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AN-005

Application Note

AN INTRODUCTION TO DIPOLE ADCOCK FIXED-SITE DF ANTENNAS

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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 the design, selection, application, and deployment of fixed-site dipole Adcock VHF/UHF radio direction finding (DF) antennas. Similarities and differences between these dipole Adcocks and their monopole Adcock mobile counterparts are also discussed. To facilitate ease of reading and to ensure that this Application Note is written at a technical level that is comfortable to the majority of readers, a bare minimum of DF antenna and system theory is presented, with the primary focus of the discussion being at a more practical level.

Many readers may already be familiar with monopole Adcock DF antennas employed in mobile DF applications. These antennas are typically mounted atop cars or other land vehicles, as well as on the undersides of aircraft. As will be discussed in a subsequent Section, monopole Adcocks perform poorly when used in fixed-site mast-mounted applications, primarily as a result of the adverse effects of the mast and the finite elevated ground plane.

Dipole Adcocks are far more suitable for fixed-site (or transportable fixed-site) applications where the best possible bearing accuracy must be obtained. In order to obtain this desired accuracy, dipole Adcocks must be mounted atop tall masts so that performance is minimally affected by surrounding objects (including the operating console and personnel). Although the inherent nature of dipole Adcocks avoids or mitigates the above-mentioned difficulties associated with the use of elevated monopole Adcocks for fixed-site DF applications, *the presence of the mast introduces new performance anomalies that most manufacturers fail to address*. Although these anomalies are more subtle than the ones associated with monopole Adcocks, their effects can be very serious. *Furthermore, the severity of the resulting performance shortcomings is magnified by the fact that the user is generally unaware of the problems due to their subtle nature and the general unwillingness of manufacturers to reveal them.*

To briefly summarize what will be discussed in detail in a subsequent Section, the close proximity of the supporting mast to the Adcock aerials results in mast re-radiation that distorts the Adcock elevation gain patterns. This distortion in turn degrades DF bearing accuracy and sensitivity. This performance degradation is not only difficult to predict, but its severity greatly changes as a function of mast height.

The problem is most noticeable with wide frequency coverage DF antennas and most acutely manifests itself as frequency "holes" (frequency bands where severe performance degradation is experienced). In addition, these holes tend to shift in frequency when the mast height is changed or the antenna is installed at a different location. Furthermore, *these holes are actually just the extreme manifestation of the broader problem that some degree of performance degradation exists over all or most of the DF antenna's frequency range as a consequence of inadequate mast decoupling.* Users are often unaware of these problems, however, attributing them instead to site anomalies or the vagaries of radio direction finding in general. The problem is further compounded by the reluctance of most manufacturers to fully meet their duty of candor to customers to disclose this serious performance shortcoming (or perhaps more likely, their lack of understanding of this important issue).

As will be clearly illustrated in subsequent Sections, these problems actually result from a design deficiency that is overcome in RDF Products mast-mounted dipole Adcock DF antennas. All dipole Adcock DF antennas manufactured by RDF Products have been specifically designed so that the aerials are properly decoupled from the mast, thus eliminating the above mentioned mast-induced performance degradations. DF antenna performance is thus unaffected by the mast and there are no frequency holes.

Dipole Adcock DF antennas that are designed without the benefit of an effective mast decoupling structure are inherently inferior designs that yield marginal to poor performance. Manufacturers offering such designs are either unaware of these performance deficiencies or have chosen to ignore them in favor of a product design and manufacturing philosophy that subordinates legitimate user performance requirements to design and manufacturing expediency. In this context then, the primary purpose of this Application Note is to illuminate these important issues in plain language so that users are better equipped to make informed purchasing decisions so that they can obtain the best value for their purchasing dollars.

SECTION II - ADCOCK DF ANTENNA HISTORY

Radio direction finders built early in the 20th century took advantage of the bi-directional properties of loop antennas to ascertain the azimuth of received signals. Although these loop DF antennas were functional for ground-wave signals, they suffered serious performance degradation when receiving sky-wave signals having horizontally-polarized components (these horizontally-polarized components caused directional pattern distortion which in turn caused bearing errors). This was known as the "night effect" since these sky-wave signals appeared mostly at night on the relatively low frequencies employed in those early years. In fact, the resulting bearing errors were so serious that loop antenna DF systems were often useless at night.

