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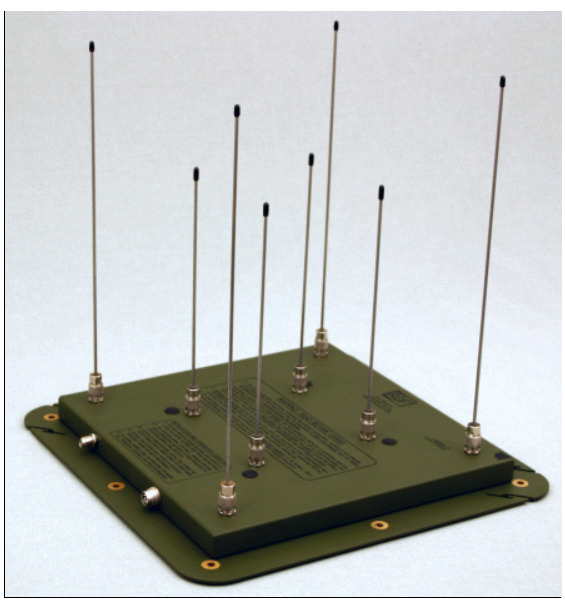
# AN-003

## Application Note

# MEASURING BEARING ACCURACY OF MOBILE ADCOCK DF ANTENNAS



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In keeping with RDF Products' business philosophy that the best customer is well informed, RDF products publishes Applications Notes from time to time in an effort to illuminate various aspects of DF technology, provide important insights how to interpret manufacturer' product specifications, and how to avoid "specsmanship" traps. In general, these Application Notes are written for the benefit of the more technical user.

RDF Products also publishes Web Notes, which are short papers covering topics of general interest to DF users. These Web Notes are written in an easy-to-read format for users more focused on the practical (rather than theoretical) aspects of radio direction finding technology. Where more technical discussion is required, it is presented in plain language with an absolute minimum of supporting mathematics. Web Notes and Application Notes are distributed on the RDF Products Publications CD and can also be conveniently downloaded from the RDF Products website at www.rdfproducts.com.

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## SECTION I - INTRODUCTION AND EXECUTIVE SUMMARY

This Application Note discusses the various considerations involved in defining and measuring bearing accuracy of mobile Adcock radio direction finding (DF) antennas and systems. Since bearing accuracy is of paramount interest to most users, specific procedures are discussed that allow technically qualified users to conduct their own measurements so as to be able to independently verify DF equipment performance. To further facilitate the employment of these procedures, easy-to-use menu driven software is provided in order to assist users in the collection and analysis of measurement data.

DF vendors frequently cloak information regarding DF antenna bearing accuracy measurement procedures under an aura of mystery and arcane technical jargon, the implication being that such measurements can be properly conducted only with the resources and technical expertise of the vendor. Tests conducted by users producing results that appear to be inconsistent with equipment performance specifications are often challenged on the basis of procedural errors, non-ideal sites, non-calibrated test equipment, and various other factors. In some cases, users might even suspect that the real policy driving such challenges is to obfuscate the issue so as to prevent users from objectively and independently verifying performance specifications.

Although DF antenna bearing accuracy measurements do require a certain level of technical expertise and access to specialized test equipment and other material resources in addition to a certain amount of care and patience, we believe that a policy of obfuscation does not well serve the interests of either the user or the vendor. We thus hope, by means of this Application Note, to provide information that will be helpful to technical users wishing to conduct their own testing programs.

# SECTION II - DF BEARING MEASUREMENT CONCEPTS AND DEFINITIONS

## A. SITE ACCURACY VERSUS INSTRUMENT ACCURACY

Instrument accuracy refers to the inherent accuracy of the DF equipment itself, taking into consideration all error contributions of the hardware and any associated software. Instrument accuracy specifically excludes errors related to the site or induced by multi-path reception. Instrument accuracy is therefore implicitly specified under ideal siting conditions.

As most users are aware, bearing accuracy obtainable in an actual operating environment is significantly worse than that obtained on an ideal site. Although users quite understandably are most interested in DF system bearing accuracy in the actual operating environment, the vendor seldom can replicate such conditions. In addition, the various environmental factors that may degrade DF bearing accuracy are generally beyond the control of the vendor. In the interests of feasibility and objectivity then, vendors cannot realistically be expected to account for ill-defined variables beyond their control, and therefore specify their DF systems in terms of instrument accuracy.

## B. THE IDEAL SITE

An ideal site is one that is infinitely large, perfectly flat, perfectly conducting, and with no objects present that can cause reflections. In addition, the illuminating wavefront is such that it presents a uniform amplitude and phase front to the DF antenna under test, with matching polarization.

Since such an ideal site is only a hypothetical construct that can never be fully realized. Since actual DF antenna testing must be done on practical non-ideal test sites, real-world testing can provide only an estimate of DF system bearing accuracy. Even so, by employing proper procedures and exercising appropriate care, excellent bearing data with accuracy approaching that attainable on an ideal site can be obtained on practical sites that can be constructed with modest effort.

## C. DF BEARING ACCURACY FIGURES-OF-MERIT

### 1. OVERVIEW

The three primary DF bearing accuracy figures-of-merit that have been used in the industry are maximum peak error, average error, and RMS error. These errors are discussed below, followed by a sample bearing accuracy tabulation in Table I where all of these bearing accuracy figures-of-merit are computed and compared.

## 2. PEAK ERROR

Peak error is found by taking bearings at some specified number of azimuthal intervals at a specified frequency and then using the largest measured error as the bearing accuracy figure-of-merit of the antenna at that frequency. If this procedure is then repeated at other frequencies of interest, the worst-case peak error is used as the overall figure-of-merit.

Peak error as a bearing accuracy figure-of-merit has the disadvantage that as the number of measurement samples is increased (i.e., as the number of test azimuths and test frequencies is increased), the peak error can only get larger. This is statistically "unclean" from the standpoint that with a proper sampling technique, a reasonable observer would expect that a larger number of samples should result in a converging bearing accuracy estimate. Since peak error as a bearing accuracy figure-of-merit instead results in a diverging estimate, it is not widely used.

## 3. AVERAGE ERROR

Average error is found by taking bearings at some specified number of azimuthal intervals at a particular frequency, summing the magnitude (absolute value) of each error and then dividing this sum by the number of intervals. If this procedure is repeated at other frequencies of interest, a composite average can then be computed simply by adding up the average error for each frequency and then dividing this number by the total number of test frequencies. Although average error is convergent (unlike peak error as discussed above) it is also not widely used as a bearing accuracy figure-of-merit. Average error can never exceed peak error and is nearly always much less in magnitude.

## 4. RMS ERROR

RMS (root mean square) error is the bearing accuracy figure-of-merit that is most widely used in the radio direction finding industry. Computationally, it is found by taking bearings at some specified number of azimuthal intervals at a particular frequency, squaring the errors at each azimuth, summing these squared errors, dividing this quantity by the number of intervals, and then taking the square root of this result. Since this process is less straightforward than the computation of peak or average error, it is demonstrated in the sample bearing accuracy tabulation presented in Table I below, along with peak, average, and bias error for comparison.

Table 1 - Sample Bearing Accuracy Tabulation

| True Azimuth | Measured Bearing | Bearing Error | Error Squared |
|---|---|---|---|
| 000.0 | 000.0 | 0 | 0 |
| 022.5 | 020.5 | -2 | 4 |
| 045.0 | 042.0 | -3 | 9 |
| 067.5 | 065.5 | -2 | 4 |
| 090.0 | 091.0 | +1 | 1 |
| 112.5 | 113.5 | +1 | 1 |
| 135.0 | 138.0 | +3 | 9 |
| 157.5 | 159.5 | +2 | 4 |
| 180.0 | 180.0 | 0 | 0 |
| 202.5 | 203.5 | +1 | 1 |
| 225.0 | 224.0 | -1 | 1 |
| 247.5 | 244.5 | -3 | 9 |
| 270.0 | 268.0 | -2 | 4 |
| 292.5 | 293.5 | +1 | 1 |
| 315.0 | 317.0 | +4 | 16 |
| 337.5 | 339.5 | +4 | 16 |

Sum of squared errors - 0+4+9+4+1+1+9+4+0+1+1+9+4+1+16+16 = 80

Mean of squared errors - 80/16 = 5.0

* Square root of mean of squared errors (RMS error) - 2.24°

* Peak error - 4° (determined by inspection)

* Average error - (0+2+3+2+1+1+3+2+0+1+1+3+2+1+4+4)/16 = 1.88°

Bias error - (0-2-3-2+1+1+3+2+0+1-1-3-2+1+4+4)/16 = 0.25°

Asterisk (*) denotes DF bearing accuracy figures-of-merit for comparison

RMS error can thus be seen to be a weighted average, where larger errors are weighted more heavily (due to the squaring process) than smaller errors. Although RMS error can be as low as average error (when all the error magnitudes are the same), in the general case it is greater than average error. In the example above, the average error is 1.88 degrees as compared to the 2.24 degree RMS error. Like average error, RMS error is generally much less in magnitude than peak error.

