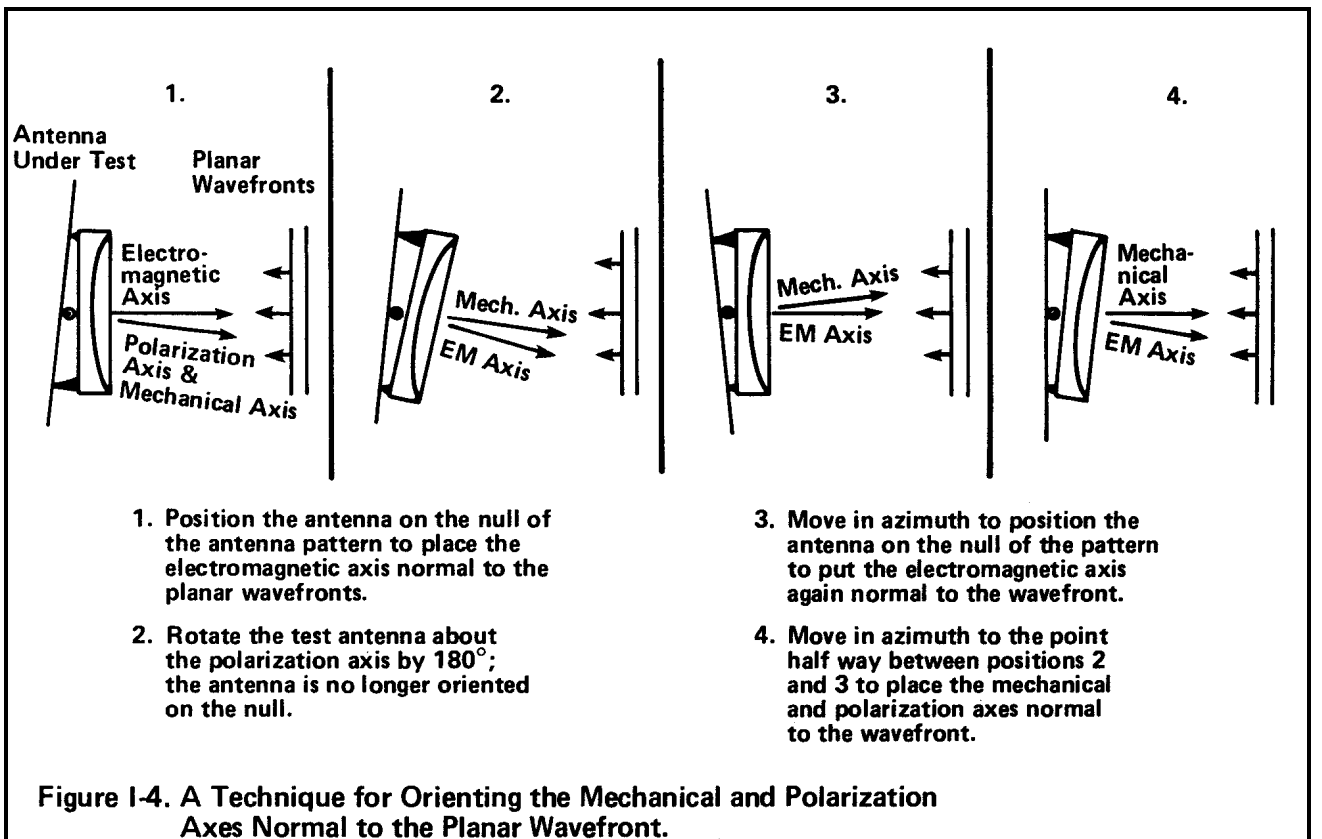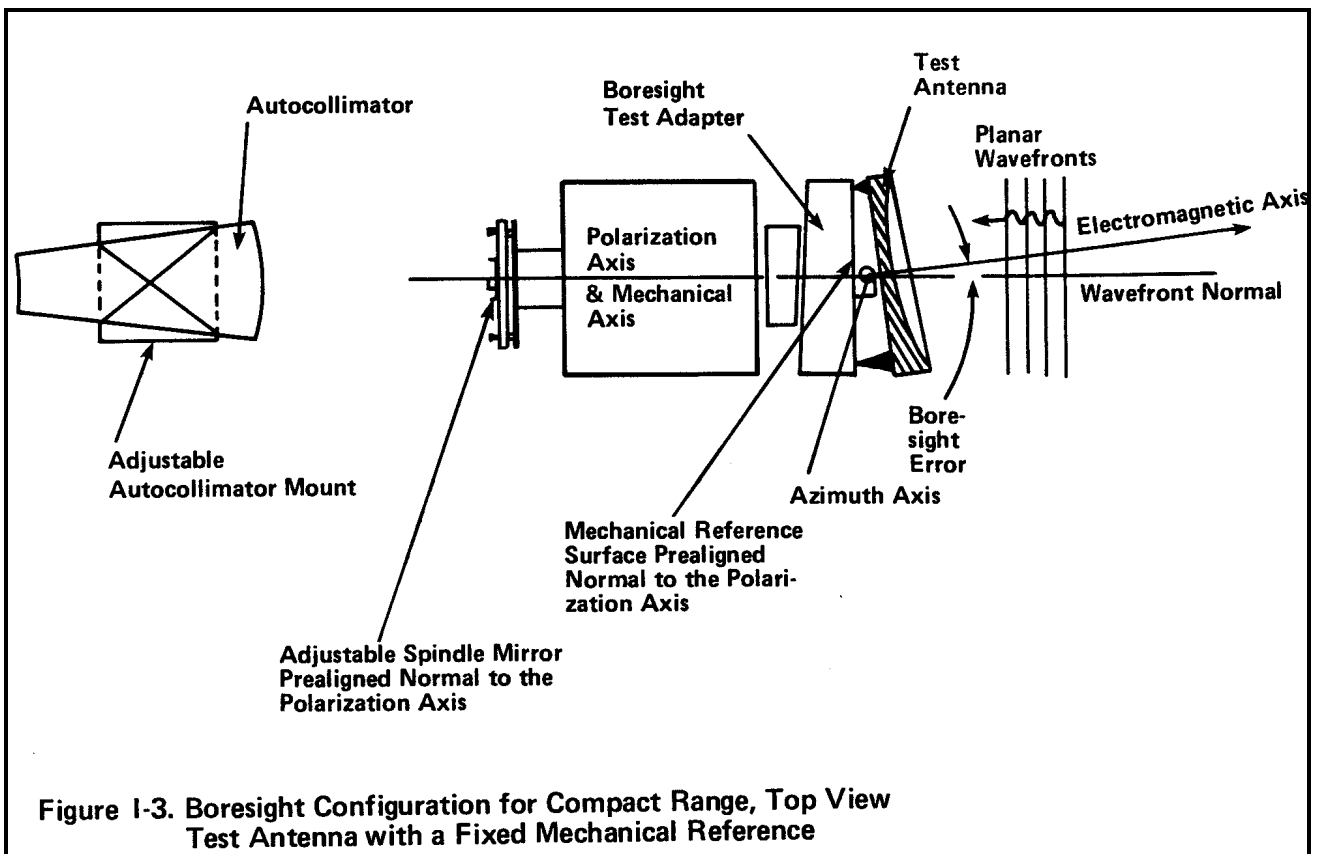
The boresight test adapter is specific to the antenna under test. It is an adjustable planar surface which can be prealigned to be normal to the polarization axis of the test positioner. The test adapter must be designed to accommodate the antenna under test whose mounting plane is defined by three or four touch points on its structure. When the test antenna is bolted to the adapter, the fixed mechanical reference axis of the test antenna defined by its touch points is normal to the mounting plane of the adapter. To within the alignment accuracies, the polarization axis is then perpendicular to the plane defined by the touch points of the antenna mount.