In 1919, F. Adcock of Great Britain patented a new DF antenna that relied on two difference-phased vertical dipoles or monopoles (rather than loops) to obtain the necessary bi-directional characteristic (British Patent No. 130490). Since these Adcock aerial pairs employed vertical rods, they offered the ability to substantially reject the offending horizontally-polarized components of sky-wave signals and accept only the desired vertically-polarized component. This resulted in far less directional pattern distortion and therefore far better immunity to bearing errors in the presence of signals having horizontally-polarized components. The invention of the Adcock DF antenna was hailed as a great advance in the state of the art of radio direction finding technology, and became very widely used.

Although loop DF antennas are still used in some applications, they can only be justified in cases where the requirement for antenna compactness is so predominant that the inevitable serious performance sacrifices inherent with loops must be accepted. In mobile DF systems, the use of loop DF antennas is frequently justified below the VHF range, particularly where covertness is a requirement. A DF antenna design that employs loops where there is room for an Adcock should be avoided, since to employ loops under such circumstances results in serious and unnecessary performance trade-offs. This issue is discussed at length in Web Note WN-007 (Ref. 1, “Questions & Answers: A User’s Guide To Using Loop Versus Adcock Radio Direction Finding Antennas”). Well-designed DF systems in the VHF and UHF ranges avoid loop DF antennas.

Both Adcocks and loops are typically employed by DF systems employing the *Watson-Watt DF technique*. This technique, developed by Sir R. A. Watson-Watt of Great Britain back in the 1920's, is the DF technique employed by most RDF Products DF systems. The Watson-Watt DF technique has withstood the test of time and is arguably the most effective DF technique available for both mobile and narrow-aperture fixed-site DF applications from very low frequencies up into the UHF range.

SECTION III - WATSON-WATT DF SYSTEM SIMPLIFIED THEORY OF OPERATION

Although this Application Note is intentionally written to avoid burdening the reader with marginally relevant technical details, the reader can nonetheless benefit from a brief and simplified discussion of the theory of operation of the Watson-Watt DF technique (see Section II). The discussion in this Section covers only the technical issues required as a background to present the essential requirements of a Watson-Watt compatible DF antenna.

In the most general sense, all non-rotating radio direction finding systems employ a DF antenna having an array of spatially-displaced aerials (three or more are required for unambiguous operation) that are illuminated by the received signal wavefront. The resulting voltages produced by these aerials exhibit attributes (phase, amplitude, or both) that are then measured. Since these attributes are unique for every received azimuth in a properly designed DF antenna, the wavefront angle-of-arrival (bearing) can be unambiguously ascertained by appropriately processing and analyzing these aerial output voltages.

A single-channel Watson-Watt DF system (i.e., one that employs a single receiver) can be broken down into the following four basic functional blocks as illustrated in Figure 1 below:

1. DF Antenna
2. DF Receiver
3. DF Bearing Processor
4. DF Bearing Display

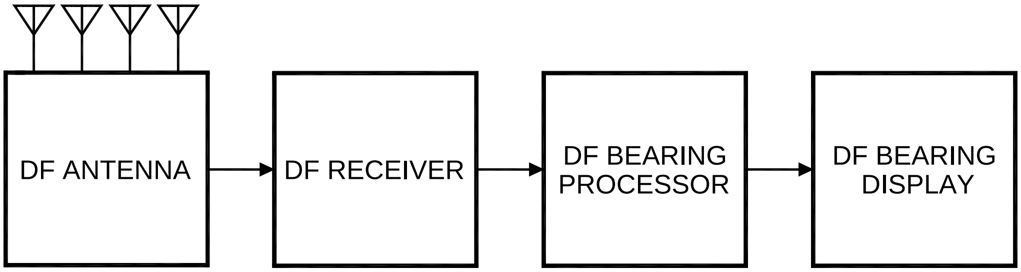

Figure 1 - Watson-Watt DF System Simplified Functional Block Diagram

Essentially, the DF antenna is illuminated by the incoming wavefront, appropriately processes the signal, and then feeds it to the DF receiver. The DF receiver further processes the signal, demodulates it, and then feeds it to the DF bearing processor. The DF bearing processor then processes the signal further still and converts it into a format suitable for driving the DF bearing display.