Because of its wide acceptance as an industry standard and its statistical correctness, all RDF Products radio direction finding equipment bearing accuracy is specified in terms of RMS bearing error.

## D. BIAS ERROR AND MULTI-PATH RECEPTION

### 1. DEFINITION

Although bias error cannot be properly categorized as an independent bearing accuracy figure-of-merit, it is a bearing measurement concept that is extremely important and relevant regardless of the measurement technique selected. Bias error can be thought of as an offset error that can (in principle) be eliminated simply by physically rotating the DF antenna appropriately so as to cancel the error. As an example, if a DF antenna exhibits a 1 degree bias error at a particular test frequency, this error can be eliminated by the simple expedient of appropriately rotating the antenna 1 degree so as to compensate for the bias error. Once this mechanical re-alignment has been accomplished, a retest will confirm that the bias error has been eliminated (although any other errors will still be present).

### 2. CAUSES

Bias errors in general can either be instrument-related or induced by multi-path reception. Instrument-related bias error is normally frequency insensitive, while bias error induced by reflections tends to be highly frequency sensitive. This author has had the opportunity to study this issue very thoroughly. In the course of this study, this author wrote the computer program ANTERR1 that mathematically models all essential components of a 4-aerial Adcock DF system (as implemented by RDF Products) that allows various error mechanisms to be modeled so as to ascertain their effects on bearing accuracy.

Fundamentally, bearing errors in an Adcock DF antenna are induced by phase and gain imbalances caused by the circuitry that subsequently processes the signals received from the four aerials. Although post-antenna signal processing in the DF receiver and bearing processor can similarly induce bearing errors, the associated error mechanisms are mathematically equivalent for modeling purposes to those occurring in the DF antenna (that is they can ultimately be attributed to equivalent phase and gain imbalances occurring in the DF antenna). For analytical purposes then, there is thus no loss in generality then by lumping these DF receiver and bearing processor errors into the DF antenna and assuming ideal (error-free) performance in the DF receiver and bearing processor. In reality, this dispensation is actually a realistic reflection of well-designed DF systems where the DF antenna is the system component responsible for the overwhelming preponderance of bearing errors.

Adcock DF antennas also have an inherent “spacing” error. Spacing error occurs as a result of a distortion in the horizontal gain pattern of Adcock aerial pairs as the distance between the Adcock aerials increases. Although the resulting bearing error is negligible for aerial spacing under 1/8 wavelength, it becomes noticeable at 1/4 wavelength and very serious at 1/2 wavelength. The bearing error computations of ANTERR1 include the effects of spacing error.

To use ANTERR1, voltage gains and phase offsets are assigned to each of the four Adcock aerials (input data lines 1-8 - see sample run print-out in Table II below). In an ideal Adcock, the gains would all be identical and there would be no phase offsets. On input data line 9, the array aperture (diagonal spacing between the N and S or E and W aerials) is entered in terms of electrical degrees at the operating frequency. Finally, the step azimuth is entered on input data line 10. The program then computes the bearing error first for a test azimuth of zero degrees, advances the test azimuth by the step azimuth and computes the bearing error at this new test azimuth, and repeats this process until the test azimuth has been stepped through 360 degrees. In the sample run below, the bearing error is computed at 360 azimuths at 1 degree intervals.

Once the error computations have been completed, ANTERR1 then outputs various statistics that define antenna bearing accuracy, including peak, RMS, and bias error. Again referring to Table II below, note that despite the fact that significant phase and gain imbalances are present that result in significant RMS bearing error, *there is no bias error whatsoever*. In fact, after exhaustively running ANTERR1 using a large number of gain and phase input combinations, *no combination of gain and phase inputs were ever found that resulted in bias error*.

The implications of this remarkable result are extremely important. Specifically, the apparent absence of any mechanism by which bias errors can occur implies that *any apparent bias errors that result in the course of DF antenna testing must be caused either by procedural shortcomings or multi-path reception*. As will be seen later in this Application Note, this is very fortunate, as it offers a straightforward means by which the multi-path errors induced by typical test sites can be readily purged from the test results by the simple expedient of zeroing out the bias error. In effect, we can computationally "rotate" the DF antenna slightly as discussed above to offset the effects of multi-path reception, *thus allowing an estimate of bearing accuracy that is virtually uncontaminated by multi-path effects*. Note than in general, a different offset will be required at each test frequency, since multi-path-induced bearing errors tend to be highly frequency sensitive.

Table II - ANTERR1 Sample Run Print-Out

```
                  *** ANTERR1 INPUT DATA ***

 1) NORTH ANTENNA VOLTAGE GAIN                         .95
 2) NORTH ANTENNA PHASE OFFSET, DEGREES                5
 3) SOUTH ANTENNA VOLTAGE GAIN                         1.05
 4) SOUTH ANTENNA PHASE OFFSET, DEGREES                -5
 5) EAST ANTENNA VOLTAGE GAIN                          .9
 6) EAST ANTENNA PHASE OFFSET, DEGREES                 0
 7) WEST ANTENNA VOLTAGE GAIN                          .95
 8) WEST ANTENNA PHASE OFFSET, DEGREES                 10
 9) ARRAY APERTURE, DEGREES                            90
10) STEP AZIMUTH, DEGREES                              1

                  *** ANTERR1 OUTPUT DATA ***

 1) PEAK POSITIVE BEARING ERROR, DEGREES               +8.3
 2) PEAK NEGATIVE BEARING ERROR, DEGREES              -12.2
 3) BIAS ERROR                                         +0.0
 4) RMS BEARING ERROR, DEGREES                          6.8
```

## 3. SUMMARY AND CONCLUSION

To succinctly summarize this discussion then, RDF Products radio direction finding equipment has been designed in such a fashion that bias errors do not appear, as confirmed by extensive computer modeling and actual system testing. As a consequence, since such bias errors are non-instrument related, they can be attributed either to procedural error or multi-path reception. By taking the necessary precautions to eliminate procedural error, bias error can then be fully attributed to multi-path reception. By then ferreting out such bias error from the test results, an excellent estimate can be made of DF system bearing accuracy even on non-ideal sites. (In a subsequent Section, software will be introduced that allows the user to easily accomplish this).

As a final note to this discussion, bias errors can appear in DF equipment built by most other manufacturers. In most cases, nearly all of this bias error is caused by the DF receiver/bearing processor. If this bias error is stable (which is not always the case), the above discussion is still valid. In such cases, the instrument bias error would first have to be measured and accounted for prior to conducting the outdoor system test. Once the instrument bias error has been established, any additional bias error that appears in the outdoor system test can then be attributed to multi-path reception as discussed above.

# SECTION III - DF BEARING ACCURACY GENERAL TEST REQUIREMENTS

## A. STATIONARY DF ANTENNA VERSUS STATIONARY TEST TRANSMITTER

When conducting outdoor DF bearing accuracy tests, the user can employ either a stationary test transmitter and rotate the DF antenna, or alternatively revolve the test transmitter around a stationary DF antenna. Both methods offer certain advantages and impose certain drawbacks.

The primary advantage of rotating the DF antenna while maintaining a stationary test transmitter is that this maintains a nearly constant reflection environment and allows multi-path error to manifest itself as bias error which can then be ferreted out (as discussed at length in Section II-D above). A secondary advantage of this approach is that no time-consuming surveying is required to stake out the necessary test azimuth locations. Finally, far less open real estate is required. The only disadvantage of this approach is that the DF antenna being tested must be placed on a calibrated turntable which must be carefully constructed both for azimuthal accuracy and to maintain good grounding of the DF antenna chassis.