The spindle mirror on the rear of the polarization axis must be adjusted to be perpendicular to the polarization axis. This is done by use of a small orientation stage. The procedure for performing the adjustment consists of a trial and error method, with the autocollimator being used to judge the results of each resetting. When the mirror is perpendicular to the polarization axis, then the axis can be rotated without losing the autocollimation condition.

Once the spindle mirror and the boresight test adapter have been aligned to the polarization axis, the boresight measurement procedure can be performed straight forwardly. It utilizes a clever technique for orienting the polarization axis normal to the planar wavefront and this must first be understood. The method will be described below for the simple case of one dimension; generalizing to the practical case of two dimensions is easily done by realizing that each adjustment in azimuth for the one dimensional case corresponds to adjustments in azimuth and elevation for the two-dimensional case.

Assume that the boresight apparatus of Figure I-3 is aligned and set up as shown. Thus, the polarization axis of the test positioner is perpendicular to the mounting plane of the test antenna. Assume that the electromagnetic axis is off at an unknown angle relative to the mechanical axis. The crucial point to realize is that one may "find" the normal to the wavefront by the following method. Refer to Figure I-4.

First, position the test antenna on its null, so that the electromagnetic axis is normal to the wavefront. Here, the polarization axis is not normal to the wavefront. Note the reading of the autocollimator. Next rotate the antenna about the polarization axis by 180°. This leaves the polarization axis in its same orientation, and the autocollimator reading is unchanged. However, the electromagnetic axis is far off of its position normal to the

Figure I-3. Boresight Configuration for Compact Range, Top View
Test Antenna with a Fixed Mechanical Reference

1. Position the antenna on the null of the antenna pattern to place the electromagnetic axis normal to the planar wavefronts.

2. Rotate the test antenna about the polarization axis by 180°; the antenna is no longer oriented on the null.

3. Move in azimuth to position the antenna on the null of the pattern to put the electromagnetic axis again normal to the wavefront.

4. Move in azimuth to the point half way between positions 2 and 3 to place the mechanical and polarization axes normal to the wavefront.

Figure I-4. A Technique for Orienting the Mechanical and Polarization
Axes Normal to the Planar Wavefront.

wavefront. Now reorient the positioner in azimuth to place the electromagnetic axis back normal to the wave; note, the autocollimator reading for the new azimuth position. Realize that in going from the first null reading position to the second, at a point half way between the two, the polarization axis was normal to the wave. Therefore, return by half the total angle moved to place the polarization axis normal to the wave.

By this method the normal to the wavefront has been "found", because the spindle mirror, (which is also perpendicular to the polarization axis) is now parallel to the wavefront and the autocollimator can read its orientation. In fact, it is often convenient at this point to reorient or rezero the autocollimator so that its zero corresponds to the direction of the wavefront normal.

Now the boresight error can be readily measured. Starting with the polarization axis normal to the wavefront, note the autocollimator reading, then move in azimuth to the null in the pattern. Read the autocollimator for the orientation associated with the null. The difference between the autocollimator readings for the polarization axis normal to the wavefront and for the pattern null is the boresight error.

COMPACT RANGE BORESIGHT PROCEDURE FOR ANTENNAS HAVING A FIXED MECHANICAL REFERENCE

1. Align the boresight test adapter so that the plane of the flat on which the antenna mounts is normal to the polarization axis. This is done by use of dial indicator placed against the surface to measure the wobble in the flat as the polarization axis is rotated through $360°$. The sensitivity of the dial indicator and its distance from the rotation axis determine the accuracy to which this alignment is performed.
2. Align the spindle mirror on the rear of the polarization axis to be normal to the polarization axis. This is done by autocollimating into this mirror and adjusting its mount until the polarization axis may be rotated without loss of the autocollimator condition.
3. Align the polarization axis to be normal to the wavefront. First, find the boresight null with the antenna. Sight into the autocollimator and note the readings. Rotate the polarization axis by $180°$, so that the antenna is also rotated by $180°$. Find the boresight null again and note the new autocollimator reading. Move the positioner half way between the two readings.
4. Align the autocollimator so that its optical axis is normal to the wavefront. This is done by adjusting the orientation of the autocollimator so that it reads zero - i.e., is perfectly autocollimated - when looking into the spindle mirror. Since the spindle mirror on the polarization axis is normal to the polarization axis and since the polarization axis is normal to the wavefront, then the objective has been accomplished.

5. Measure the boresight error. To do this, move the test positioner to the null of the antenna pattern and note the new readings of the autocollimator. These readings are the angles through which the antenna is moved in going from an orientation in which its mechanical axis is normal to the wavefront to an orientation in which its electromagnetic axis is normal to the wavefront. Therefore, these readings represent the boresight error of the antenna.