Before discussing the DF antenna, it might be helpful at this point to digress for a moment and discuss the concept of *antenna gain patterns*. An antenna gain pattern is nothing more than a graphical representation of the directional response of an antenna (or antenna array). As a simple example, a vertical dipole or monopole has an azimuthal gain pattern as illustrated in Figure 2. As can be seen, this pattern is omni-directional (in the horizontal plane), which is to say that the antenna responds equally well to signals from any azimuth (compass point).

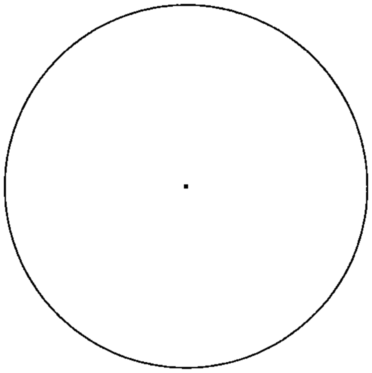

Figure 2 - Omni-directional Azimuthal Gain Patten Of Monopole Or Vertical Dipole

To understand the physical significance of the azimuthal gain pattern of Figure 2, imagine that a test transmitter must be walked around the omni-directional receiving antenna *in such a fashion that the indicated received signal strength at the antenna output terminals is always constant.* If the receiving antenna (i.e., the vertical dipole or monopole in this example) is truly omni-directional, the test transmitter would have to be walked in a perfect circle centered on this receiving antenna as illustrated in Figure 2.

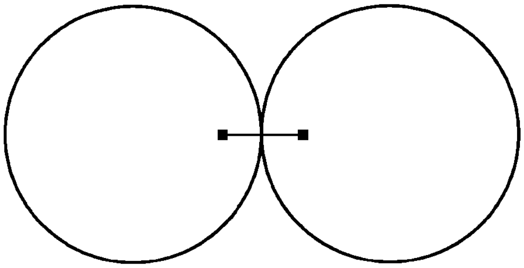

Figure 3 - Bi-directional Azimuthal Gain Pattern Of Adcock Aerial Pair

If two such omni-directional antennas are spatially displaced (separated) by a small fraction of a wavelength at the operating frequency and their outputs are *difference-phased* (i.e., the antenna output voltages are vectorially subtracted in a differencing network), a bi-directional azimuthal "figure-of-eight" gain pattern with circular lobes similar to those of Figure 3 results. Again, this pattern graphically represents the path that the test transmitter must be walked to maintain a constant received signal strength at the differencing network output. Notice that *nulls* (azimuths at which the difference-phased antennas produce greatly diminished or no output) appear broadside to the axis of the two antennas. This same pattern can also be obtained using an appropriately designed loop antenna.

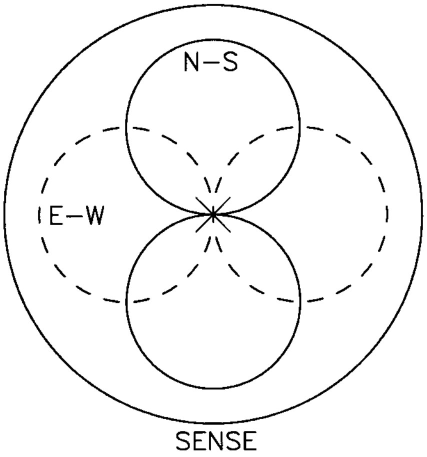

Figure 4 - Required Azimuthal Gain Patterns For A Watson-Watt DF System

A DF antenna suitable for use with a Watson-Watt DF system actually requires three separate but co-located antennas. Two of these are identical but orthogonally-oriented bi-directional antennas exhibiting the gain pattern of Figure 3. The third is a centrally-located omni-directional "sense" antenna exhibiting the gain pattern of Figure 2. Figure 4 is a combined illustration of all three gain patterns.