The primary advantage of walking the test transmitter around a stationary DF antenna is that no unusual difficulties are encountered in maintaining good grounding of the DF antenna chassis (since the DF antenna need not be mounted atop a turn-table). The primary disadvantage of this approach is that moving the test transmitter around the DF antenna changes the dynamics of the reflection environment and does not allow multi-path error to manifest itself as bias error which can then be ferreted out. For this reason alone, we do not recommend this approach unless a very good site is available.

In light of the compelling advantages of rotating the DF antenna while maintaining a stationary test transmitter, this preferred technique will be assumed during the remainder of this Application Note.

## B. REQUIRED NUMBER OF TEST AZIMUTHS

During the course of this author's extensive study of the effects of multi-path reception on DF bearing accuracy, the surprising fact emerged that when conducting bearing accuracy tests, it is not necessary to employ a large number of test azimuths. This contention is easily confirmed by running ANTERR1 to compute bearing error as discussed in Section II-D above. For this simulation, although input data was kept the same as that presented in Table II, the number of test azimuths was varied so as to ascertain the resulting effect on bearing accuracy. The output results are summarized in Table III below, using 360, 72, 36, 16, 30, and 6 test azimuths (corresponding to test azimuth increments of 1, 5, 10, 22.5, 30, and 60 degrees, respectively).

Table III - Effect Of Number Of Test Azimuths On Bearing Accuracy

| # OF TEST AZIMUTHS | 360 | 72 | 36 | 16 | 12 | 6 |
|---|---|---|---|---|---|---|
| 1) PEAK POS ERROR | 8.3 | 8.2 | 8.2 | 8.1 | 7.6 | 7.2 |
| 2) PEAK NEG ERROR | 12.2 | 12.2 | 12.1 | 12.1 | 12.0 | 12.0 |
| 3) BIAS ERROR | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4) RMS ERROR | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 7.0 |

As the results tabulated in Table III clearly indicate, a large number of test azimuths is not required to obtain an accurate estimate of RMS bearing error. After a large number of such simulations using ANTERR1 as well as a great deal of field experience, we have standardized our field test procedures and software using a 16-azimuth antenna rotation (22.5 degree increments). Using 16 azimuths provides a more than adequate number of samples (as indicated in Table III above) while not imposing an undue test burden.

## C. REQUIRED NUMBER OF TEST FREQUENCIES

Although there are no rigid rules dictating a specific number of test frequencies, there are some general guidelines that can be helpful in making this determination. These guidelines are discussed below.

For wideband DF antennas, eight test frequencies per octave are usually more than adequate. Ideally, these frequencies should be separated by a constant percentage factor (approximately 10.5% for eight test frequencies per octave. For a DF antenna with a low-end test frequency of 100 MHz for example, the next test frequency would then be 100 x 1.105 = 110.5 MHz, followed by 110.5 x 1.105 = 122.1 MHz, etc. In practice, it is not necessary that they be spaced with such precision, a dispensation that allows selection of specific frequencies of interest, or other frequencies that might somehow be convenient for test purposes. It is important, however, that test frequencies at or very near the specified upper and lower band limits of the DF antenna be included.

For narrowband DF antennas (those having bandwidths of 20% or less), a minimum of three test frequencies should be employed; one each at or near the upper and lower band limits and the third near the center frequency. One exception to this guideline is for a DF antenna designed to work at a single specific frequency, where testing at the single frequency is sufficient. The other exception is for a wideband DF antenna that has effectively been converted into a narrowband DF antenna by the use of a narrow output filter. In this case, testing at only one or two frequencies is acceptable.

With some DF antenna designs, performance can be compromised in specific narrow frequency ranges as a consequence of certain engineering design trade-offs that may have been necessary. One example of this is for a monopole DF antenna that is elevated on a mast or tripod. When the antenna is removed from the ground, plane, the mast or tripod effectively becomes part of the DF antenna, with the result that performance can be degraded, specifically at frequencies where the mast or tripod is resonant. Another example of this is in a multiband DF antenna where monopoles are used to cover one frequency range and loops another. It frequently happens that loop resonances occur that result in compromise performance at certain frequencies covered by the monopoles.

Since the vendor is sometimes reluctant to reveal such design trade-offs to customers, it is important that the customer carefully examine the DF antenna and conduct tests at any specific frequencies where performance might be suspect.

## D. REQUIRED DISTANCE BETWEEN TEST TRANSMITTER AND DF ANTENNA

There are two conflicting requirements to consider when setting the distance between the test transmitter and the DF antenna. On the one hand, it is desirable that this distance be as great as possible so as to ensure that the DF antenna is illuminated by a far-field wavefront presenting a nearly uniform phase and amplitude front. On the other hand, it is also desirable that this distance be as close as possible so that the received field strength of the direct ray from the test transmitter be as large as possible in comparison to any indirect (multi-path) rays. The first requirement is imposed to minimize "near-field" bearing errors (bearing errors induced as a consequence of the DF antenna being illuminated by a wavefront presenting a non-uniform phase and amplitude front). The second requirement is imposed to minimize bearing errors caused by multi-path reception.

The near-field versus far-field issue is illustrated in simplified pictorial form in Figure 1 below. The vertical rod represents the vertically-polarized monopole antenna that would ordinarily be employed as the test transmitter antenna. Even though the electric lines of force emanating from the rod ultimately become vertically-polarized in the far-field, this process is incomplete in the near-field. Note that the electric lines of force (illustrated by the arcs in Figure 1) are actually horizontal as they leave the rod, arcing into a more vertical orientation as they strike the ground. As the distance from the rod increases, these lines become progressively more vertical, until finally at some distance, the lines become so nearly vertical as to have negligible horizontal components. The distance at which the far-field begins is thus defined as that distance at which the horizontal component is truly negligible. The definition of "negligible" in turn depends upon the application.

Using one rule-of-thumb, the far-field is said to begin at a distance of 10 wavelengths from the source. (The wavelength in meters is computed by dividing 300 by the frequency in MHz. As a case in point the wavelength for 100 MHz is 3 meters.) This is an extremely conservative standard that would result in an unnecessarily large (and inconvenient) separation between the test transmitter and DF antenna. Such a large separation would also make the DF antenna more susceptible to reflections.

At the other end of the spectrum, the FCC (Federal Communications Commission) frequently employs a 1-meter test site in the VHF/UHF range. Although this results in sufficient accuracy for EMI testing (the FCC's primary concern), it is too close for most DF antenna testing.

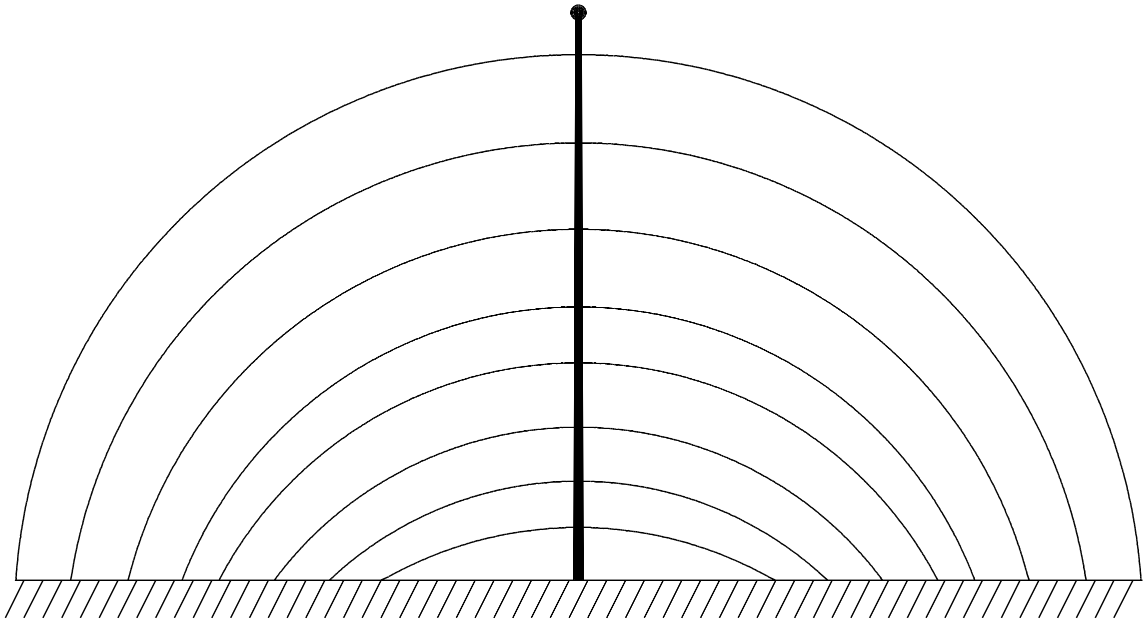

Figure 1 – Representation Of Electric Lines Of Force Near A Vertical Monopole

On the basis of our experience, we recommend that the distance between the test transmitter and the DF antenna be no less than 5 times the DF antenna aperture (i.e., the distance between the N and S or E and W aerials). If the site is very "clean" (free from obstructions that can result in multi-path reception), this distance can be increased, if desired, but there is no benefit to making this distance more than three wavelengths at the lowest rated operating frequency of the DF antenna under test.