SECTION II-A
BORESIGHTING ANTENNAS HAVING AN ADJUSTABLE OPTICAL/MECHANICAL REFERENCE

An antenna is boresighted by making a measurement of the angular correspondence between an optical or a mechanical reference on the structure of the antenna and an electromagnetic reference defined by a unique point on the amplitude pattern of the antenna. Once this is done, the axis system with which the pattern is measured can be referred to the axis system on which the antenna is mounted.
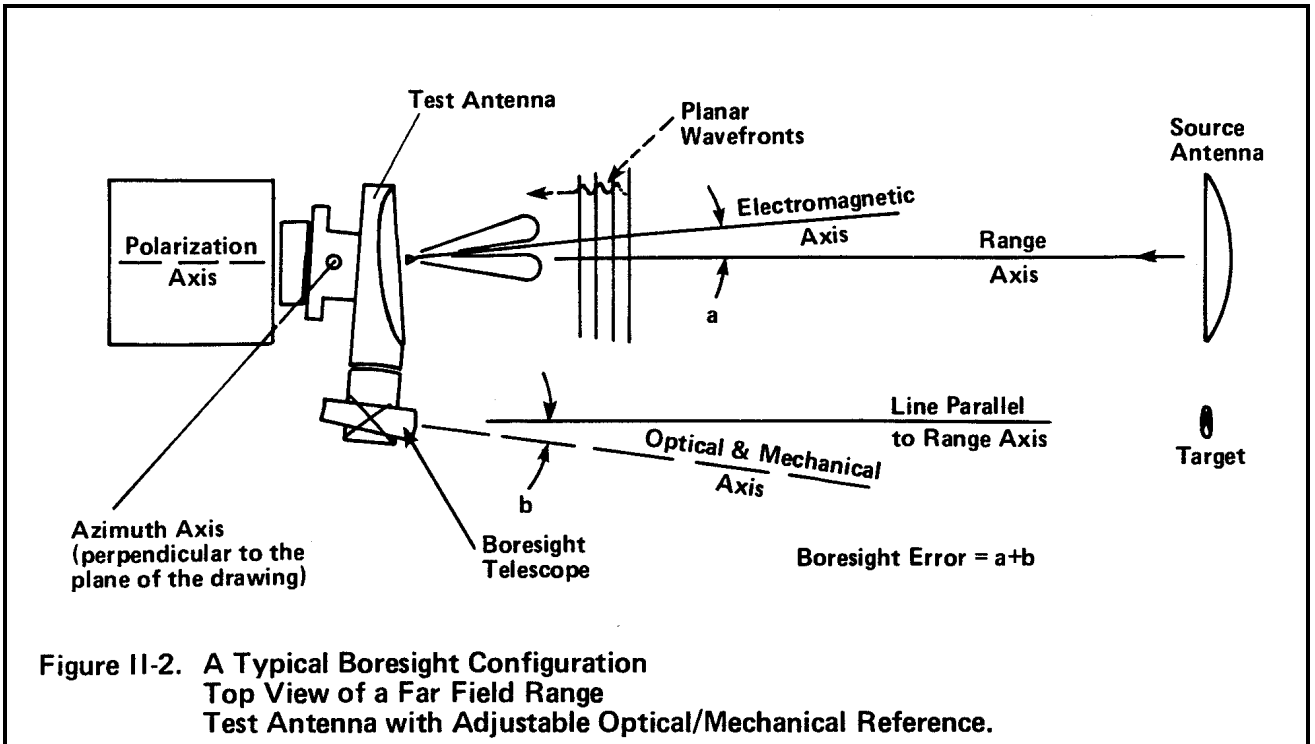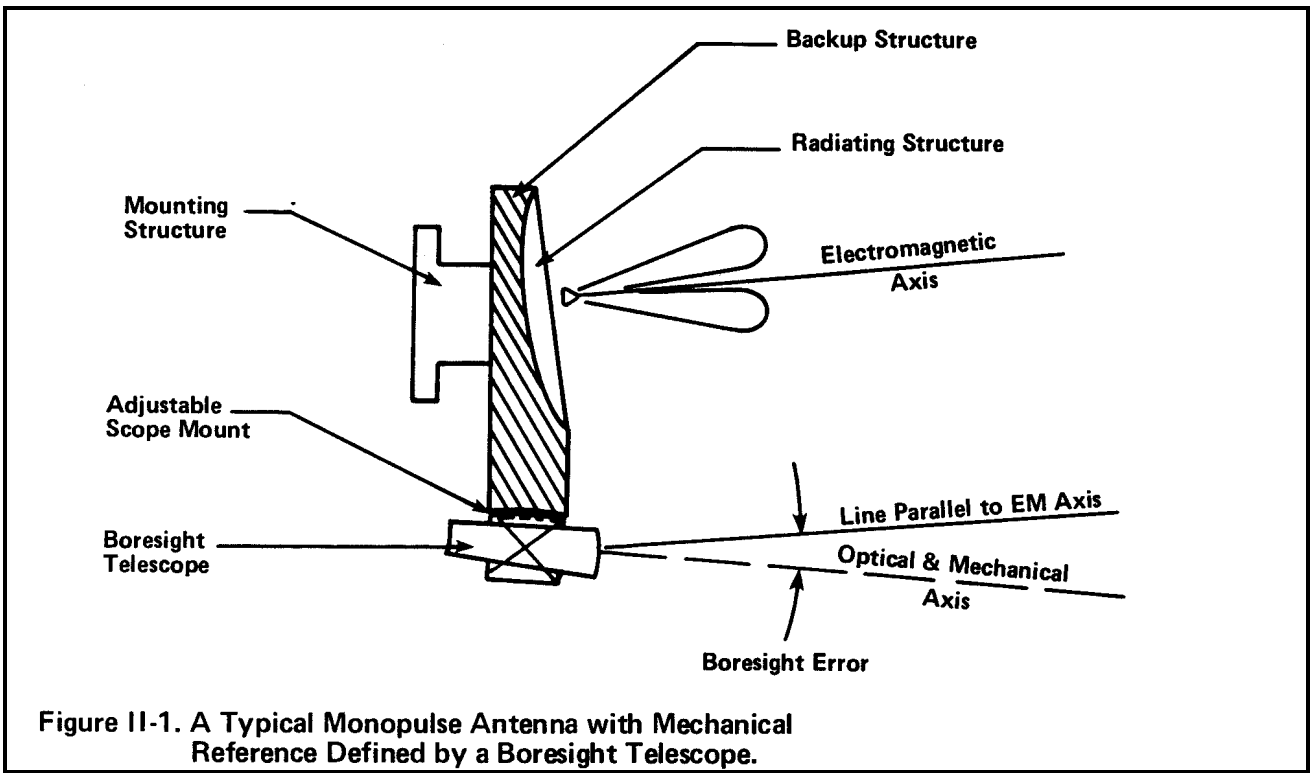
To get a more definite idea of these terms, consider the antenna illustrated in Figure II-1. This shows a monopulse antenna that has a null point on its pattern which defines the electromagnetic axis of the antenna. The antenna shown mounts in an ordinary way; for this type of boresight arrangement, the mounting structure is not part of any boresight scheme. Rather, the antenna is provided with an optical telescope, or perhaps a fixture for mounting a telescope, and the scope is used to define a mechanical reference direction. For definiteness, the antenna shown, should be thought of as having an adjustment that permits the scope to be reoriented with respect to the backup structure of the antenna.

The antenna is said to be "boresighted" when the electromagnetic axis and the optical-mechanical axis are parallel. Any angular discrepancy between the electromagnetic axis and the mechanical axis is called the "boresight error"; a "boresight measurement" is a measurement of this angle.

To understand how the boresight error might be measured, consider the illustration on Figure II-2. This shows a far-field range with a source antenna illuminating the antenna under test with planar wavefronts. The axis of the range is defined by the line joining the center of the source antenna and the azimuth axis of the test positioner on which the antenna under test is mounted. The range axis is normal to the planar wavefronts.