In light of the discussion in Section II-D regarding the process by which multi-path error manifests itself as a bias error which can then be legitimately ferreted out, the reader may question our continuing implorations to mitigate factors that can induce multi-path error. Ideally, we should be able to ignore multi-path errors, being confident that we can conveniently eliminate them by purging the resulting bias error with a suitable software tool. Practically, however, the process appears to be imperfect, with decreasing effectiveness as the magnitude of multi-path error increases. The reason for this is not completely clear, although a possible explanation is that the rotation of the DF antenna itself causes small site perturbations that alter the dynamics of the reflection environment. It is therefore still important to conduct bearing accuracy tests in a fashion that minimizes multi-path reception.

## E. TEST TRANSMITTER REQUIREMENTS

Ordinarily, the best choice for a test transmitter is a standard RF signal generator capable of covering the frequency range of interest. A synthesized RF signal generator with programmable memory channels is particularly convenient, as it allows the user to rapidly change test frequencies. The selected RF signal generator should have a wide-range variable RF output attenuator.

Bearing accuracy tests should be conducted using an unmodulated (CW) signal. Although most DF techniques have vulnerabilities to certain types of modulation on the received signal, the resulting ill-effects manifest themselves as bearing *jitter* (which can be mitigated through temporal averaging) rather than bearing error. Although users may have a legitimate interest in ascertaining the effects of such modulation, these effects should be investigated separately. In fact, these effects can be much more conveniently studied using indoor testing techniques.

Since it is most convenient to locate the RF signal generator at the operator's console, it will be necessary to connect the RF signal generator output to the test transmitter antenna using a length of coaxial cable. It is important that this cable be sufficiently well shielded so as to minimize cable radiation. We strongly recommend a double-shielded premium coaxial cable such as RG-223.

Sometimes, a battery-operated "comb frequency" generator is used in lieu of a standard RF signal generator for the test transmitter. This comb generator consists of a lower frequency crystal oscillator (typically 5 or 10 MHz) that's output is then passed through a harmonic generator so as to produce a large number of harmonically related frequencies throughout the frequency band of interest. These harmonics are then used as the test frequencies. The comb generator is usually physically integrated with both the battery and the test transmitter antenna for maximum convenience. Although the comb generator does offer some convenience, it sacrifices important flexibility in that it does not allow the transmitter output level to adjusted or the transmitter frequency to be moved slightly as may be required to avoid interference.

## F. TEST TRANSMITTER ANTENNA

The fundamental requirement of the test transmitter antenna is that it generate a vertically-polarized wavefront. It is not necessary that the antenna be particularly efficient, present a low VSWR to the test transmitter, or otherwise be elaborate or elegant. Although a suitable antenna can be purchased, it can also be easily constructed using readily available materials.

If the antenna is to be user-constructed, a vertical monopole is particularly straightforward and easy to build. Such a unit should be built on a square aluminum chassis approximately 12" x 12" and no greater than 1" high. A TNC or BNC female chassis connector (that will accept the aerial) should then be mounted at the center point of the top surface. RG-223 coaxial cable should then be connected to the other end of this connector (on the underside of the top surface) and run through an exit hole drilled at the center of either of the four chassis sidewalls (see Figures 2 and 3 below). Aerials that are tuned to a specific frequency range (typically via base or center loading) should be avoided.

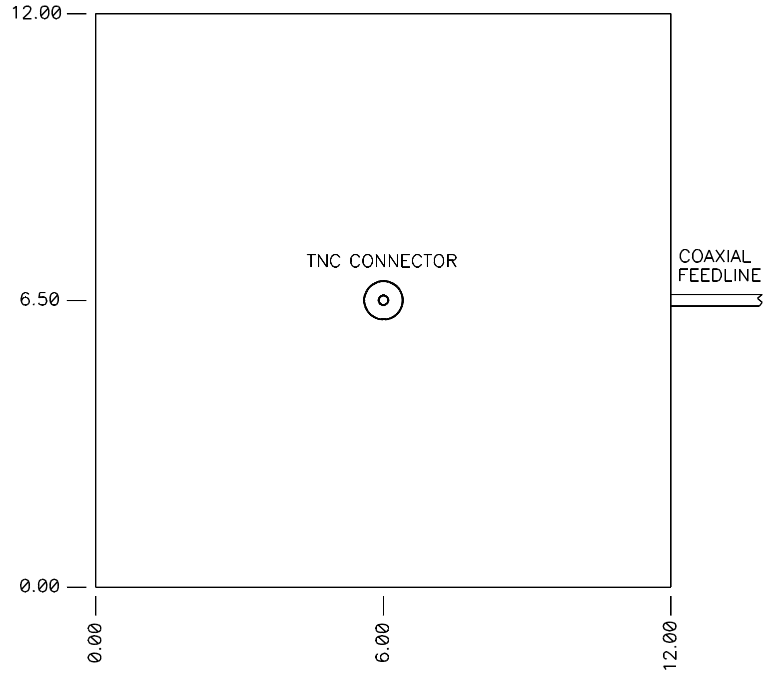


Figure 2 – Test Transmitter Antenna, Top View

The chassis sidewalls should have bare-metal horizontal base flanges so that the chassis can make good electrical contact with the ground plane. It is not important whether these flanges protrude inward or outward.

The aerial itself can be a spare DF antenna aerial if one is available and has an appropriate connector (usually TNC). Alternatively, suitable connectorized aerials can also be readily obtained from two-way radio retail outlets (these aerials are sold as replacement whip antennas for the mobile radio market). Telescoping versions are particularly convenient, as they allow convenient length adjustment.

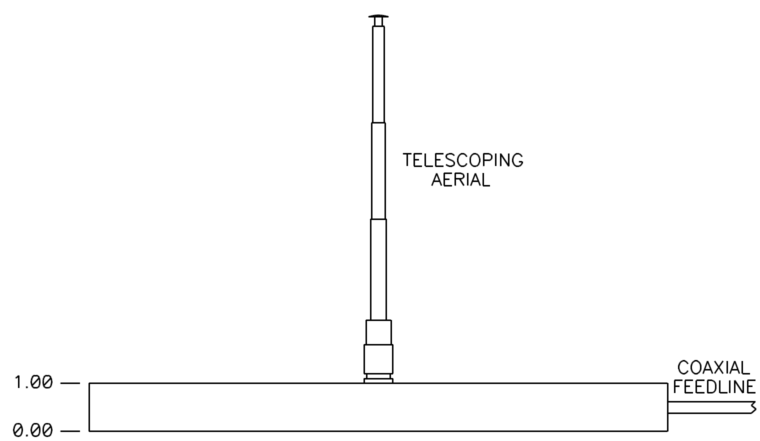


Figure 3 – Test Transmitter Antenna, Profile View

The actual length of the test transmitter aerial is not critical. On the one hand, it should be long enough to provide reasonably efficient operation in the frequency range of interest, as this reduces potential measurement errors induced by signal generator and coaxial cable leakage. On the other hand, the aerial should not be greater than 5/8 wavelength at the highest test frequency so as to avoid pattern elevation. Also, some caution is in order if the aerial height is ½ wavelength since the very high resulting feedpoint impedance can cause erratic results.

## G. DF ANTENNA TURNTABLE

A calibrated turntable is necessary to provide a convenient means of precisely rotating the DF antenna through the required 16 test azimuths. The primary requirements for this turntable are mechanical accuracy and good electrical connection to the underlying ground screen (the details of this ground screen are discussed in Section III-H below).

A suitable turntable can be constructed with modest effort. First, procure a 48" x 48" base plate of unpainted aluminum. This base plate should be at least 3/32" thick for rigidity. Next, procure a 36" diameter 3/32" thick circular plate of unpainted aluminum. This circular plate should be obtained from a machine shop where the center can be precisely established and the 16 azimuth calibration marks accurately engraved along the perimeter. Next, drill small pilot holes through the centers of both plates so that the circular plate can be secured to the topside of the baseplate. Thread the hole in the baseplate using a #8 tap, and install a 3/16" #8 machine screw from the underside. The circular plate can then be mounted atop the base plate using the protruding #8 screw as a pivot.

Finally, use the baseplate of the DF antenna to be tested as a template to draw an outline on the circular plate so that the DF antenna can be precisely centered atop the plate during test. Duck tape can then be used to temporarily secure the DF antenna to the circular plate during test. The fixture is illustrated in Figure 4 below.

## H. GROUND SCREEN REQUIREMENTS

It is very important that the DF antenna (and to a lesser extent the test transmitter antenna) be placed on a conductive ground screen in order to augment the normally poor and non-uniform conductivity that is characteristic of most soil. An excellent material for this ground screen is so-called "hardware cloth".

Hardware cloth consists of meshed galvanized wire and is available typically in 3' or 4' wide rolls from most building supply stores. All wire junctions are welded for good conductive continuity. Hardware cloth with a 1/4" mesh is particularly well suited for ground screen applications.

Hardware cloth should not be confused with "chicken wire", which does not have welded junctions and has a coarser mesh. Although other materials can be substituted for hardware cloth, it is important that the selected material have a fine mesh and exhibit good conductive continuity.

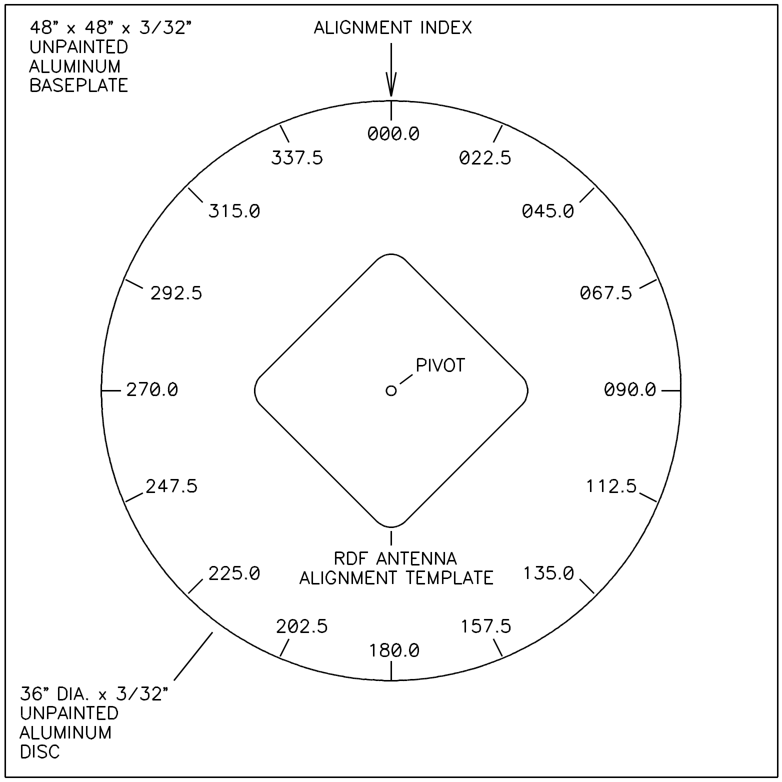


Figure 4 – RDF Antenna Turntable And Baseplate

The DF antenna ground screen should be laid down in a square configuration centered on the desired location of the turntable. Each side of the square should be at least 10 times the effective radiating height of the tallest aerial employed by the DF antenna (assuming a monopole), but in no case less than a half wavelength at the lowest test frequency.

The test transmitter antenna ground screen should be the same size as the DF antenna ground screen, centered on the desired location of the test transmitter. If the two ground screens do not overlap, a "runway" should be constructed using a 3' or 4' wide length of hardware cloth to join the two ground screens. This runway should be centered on a line connecting the center points of the two ground screens.

Figure 5 illustrates a ground screen layout that would be suitable for testing the RDF Products DMA-1315B1 80-520 MHz Mobile Adcock DF antenna. It is important that both the turntable and test transmitter antenna be mounted so that they make good electrical contact with their respective ground screens.

## I. MISCELLANEOUS SITE PREPARATION ISSUES

The site should be as flat as possible, and any tall grass or other vegetation should be cleared. The ground screen in particular should be laid down flat. Notice in Figure 5 how the operator's console is positioned as far as possible behind the test transmitter antenna directly

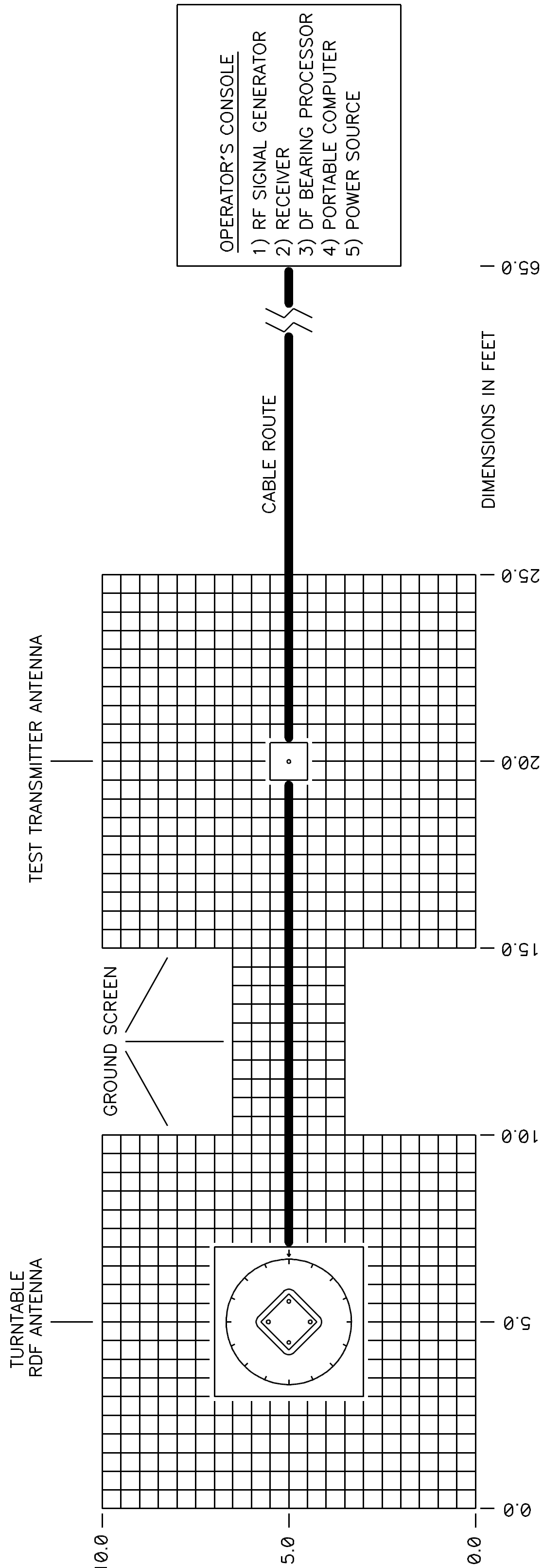


Figure 5 – Recommended Bearing Accuracy Test Site For DTI DMA–1315 RDF Antenna

in line with the DF antenna. This positioning minimizes bearing errors caused by reflections from the operator's console. The operator's console should be organized such that it is as low and narrow as possible. A typical two-man operator's console consists of two folding chairs and a small table, with all the equipment on or underneath the table. If a portable generator is employed as a power source, it should be positioned as far as possible behind the operator's console (directly in line with the cable route).

Ideally, the operator's console would be in a trench so as to be completely out of sight of the test transmitter and DF antenna. Since it is very inconvenient to dig such a large trench, an acceptable and more practical alternative is to place the operator's console as far as possible behind the test transmitter as illustrated in Figure 5.