The range has been set up with a target that is offset from the source antenna by the same distance that the telescope is offset from the azimuth axis. When the optical axis of the boresight telescope intersects the center of the target, the optical-mechanical axis of the antenna under test is parallel to the range axis.

Figure II-1. A Typical Monopulse Antenna with Mechanical Reference Defined by a Boresight Telescope.

Figure II-2. A Typical Boresight Configuration Top View of a Far Field Range Test Antenna with Adjustable Optical/Mechanical Reference.

The boresight error is measured by noting the angle through which the azimuth axis rotates as the antenna is reoriented in azimuth from the position at which the axis of the telescope intersects the target to the position at which the null of the pattern appears at the port of the antenna. The null of the pattern occurs when the electromagnetic axis of the antenna is coincident with the range axis; at this position the electromagnetic axis is normal to the wavefronts illuminating the antenna.

For antennas that do not have an adjustable scope mount, but rather a fixed mount, a measurement of the boresight error may be the point of the procedure. Usually, however, either the scope mount or the antenna's beam is adjustable and the point of the boresight procedure is to make the boresight error negligibly small.

To cause the antenna to be boresighted, one of two kinds of changes must be made: either the radiating structure must be altered to move the position of the electromagnetic axis relative to the backup structure, or the telescope must be adjusted to move the optical-mechanical axis relative to the backup structure. In general, one might conceive of a variety of possible ways to make the electromagnetic and optical-mechanical axes to be parallel. For example, on a reflector antenna, the feed can be moved in the focal plane plane of the reflector to cause the electromagnetic axis to shift relative to the backup structure. However, antennas with adjustable scope mounts, are boresighted by reorienting the optical axis of the scope to make it parallel to the electromagnetic axis.

In general, then, a boresight procedure is carried out in three steps. First, the angular discrepancy between the electromagnetic axis and the optical-mechanical axis is measured by reading the angle(s) through which the antenna is moved in going from the optical zero to the electromagnetic null. Then an adjustment is performed to bring the electromagnetic and mechanical axes into parallelism. Finally, the measurement of the first step is repeated to verify the accuracy of the adjustment. It is sometimes necessary to repeat these three steps and iteratively seek the optimum point. The critical step, however, is the measurement of the boresight error.

For an antenna with an adjustable scope mount the practical steps that correspond to the general description above, consist simply of the following: first set the antenna on the null in its pattern. Then adjust the orientation of the scope until its optical axis intersects the center of the target. This leaves the optical and electromagnetic axes parallel and the boresight error zero.

In general an antenna pattern is a two-parameter function - that is, it is the received amplitude as a function of the two angles of a spherical coordinate system. The illustrated example discussed above took account of one angle only - azimuth. In practical situations one must work with two angles, usually azimuth and elevation. To first order, the

adjustments are independent and orthogonal so that no complexity is introduced by including the second angle; it is simply a matter of repeating measurements for the second axis. The discussion to follow illustrates a technique for boresighting on a Compact Range. Only one axis will be illustrated for simplicity, but the approach also applies to the practical case.
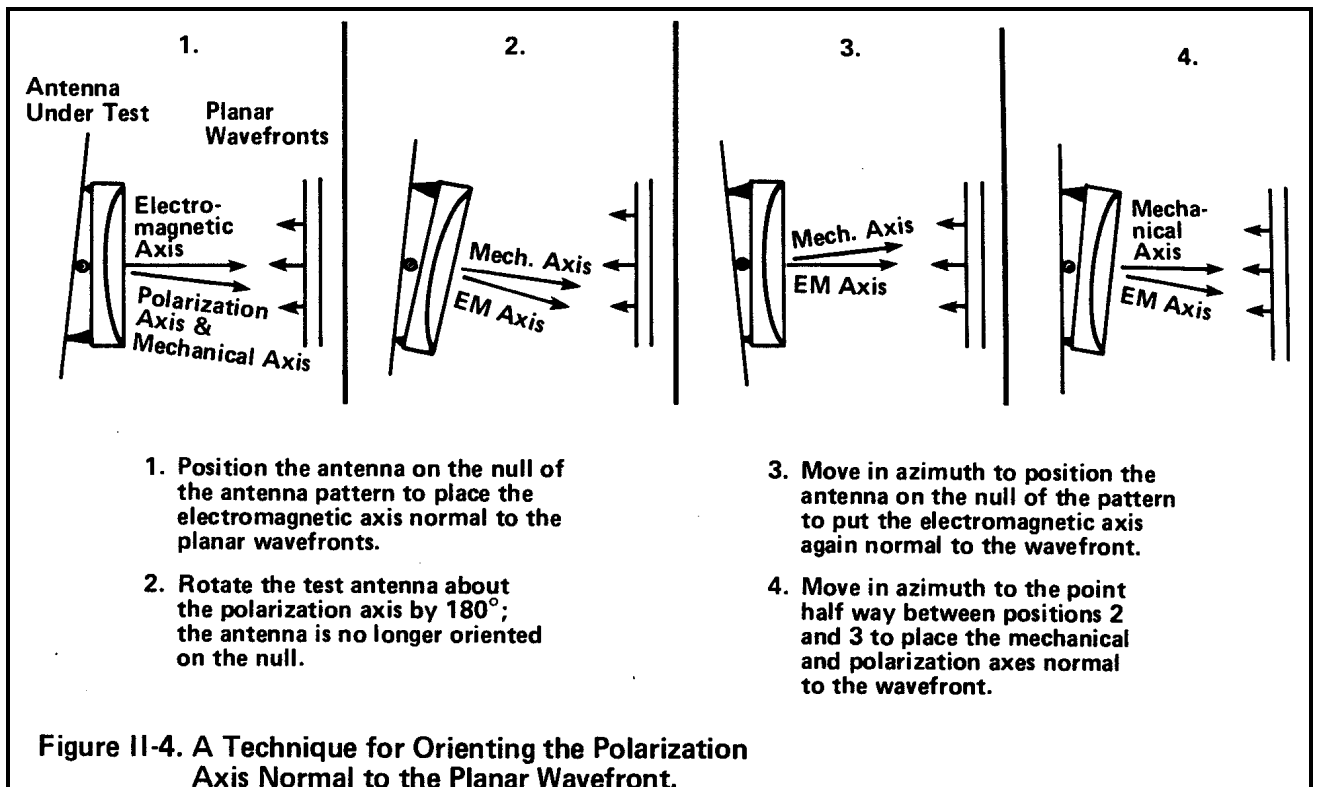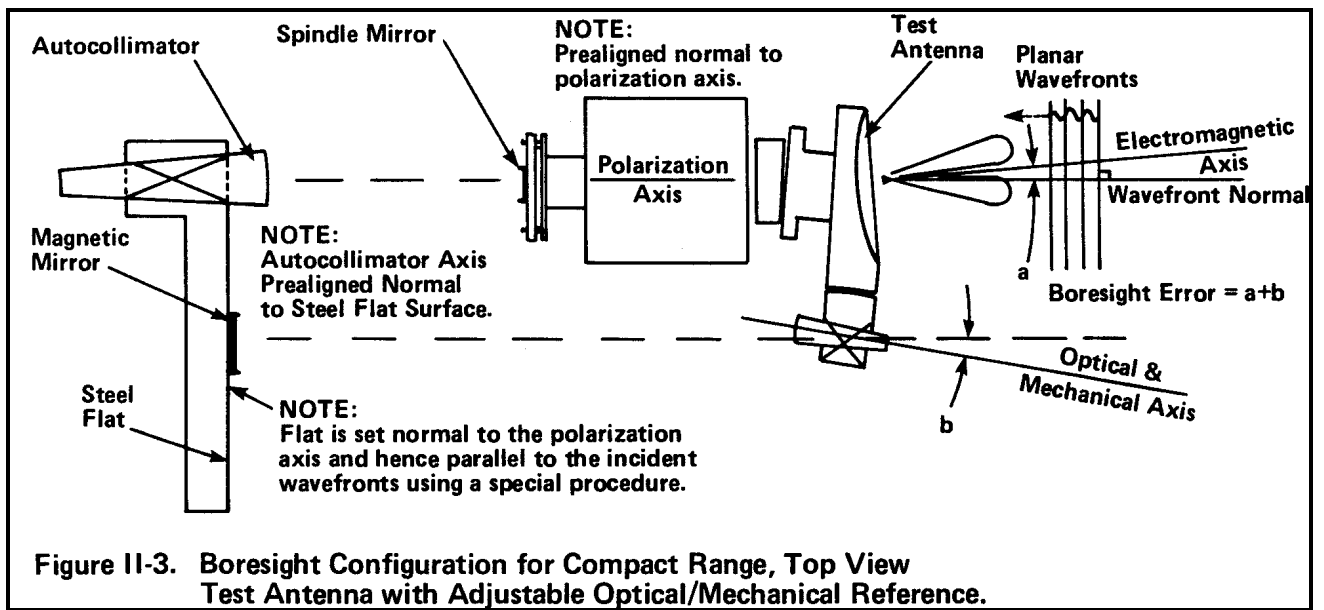
SECTION II-B
BORESIGHTING ON A COMPACT RANGE FOR ANTENNAS HAVING AN ADJUSTABLE OPTICAL/MECHANICAL REFERENCE