It is important that the DF antenna and test transmitter cables be routed as illustrated in Figure 5 ("cable route"). These cables must also be kept flat to the ground to avoid causing perturbations to the test transmitter wavefront that might result in bearing errors. Nylon cable ties offer a convenient means by which the cables can be secured to the ground screen.

## J. ELEVATED TEST SITE

An elevated test site offers the advantage that the operator's console and operating personnel can be located *below* the test platform and thus not be a source of reflections. Similarly, nearby vegetation and other obstacles can also be eliminated as reflection sources provided that they do not extend above the height of the test platform. Finally, the test platform can be made very flat for best antenna site characteristics. For these reasons, elevated test sites are highly desirable.

On the down side, construction of a good quality elevated test site is very expensive and time consuming. Furthermore, elevated test sites need to be quite large, since the ground screen is not augmented by earth ground (as is the case when the test site is constructed on the ground). Finally, ongoing maintenance is usually necessary to keep the test platform level and for periodic repainting. For these reasons, elevated test sites are impractical for most users (and even for most DF equipment vendors, for that matter).

Despite these difficulties, RDF Products constructed an elevated test site in the Arizona desert. The test platform is 20' x 60', and is mounted approximately 7' off the ground as illustrated in Figures 6 and 7 below. This elevated test site provides outstanding performance for all DF antenna tests and measurements. RDF Products has also constructed a ground level test site in Vancouver, Washington, with equally good results.

## K. BEARING DISPLAY ACCURACY, RESOLUTION, AND AVERAGING

In order to obtain the degree of bearing display accuracy and resolution required for DF antenna bearing accuracy testing, it is necessary for the DF receiver/bearing processor to

Figure 6 - Elevated DF Antenna Test Site (full view)

Figure 7 - Elevated DF Antenna Test Site (end view)

provide a high-resolution numeric display or remote data output. (Analog displays do not provide the required bearing accuracy or resolution.) All RDF Products DF recdeivers/processors include an RS-232 data output that allows bearings to be conveniently displayed on a PC. When used with DefCon2b (the supplied Windows user-interface program), user-selectable bearing resolutions of 0.1, 0.2, 0.5, or 1.0 degrees are available. For best test results, maximum resolution (0.1 degree) is desirable. Although RDF Products DF equipment is sufficiently stable to allow 0.1 degree resolution, site environmental factors associated with outdoor field testing (such as wind and moving objects) may prevent stable bearings from being obtained with such fine resolution.

0.1 degree bearing resolution should be employed during the DF receiver/bearing processor calibration procedure discussed in Section IV-A below (since site environmental factors are not an issue). On the other hand, it may be more convenient to employ 0.5 degree resolution when conducting the outdoor field test.

For the calibration procedure, DefCon2b should be set to one of its slow Mode/DF Response (e.g., FM/Slow, CW/Slow, etc.). This same setting is usually suitable for the outdoor field test as well.

# SECTION IV - DF BEARING ACCURACY TESTING

## A. DF RECEIVER/BEARING PROCESSOR CALIBRATION

Although the DF antenna is nearly always the dominant source of bearing error in a DF system, it is always good practice to account for the bearing error contribution of the DF receiver/processor prior to conducting the outdoor DF antenna bearing accuracy test. This procedure allows the user to determine DF antenna bearing error independently of any bearing errors contributed by the DF receiver/bearing processor.

By way of brief summary, this calibration process is accomplished by employing an antenna simulator that replicates a nearly ideal (error-free) DF antenna. The output of this antenna simulator is then applied to the DF receiver/bearing processor. Bearings are then recorded in succession for each of the 16 standard test azimuths. These recorded bearings are then entered as the ADJUSTED AZIMUTHS in the computer program ANTDATA1. A sample ANTDATA1 DF Antenna Bearing Error Analysis And Outdoor Field Test Report is presented in the Appendix.

When the DF antenna is then substituted for the antenna simulator and the outdoor field test conducted, the resulting bearings are similarly recorded in succession for each of the 16 test azimuths (rotating the DF antenna with the turntable) and entered as MEASURED BEARINGS in ANTDATA1. ANTDATA1 then computes and displays the bearing error contributed by the DF antenna only.

This antenna simulator that replicates the ideal DF antenna is the DTI-100B DF Bearing Synthesizer in conjunction with an RF signal generator. The test setup is illustrated in Figure 8 below.

The RF signal generator external amplitude modulation should be set for 30% with the DTI-100B AZIMUTH selector set at zero degrees. Signal generator output amplitude should be set for a moderate receiver signal strength indication (typically -60 dBm). The DF receiver/bearing processor settings should be as discussed in Section III-K above. The DF receiver/bearing processor IF bandwidth should be 15 kHz. The DF receiver/bearing processor settings should not be changed for the subsequent outdoor DF antenna bearing accuracy test. Refer to the DTI-100B Operator's Manual for more details regarding this test setup.

For best results, both the RF signal generator and receiver should be synthesized (or otherwise frequency-locked) for good frequency stability. The calibration procedure may be conducted at any frequency within the capabilities of both the signal generator and receiver.

If the user wishes to compute the bearing error of the DF receiver/bearing processor alone, the same procedure as discussed above should be employed. In this case, however, no adjustments are made to the reference azimuths in ANTDATA1 and the recorded bearings are entered as the MEASURED BEARINGS. The resulting bearing error computations will then be for the DF receiver/bearing processor combination alone.

Finally, if the user is interested only in an overall DF system bearing accuracy test and does not need to know the error contributions of the individual system components, the above calibration procedure can be omitted altogether. In this case, no adjustments are made to the reference azimuths (that is, the ADJUSTED AZIMUTHS are set equal to the TRUE AZIMUTHS in ANTDATA1) and the recorded bearings from the outdoor DF antenna bearing accuracy test are entered as the MEASURED BEARINGS.

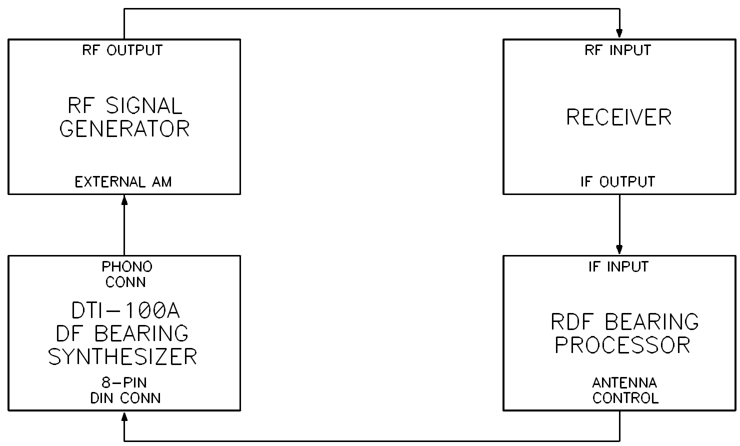


Figure 8 - Calibration Test Setup, Receiver/DF Bearing Processor with DTI-100B and RF Signal Generator

## B. DF ANTENNA OUTDOOR BEARING ACCURACY TEST PROCEDURE

Once the site has been prepared and the DF receiver/bearing processor calibrated as discussed above, the DF antenna outdoor bearing accuracy test can be conducted using the following procedure:

1. Mount the DF antenna atop the turntable. The turntable should be oriented so that the alignment index is at 0 degrees with the DF antenna positioned so that the N and S aerials are precisely in line with the test transmitter antenna (N aerial closest to test transmitter antenna). The DF antenna should be precisely centered on the turntable to avoid eccentric rotation (this process is greatly simplified if an alignment template has been drawn as recommended in Section III-G above). Firmly secure the DF antenna to the turntable using duck tape or other suitable means.

2. Set the RF signal generator and receiver to the lowest test frequency and set the generator for a CW output amplitude that results in a moderate receiver signal strength indication. With an ICOM R8500, for example, the signal generator output amplitude should be such that the S meter reads between S9 and 20 dB over S9. Be sure that the DF processor IF bandwidth and bearing integration time are the same as that employed during the calibration procedure discussed in Section IV-A above.

3. Record the measured bearing for the lowest test frequency.

4. Repeat steps (2) and (3) above for the next test frequency. Repeat this process until

measured bearings have been recorded for all test frequencies. Caution: Be sure to readjust the RF signal generator output amplitude as required to maintain a moderate receiver signal strength indication as discussed in step (2) above.

5. Rotate the turntable to the next test azimuth and repeat steps (2)-(4) above.

6. Repeat step (5) above for the remaining 14 test azimuths.

## C. DATA ANALYSIS

### 1. ANTDATA1

All necessary bearing error data analysis at any given test frequency is performed by ANTDATA1. It is necessary only for the user to enter the measured bearings (recorded as discussed in Section IV-B above) and let the program perform the computations and display the results.

Bearings recorded from the calibration procedure presented in Section IV-A above should be entered as ADJUSTED AZIMUTHS, after which the measured bearings can be entered. Although new measured bearings must be entered for each test frequency, the ADJUSTED AZIMUTHS need not be re-entered since the DF receiver/bearing processor calibration procedure is frequency independent.

A sample test report is presented in the Appendix for measured bearings recorded at a specific frequency. In addition to listing all input data, the report provides the desired error statistics in addition to a graphical presentation of the adjusted RMS bearing error. Refer to this sample report to facilitate the following explanation of its terminology:

TRUE AZIMUTH - The actual physical azimuth of the position of the test transmitter relative to the N-S axis of the DF antenna.

ADJUSTED AZIMUTH - The bearings obtained from the DF receiver/bearing processor when driven by the error-free antenna simulator. These bearings facilitate calibration of the DF receiver/bearing processor so that the bearing accuracy of the DF antenna can be computed independently of any bearing errors that might be imposed by the DF receiver/bearing processor. The ADJUSTED AZIMUTH is the same as the TRUE AZIMUTH if the calibration process is omitted, or if no bearing errors are found in the DF receiver/bearing processor.

MEASURED BEARING - The actual bearing recorded by the operator during the course of a test as displayed on the DF receiver/bearing processor display.

APPARENT ERROR - The bearing error of the MEASURED BEARING with respect to the ADJUSTED AZIMUTH (MEASURED BEARING minus ADJUSTED AZIMUTH).

ADJUSTED ERROR - The result of subtracting the BIAS ERROR from the APPARENT ERROR. ADJUSTED ERROR is thus APPARENT ERROR after it has been corrected by removing the BIAS ERROR (BIAS ERROR is assumed to be an offset error caused by multi-path - refer to discussion in Section II-D above.)

BIAS ERROR - A constant offset error assumed to occur as a result of multi-path reception - refer to discussion in Section II-D above).

APPARENT RMS ERROR - The root mean square error computed from the 16 APPARENT ERROR values at a given test frequency. APPARENT RMS ERROR includes the effect of BIAS ERROR, and is equal to ADJUSTED RMS ERROR if there is no BIAS ERROR.

ADJUSTED RMS ERROR - The root mean square error computed from the 16 ADJUSTED ERROR values at a given test frequency. ADJUSTED RMS ERROR is equivalent to APPARENT RMS ERROR after the APPARENT RMS ERROR has had its BIAS ERROR component removed. If there is no bias error, ADJUSTED RMS ERROR and APPARENT RMS ERROR are equal. ADJUSTED RMS ERROR is the final bearing error figure-of-merit used for DF antenna bearing accuracy evaluation at the given test frequency.

2. ANTDATA2

Once the APPARENT RMS ERROR has been computed for each test frequency, the COMPOSITE ADJUSTED RMS ERROR for the DF antenna being tested can be computed using ANTDATA2. ANTDATA2 prompts the user for the test frequency and corresponding ADJUSTED RMS ERROR (computed at each test frequency by ANTDATA1 as discussed above).

ANTDATA2 then computes the COMPOSITE ADJUSTED RMS ERROR for the DF antenna and generates a graph of ADJUSTED RMS ERROR as a function of the test frequency. COMPOSITE ADJUSTED RMS ERROR is determined by computing the root mean square error for all of the entered ADJUSTED RMS ERROR results using the same technique outlined in Table I.

A sample ANTDATA2 DF Antenna Bearing Accuracy Test Summary Report is presented in the Appendix. This report, along with the DF Antenna Bearing Error Analysis And Outdoor Field Test Report generated for each test frequency by ANTDATA1 can then be retained as a permanent and complete record of the DF antenna bearing accuracy test.

## D. USER SOFTWARE

For the user's convenience, the DOS programs ANTDATA1, ANTDATA2, and DFDATA are provided on RDF Products' Literature & Software CD. This CD is available from any RDF Products sales representative or directly from RDF Products. The executable DOS files are ANTDATA1.EXE, ANTDATA2.EXE, and DFDATA.EXE, respectively. DefCon2b (the DFP-1000B/DFP-1010B Windows user-interface software) is also supplied on this CD.

## E. TROUBLESHOOTING

### 1. OVERVIEW

During DF antenna bearing accuracy testing, anomalous results sometimes occur. Although such results may in fact be truly indicative of poor DF antenna performance, it is also possible that the problem may be site related or procedural. Troubleshooting techniques that are often effective in diagnosing such problems are discussed below.

### 2. MULTI-PATH RECEPTION

As already discussed at great length, multi-path reception can result in bearing errors. Although such errors usually manifest themselves as bias errors as discussed in Section II-D that can subsequently be ferreted out with ANTDATA1, the process is less effective as the magnitude of the multi-path error increases.

A good test to determine the presence of multi-path reception is to move the test transmitter antenna along the cable route line (see Figure 5) to see if the measured bearing changes with distance from the DF antenna. Note that such repositioning must be done carefully so as not to alter the true azimuth. Any change in the measured bearing is an indication of multi-path reception.

The best remedy is to determine the cause of the reflection and then either remove it or relocate the site. A more convenient alternative is to reposition the test transmitter antenna as discussed above to a point where the bearing error is eliminated (or at least greatly reduced) and then re-run the test at that frequency.

Sometimes, a multi-path-induced bearing error at a particular frequency can be caused by the presence of the operators or the equipment. A good test for this is for one of the operators to stand up and move around slightly to see if this has any effect on the measured bearing. The work table should also be moved around slightly as well. If multi-path reception is suspected, the operator's position should be moved farther back from the test transmitter.

It should be kept in mind that multi-path-induced bearing errors in general are highly frequency sensitive, even to the extent that they might be very severe at one test frequency and almost non-existent at the next test frequency.

### 3. CABLE AND GROUND SCREEN POSITIONING

Bearing errors can occur if the ground screen is not flat, and if the various cables are not similarly kept flat (by securing them to the ground screen). The DF antenna cables are particularly prone to this problem as they leave the antenna, since it is sometimes inconvenient to keep these cables flat while simultaneously accommodating the rotation of the turntable.

It is thus very important to expend whatever effort is necessary to keep the ground screen and cables flat, particularly between the turntable and the transmit antenna.

As is the case for multi-path-induced bearing errors, bearing errors induced by protruding cables and rolling ground screens are frequency sensitive.

## 4. POOR ANTENNA/TURNTABLE GROUNDING

If the DF antenna or turntable is not well-grounded to the ground screen, the DF antenna cable effectively becomes part of the DF antenna. This results in pattern distortion which in turn causes bearing errors.

If the turntable is constructed as illustrated in Figure 4, it will be properly grounded to the ground screen. If the turntable has been elevated, however (most likely to accommodate a "lazy Susan" or other rotator), or non-metallic materials are employed, grounding is far more likely to be inadequate.

Since most mobile Adcock antennas are designed to be mounted atop vehicles, a foam pad is placed on the underside of the DF antenna baseplate to prevent the vehicle top from being marred. Grounding is thus established through the relatively large capacitance present between the DF antenna baseplate and the metallic vehicle top. Sometimes, this capacitance can interact in complex ways with the cables that result in a parallel-resonant circuit between the baseplate and the vehicle top (or ground screen when the antenna is being field tested). This results in very erratic performance over a narrow frequency range.

If such a cable resonance is suspected, a good test is to change cable lengths to see if the symptoms disappear (actually, the symptoms just move to a different frequency).

A more general solution is to directly ground the DF antenna to the turntable rather than relying upon capacitive coupling. All RDF Products mobile Adcock DF antennas with flanged baseplates have mounting holes along the baseplate flange that are cleared of paint (exposing bare metal), thus making it easy to ground the baseplate.