The nature of the boresight procedure for a Compact Range differs from that for a far field range because of an essential difference between the far field range and the Compact Range: on a far-field range the range axis is defined optically by the visual line joining the rotation center of the test positioner and the center of the source antenna. On a Compact Range there is no inherent optical definition of the wavefront normal. In order to circumvent the difficulty a boresight procedure has been devised which utilizes the polarization axis of the test positioner to relate the mechanical and electromagnetic axes of the test antenna. This procedure can also be implemented on an outdoor range; when used it eliminates the need to set up a visual target at the source antenna.

The equipment required for boresighting on a Compact Range is illustrated schematically in Figure II-3. It consists of an adjustable spindle mirror and an autocollimator/steel flat assembly whose orientation is adjustable. The autocollimator and assembly mount on a stand directly behind the test positioner near the rear wall of the room.

The autocollimator assembly is mounted so that the axis of the autocollimator coincides with the polarization axis of the test positioner when the polarization axis is normal to the phase front of the Compact Range. The autocollimator mounts rigidly to a large steel flat; a factory alignment provides that the optical axis of the autocollimator is normal to the plane of the flat. A three-point magnetic mirror can thus be set anywhere on the flat and its normal will remain parallel to the axis of the autocollimator. As one can imagine from the illustration, various antennas may have their telescopes mounted in such a way that the scope axes intersect the flat at different points. By use of the flat, the mirror can always be moved to pick up the line of sight of the boresight telescope.

The spindle mirror on the rear of the polarization axis must be adjusted to be perpendicular to the polarization axis. This done by use of a small orientation stage. The procedure for performing the adjustment consists of a trial and error method, with the autocollimator being used to judge the results of each resetting. When the mirror is perpendicular to the polarization axis, then the axis can be rotated without losing the autocollimator's condition.

Figure II-3. Boresight Configuration for Compact Range, Top View Test Antenna with Adjustable Optical/Mechanical Reference.

1. Position the antenna on the null of the antenna pattern to place the electromagnetic axis normal to the planar wavefronts.

2. Rotate the test antenna about the polarization axis by 180°; the antenna is no longer oriented on the null.

3. Move in azimuth to position the antenna on the null of the pattern to put the electromagnetic axis again normal to the wavefront.

4. Move in azimuth to the point half way between positions 2 and 3 to place the mechanical and polarization axes normal to the wavefront.

Figure II-4. A Technique for Orienting the Polarization Axis Normal to the Planar Wavefront.

The autocollimator assembly can be set so that the axis of the autocollimator is perpendicular to and the plane of the flat is parallel to the planar wavefront of the Compact Range. This step is carried out by a special procedure that utilizes the antenna under test and the polarization axis of the test positioner to find the wavefront. It is described in detail in the following paragraphs.

First, position the test antenna on its null, so that the electromagnetic axis is normal to the wavefront. Here, the polarization axis is not normal to the wavefront. Note the reading of the autocollimator. Next rotate the antenna about the polarization axis by 180°. This leaves the polarization axis in its same orientation and the autocollimator reading is unchanged. However, the electromagnetic axis is far off of its position normal to the wavefront. Now reorient the positioner in azimuth to place the electromagnetic axis back normal to the wave; note the autocollimator reading for the new azimuth position. Realize that in going from the first null reading position to the second, at a point half way between the two, the polarization axis was normal to the wave. Therefore, return by half the total angle moved to place the polarization axis normal to the wave.

Once the polarization axis is oriented normal to the wavefront, the autocollimator assembly may be aligned to the wavefront by use of the known relationship between the spindle mirror and the polarization axis. By adjusting the orientation of the autocollimator so that it precisely autocollimates into the spindle mirror, one succeeds in making the steel flat parallel to the wavefront. Since the spindle mirror is normal to the polarization axis and the polarization axis is normal to the wavefront, this adjustment leaves the autocollimator/steel flat assembly also aligned to the wavefront.