## 5. INTERFERENCE

Bearing errors will result if interfering signals are present on the test frequency. Since such interference can usually be heard (via the receiver audio output), it is good practice to audibly monitor the test frequency. When interference is heard, the test frequency can simply be moved slightly so as to avoid it.

## 6. CABLE LEAKAGE

Since the test transmitter signal cable and the DF antenna output cable lie close together over a considerable distance, imperfect coaxial cable shielding can result in signal leakage between the test transmitter signal cable and the DF antenna RF output cable. Since such leakage effectively bypasses the DF antenna, erratic performance can result.

A simple way to test for such undesired cable leakage is to temporarily remove the test transmitter aerial from the test transmitter chassis and verify that the signal strength (as indicated on the receiver S meter) drops by at least 40 dB. (For the purpose of this test, the receiver S meter can be calibrated with the RF signal generator.) This test should be conducted at several test frequencies throughout the band of interest.

The undesirable effects of cable leakage can be reduced by increasing the separation between the two cables. In more difficult cases, it may be necessary to employ a line amplifier at the test transmit antenna and/or the DF antenna output.

## APPENDIX

This Appendix presents the following sample output reports of the various computer programs discussed in this Application Note:

1. ANTDATA1 - DF Antenna Bearing Error Analysis And Outdoor Field Test Report (provides bearing accuracy statistics for a 16-azimuth DF antenna outdoor field test at a single frequency).

2. ANTDATA2 - DF Antenna Bearing Accuracy Test Summary Report (accepts adjusted RMS bearing error data computed at each test frequency by ANTDATA1 and computes overall adjusted RMS bearing error).

For the user's additional benefit, a worksheet form (titled DF Antenna Bearing Accuracy Measurement Worksheet) is provided that enables the user to conveniently record data taken during testing. Copies of this form can be made as required. This form can also be printed from ANTDATA1.

**** DF ANTENNA BEARING ERROR ANALYSIS AND OUTDOOR FIELD TEST REPORT ****

UNIT: DMA-1315R0 SER#: 94DAE227 FREQ: 160 MHZ
DATE: 10-08-1994 TEST: 8 ENGR: P. F. SCHULTZ
NOTE:

| TRUE AZIMUTH | ADJUSTED AZMUTH | MEASURED BEARING | APPARENT ERR | ADJUSTED ERR |
|---|---|---|---|---|
| 0 | 0 | 0 | +0.0 | -0.1 |
| 22.5 | 22.7 | 23 | +0.3 | +0.2 |
| 45 | 45.1 | 46.5 | +1.4 | +1.3 |
| 67.5 | 67.3 | 69.5 | +2.2 | +2.1 |
| 90 | 90.1 | 89.5 | -0.6 | -0.7 |
| 112.5 | 112.2 | 110 | -2.2 | -2.3 |
| 135 | 134.9 | 133.5 | -1.4 | -1.5 |
| 157.5 | 157.8 | 158.5 | +0.7 | +0.6 |
| 180 | 180.1 | 182 | +1.9 | +1.8 |
| 202.5 | 202.4 | 204.5 | +2.1 | +2.0 |
| 225 | 224.9 | 224 | -0.9 | -1.0 |
| 247.5 | 247.4 | 245 | -2.4 | -2.5 |
| 270 | 270 | 269 | -1.0 | -1.1 |
| 292.5 | 292.3 | 294.5 | +2.2 | +2.1 |
| 315 | 315.1 | 316.5 | +1.4 | +1.3 |
| 337.5 | 337.8 | 335 | -2.8 | -2.9 |

```
  -15       -10       -5        0        +5       +10       +15
   +----+----+----+----+----+----+----+----+----+----+----+----+
   |                             |                             |     R
000|    -    -    -    -    -    *    -    -    -    -    -    |000  E
   |                             *                             |     F
045|    -    -    -    -    -    |  * -    -    -    -    -    |045  E
   |                             |   *                         |     R
090|    -    -    -    -    -   *|    -    -    -    -    -    |090  E
   |                        *    |                             |     N
135|    -    -    -    -    - *  |    -    -    -    -    -    |135  C
   |                             |*                            |     E
180|    -    -    -    -    -    |   *-    -    -    -    -    |180
   |                             |   *                         |     A
225|    -    -    -    -    -  * |    -    -    -    -    -    |225  Z
   |                        *    |                             |     I
270|    -    -    -    -    -  * |    -    -    -    -    -    |270  M
   |                             |   *                         |     U
315|    -    -    -    -    -    |  * -    -    -    -    -    |315  T
   |                       *     |                             |     H
   +----+----+----+----+----+----+----+----+----+----+----+----+
  -15       -10       -5        0        +5       +10       +15
                           ADJUSTED ERROR
```

PEAK POS ADJUSTED ERROR= +2.1
PEAK NEG ADJUSTED ERROR= -2.9
BIAS OR MEAN ERROR= +0.1
APPARENT RMS ERROR= 1.7
ADJUSTED RMS ERROR= 1.7

RF PRODUCTS - SAN DIEGO CA

## ** DF ANTENNA BEARING ACCURACY TEST SUMMARY REPORT **

**DF ANTENNA MODEL:** DMA-1315R0 (VHF SECTION)
**SERIAL NUMBER:** 94DAE227
**TEST DATE:** 10-08-1994
**TEST ENGINEER:** P. F. SCHULTZ

| TEST NUMBER | TEST FREQ (MHz) | ADJUSTED RMS ERROR (DEGS) |
|---|---|---|
| 1 | 80.000 | 4.6 |
| 2 | 88.000 | 3.9 |
| 3 | 98.000 | 2.4 |
| 4 | 108.000 | 1.4 |
| 5 | 118.000 | 1.9 |
| 6 | 128.000 | 1.6 |
| 7 | 138.000 | 2.5 |
| 8 | 148.000 | 1.7 |
| 9 | 160.000 | 1.7 |
| 10 | 174.000 | 2.2 |
| 11 | 188.000 | 2.0 |
| 12 | 204.000 | 1.9 |
| 13 | 220.000 | 2.3 |
| 14 | 245.000 | 2.0 |
| 15 | 270.000 | 2.7 |

*** COMPOSITE ADJUSTED RMS BEARING ERROR = 2.5 DEGREE(S) ***

```
      +----+----+----+----+----+----+----+----+----+----+    0.0
R     |                                                 |
M     |                                                 |
S     |      *     *    *  *                            |
      |         *              *  *    *         *      |
      +    *    -    *    -    -    -    - *  -    -    *    2.5
      |                                                 |
      |                                                 |
E     | *                                               |
R     *                                                 |
R     +    -    -    -    -    -    -    -    -    -    +    5.0
O     |                                                 |
R     |                                                 |
      |                                                 |
      |                                                 |
      +    -    -    -    -    -    -    -    -    -    +    7.5
D     |                                                 |
E     |                                                 |
G     |                                                 |
S     |                                                 |
      +----+----+----+----+----+----+----+----+----+----+   10.0
    80.000   118.000   156.000   194.000   232.000   270.000
                         FREQUENCY (MHz)
```

RF PRODUCTS - SAN DIEGO CA

## DF ANTENNA BEARING ACCURACY MEASUREMENT WORKSHEET

ANTENNA MODEL #: S/N:
TEST DATE: TEST #:
TEST CONDITIONS:

| TRUE AZMTH | ADJ AZMTH | MEASURED BEARINGS AT FOLLOWING FREQUENCIES, MHz | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 000.0 | | | | | | | | | |
| 022.5 | | | | | | | | | |
| 045.0 | | | | | | | | | |
| 067.5 | | | | | | | | | |
| 090.0 | | | | | | | | | |
| 112.5 | | | | | | | | | |
| 135.0 | | | | | | | | | |
| 157.5 | | | | | | | | | |
| 180.0 | | | | | | | | | |
| 202.5 | | | | | | | | | |
| 225.0 | | | | | | | | | |
| 247.5 | | | | | | | | | |
| 270.0 | | | | | | | | | |
| 292.5 | | | | | | | | | |
| 315.0 | | | | | | | | | |
| 337.5 | | | | | | | | | |
| Peak + error | | | | | | | | | |
| Peak - error | | | | | | | | | |
| Bias error | | | | | | | | | |
| RMS error | | | | | | | | | |

Test Engineer: ________________________ Page___of___

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