Now the antenna can be boresighted, once the steel flat has been aligned. First the antenna is positioned on the null and its pattern, which places the electromagnetic axis normal to the wavefront. Then the magnetic mirror is moved over the surface of the flat until the boresight scope retroreflects via the magnetic mirror into a target located around the periphery of its large end. The antenna is boresighted when the adjustments leave the scope retroreflecting precisely on its own target. In this condition the axis of the scope is perpendicular to the flat and thus perpendicular to the wavefront. Because the electromagnetic axis is also perpendicular to the wavefront, the optical axis of the scope is parallel to the electromagnetic of the antenna.

Any boresight error can be measured very simply using the autocollimator. See Figure II-3 for reference. To do this, first note the autocollimator reading with the antenna positioned on its null. Then, reorient the test positioner until the boresight scope retroreflects into the magnetic mirror. Note the autocollimator reading for this new position. The boresight error is the difference between these autocollimator readings.

COMPACT RANGE BORESIGHT PROCEDURE FOR ANTENNAS HAVING AN OPTICAL-MECHANICAL REFERENCE

0. To be carried out at the factory: align the autocollimator with the steel flat so that its axis is normal to the plane of the flat. Align the three-point magnetic holder of the movable mirror so that the surface of the mirror is parallel to the flat for arbitrary

positions of the mirror on the flat. Therefore, for any point on the flat at which the mirror may be attached, the autocollimator axis is parallel to the normal of the mirror surface.

1. Align the mirror on the rear of the polarization axis to be normal to the polarization axis. This is done by autocollimating into this mirror and adjusting its mount until the polarization axis may be rotated without loss of the autocollimation condition.

2. Align the polarization axis to be normal to the wavefront. First, find the boresight null with an antenna. Sight into the autocollimator and note the readings. Rotate the polarization axis by 180°, so that the antenna has also rotated by 180°. Find the boresight null again and note the new autocollimator readings. Move the positioner half way between these two readings.

3. Align the autocollimator - steel flat assembly so that the autocollimator axis and the normal to the steel surface are perpendicular to the wavefront. This is done by adjusting the tilt of the steel flat so that the autocollimator axis is aligned with the normal to the mirror on the polarization axis. Since the mirror on the polarization axis is normal to the polarization axis and since the polarization axis is normal to the wavefront, then the objective has been accomplished.

4. Position the test antenna on the electromagnetic boresight direction by finding the null of the difference pattern.

5. Set up the boresight telescope that affixes to the test antenna so that it looks into the mirror on the steel plate. The magnetically mounted mirror on the steel plate can be moved anywhere on the ground surface in order to accomplish this. The boresight telescope retroreflects into this mirror and the retroreflected target appears when viewing through the scope. Sight through the scope toward the retroreflected target.

6. If the test antenna has an adjustable boresight reference, then perform the adjustments necessary to get the telescope to retroreflect precisely on its target.

7. If the test antenna has a fixed boresight reference, then first note the reading of the autocollimator with the antenna oriented on its boresight null. Then reposition the test antenna positioner until the boresight telescope retroreflects precisely on its target? note the autocollimator reading for this second orientation.

The angular difference between the orientation of the test antenna positioner when the antenna is set on its boresight null and the orientation when the telescope precisely retroreflects precisely on its target is the boresight error of the antenna.

APPENDIX A
PLANE WAVES

The test zone of an ideal antenna range consists of an imaginary volume in which there is produced (in the absence of a test antenna) an electromagnetic field which is a uniform continuous plane wave.

Mathematically, a plane wave is a complex function of the form:

$$E(x, t) = E_o \exp i\, (k : x - \omega t) \qquad\qquad (1)$$

where

    x = spatial position vector
    t = time parameter
    k = wave vector
    $k = 2\pi/\lambda$
    λ = wave length
    ω = frequency in radians per unit time
    E_o = complex amplitude

In general, for an electromagnetic wave, E must be considered a vector with three spatial components; however, one often simplifies the description to deal with scalar quantities and the scalar E then might represent one of the transverse vector components of the wave.

In general, also E_o is a function of x and t; however, only the amplitude of the quantity E_o may vary if the wave is to be planar. Thus, one may write:

$$E_o = A_o\, (x, t) \exp i\phi \qquad\qquad (2)$$

where

    $A_o\, (x, t)$ = amplitude, a real variable
    ϕ = phase, a real constant

A uniform plane wave is one for which the amplitude A is independent of position - i.e., $A_o = A_o(t)$.

A continuous wave is one for which the amplitude A_o is independent of time - i.e., $A_o = A_o\, (x)$.

A uniform, continuous plane wave is one whose amplitude is independent of both position and time - i.e., A_o is a real constant.

For a uniform, continuous wave the mathematical expression of equation (1) simplified to:

$$E(x,t) = A \exp i\, (k \cdot x + \phi) \exp i\, \omega t$$

The phase of the field is the argument of the first exponential function. provided one uses the common phasor description of time varying sinsoids.

The points in space at which the field oscillates "in phase" are those which satisfy the criterion that the phase be constant; namely that:

$$k \cdot x = \text{constant} \tag{3}$$

When the explicit forms of the vectors k and x are substituted into (3) one finds that (3) is in the form of the equation for a plane. To see this, use:
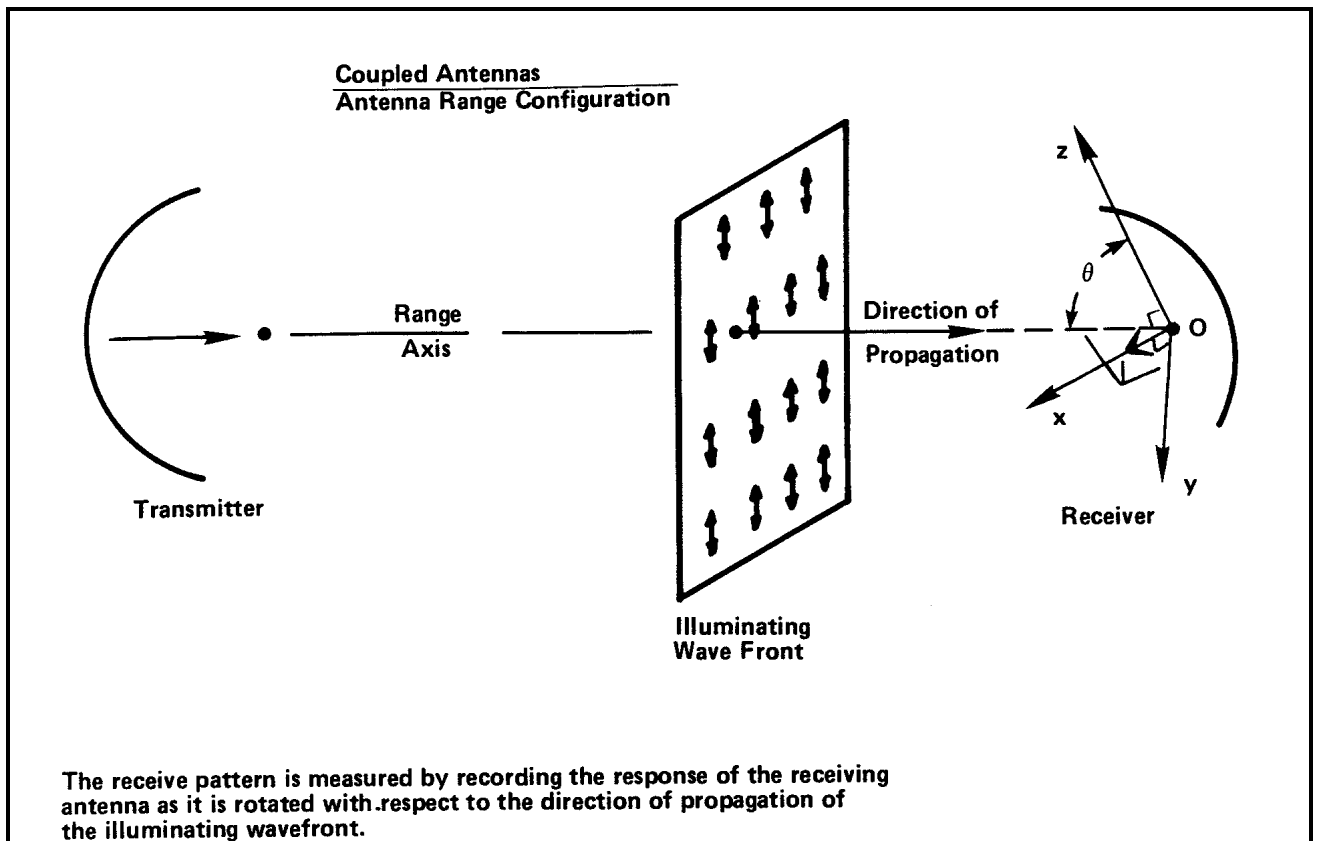
$$k = 2\pi \ (n_x \hat{x} + n_y \hat{y} + n_z \hat{z})$$

and

$$x = x\hat{x} + y\hat{y} + z\hat{z}$$

to get

$$n_x x + n_y y + n_z z = \text{new constant} \tag{4}$$

The vector $n = (n_x, n_y, n_z)$ is a unit vector in the direction of propagation. Equation (4) is an equation in three unknowns x, y, z. The solutions are a set of points which lie on a planar surface. This last fact is the reason that expressions of the form of equation (1) are called plane (or planar) waves.

Coupled Antennas
Antenna Range Configuration

Range Axis

Transmitter

Illuminating Wave Front

Direction of Propagation

θ

Receiver

The receive pattern is measured by recording the response of the receiving antenna as it is rotated with respect to the direction of propagation of the illuminating wavefront.

APPENDIX B
ANTENNA PATTERNS

When a continuous wave is incident upon a receiving antenna, a signal of the form $V \exp j(wt-\phi)$ will appear at the transmission line or waveguide port of the antenna; this response to the incident wave is characterized by an amplitude V and a phase ϕ that is referred to the plane of the port. If the wave is uniform, continuous, and planar the response is unique. Deviations from these conditions cause the response to change. Always, in testing an antenna, the conditions of the test must be stated and controlled. It is most simply done if the incident wave is a continuous uniform plane wave. When testing an antenna, one wishes in the majority of cases to achieve as close an approximation to this condition as possible.

ARRANGEMENT FOR ANTENNA PATTERN TEST

Antenna Under Test

φ

Incident Plane Wave

20 Log V/Vo

φ
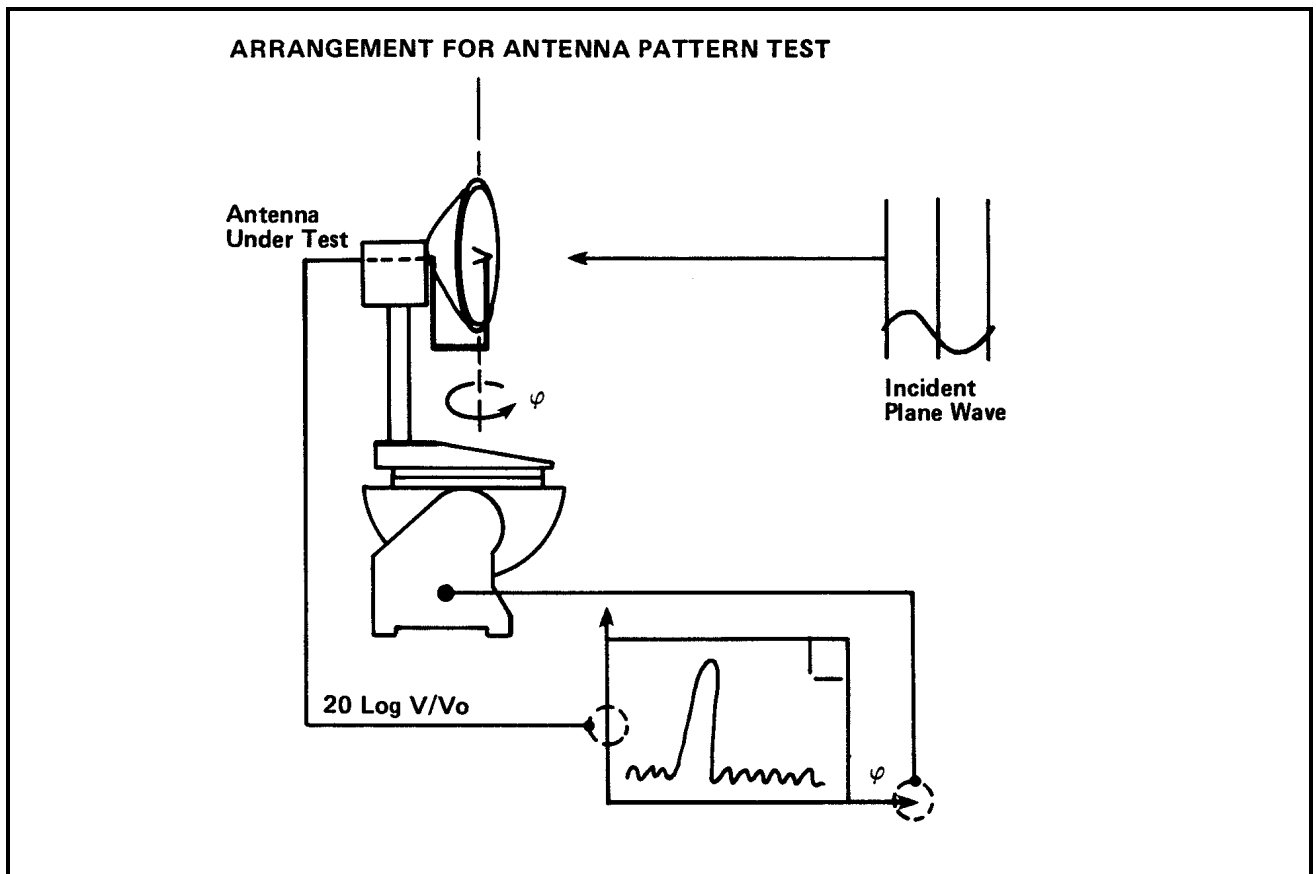
If the direction of propagation of the incident plane wave is varied, the amplitude and phase of the received signal will correspondingly change. Alternatively, if the receiving antenna is reoriented by rotating it about an axis as the direction of propagation of the wave is held fixed, the response will also change. This dependence of the antenna's response upon the geometrical relationship between the incoming plane wave and the antenne is an important characteristic of every antenna. The information describing this relationship is usually displayed in the form of a plot of the amplitude of the response

versus the angle of rotation. This plot is called an antenna pattern. Equipment for producing patterns is available commercially.

APPENDIX C
AN OUTDOOR RANGE

An outdoor range is an arrangement for production in a specified volume of a nearly uniform, nearly planar electromagnetic wave. This wave serves as an excellent approximation to a uniform plane wave.

The outdoor range utilizes the far field of a source antenna to produce the planar wavefront. The far field of the source antenna consists of spherical wavefronts with a radius of curvature equal to the length of the range that is the distance between the source antenna and the test zone. Directly in front of the source antenna the amplitude of the wave tapers slowly away from its peak value. With the source antenna pointed directly at the test zone, there is an electromagnetic field in the test zone which tapers gradually in amplitude and which consists of a spherical phase front. For long ranges, the taper in amplitude and phase may be made quite small, although for other practical reasons a compromise is made between the range length and the limits of the amplitude and phase variations. The spherical wavefronts from the source, having only small deviations from planarity and uniformity, are used to illuminate an antenna in the test zone of the outddor range.

OUTDOOR ELEVATED ANTENNA RANGE
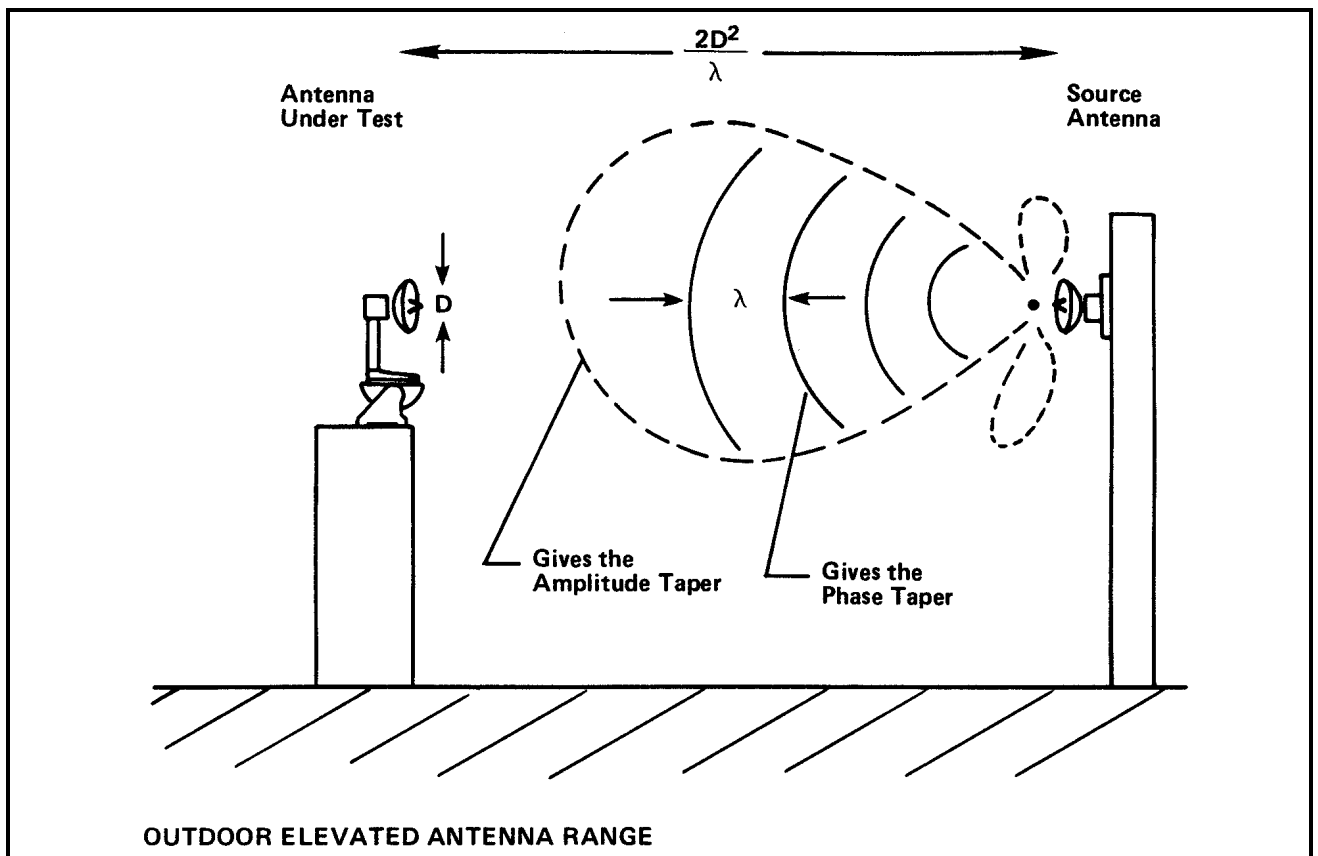
APPENDIX D
A COMPACT RANGE

A Compact Range is an arrangement for producing in a specified volume a nearly uniform nearly planar electromagnetic wave. This wave is an excellent approximation to a uniform plane wave. The arrangement of the Compact Range can be implemented in a much smaller space than can the arrangement for an outdoor range.

The Compact Range utilizes the collimating properties of a paraboloidal reflective surface in order to achieve a planar wavefront. A horn, which may have a broad pattern, is located at the focal point of an offset paraboloid; this feed horn, is tilted toward the center of the paraboloid and illuminates the metallic surface with spherical wavefronts of microwave energy. The illumination peaks near the center of the reflector and tapers off near the edges. The paraboloidal surface transforms the incoming spherical wave into a planar outgoing wave. The phase front of the outgoing wave deviates only slightly from a planar wave provided one is restricted to the field near to the reflector. The amplitude of the field tapers due to the effect of the feed's primary pattern and free space propagation loss as the reflector is illuminated. The outgoing planar wavefronts are used to illuminate an antenna situated behind the feed in the test zone of the Compact Range.

COMPACT RANGE SCHEMATIC