The sense antenna is required to resolve a 180 degree ambiguity that would otherwise result. In early Adcock designs, a *central* sense antenna was implemented using a single omni-directional antenna physically centered in the Adcock array. Most (but not all) modern Adcocks employ a *derived* sense antenna configuration whereby the required omni-directional sense gain pattern is derived by vectorially *summing* the output voltages of all four aerials.

Actual RDF Products mobile and fixed-site DF antennas are illustrated in Figures 5 and 6, respectively. Note that the mobile DF antenna of Figure 5 employs monopoles as aerials. This antenna must be mounted on a large metallic ground plane (e.g., a vehicle roof-top) for proper operation.

The dipole Adcock of Figure 6, in contrast, employs vertical dipoles rather than monopoles

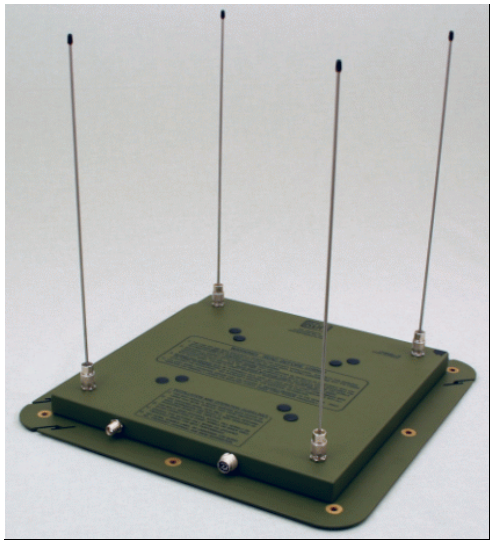

Figure 5 - **Mobile Adcock DF Antenna**

Figure 6 - **Mast-Mounted H-Dipole Adcock DF Antenna**

as aerials and thus requires no ground plane. This unit is designed to be mounted atop a mast.

Early Watson-Watt DF systems required three separate but very carefully matched receivers to process the three DF antenna outputs. Since this was expensive and it was operationally difficult to maintain the precise gain and phase matching among the three receivers necessary for good bearing accuracy, an antenna axis tone encoding (modulation) scheme was developed so that all three DF antenna outputs could be combined into a single composite signal that could be fed to a single receiver. Essentially, this is done by amplitude modulating the N-S axis bi-directional output with one tone and the E-W axis bi-directional output with another. The receiver then processes this composite signal in the standard fashion and recovers the two tones (whose respective amplitudes are now proportional to the two bi-directional antenna outputs) from its AM demodulator. These recovered tones are then fed to the DF bearing processor where they are separated and converted into proportional DC voltages, which in turn drive the bearing display.

Figure 7 - **DFP-1000B DF Bearing Processor/Display**

Analog bearing displays are typically two-phase devices such as a CRT (cathode ray tube) or magnetically controlled mechanical pointer. For a CRT display, these two DC voltages are “chopped” into voltage ramps that drive the CRT X and Y deflection amplifiers, resulting in a true real-time polar bearing display. For a mechanical pointer display, these two DC voltages drive the X and Y deflection coils.

Bearings can also be computed in software and then displayed in a variety of different formats. This is typically accomplished by first converting the X and Y DC voltages to a digital format using an analog-to-digital converter. The resulting digitized representation of these DC voltages is then fed to a microprocessor, which in turn computes the bearing in software using a 4-quadrant arc-tangent algorithm. Once the bearing has been computed, the microprocessor can then drive one or more of several different types of bearing displays, including azimuth rings, numeric displays, or even software emulations of analog bearing displays as is done in the RDF Products DFP-1000B DF processor/display illustrated in Figure 7. Figure 8 illustrates the main screen for the RDF Products' DefCon2b Windows-based user interface program supplied with all RDF Products DF receivers/processors.

For additional information regarding the Watson-Watt DF technique, see Web Note WN-002 (Ref. 2, "Basics Of The Watson-Watt DF Technique").

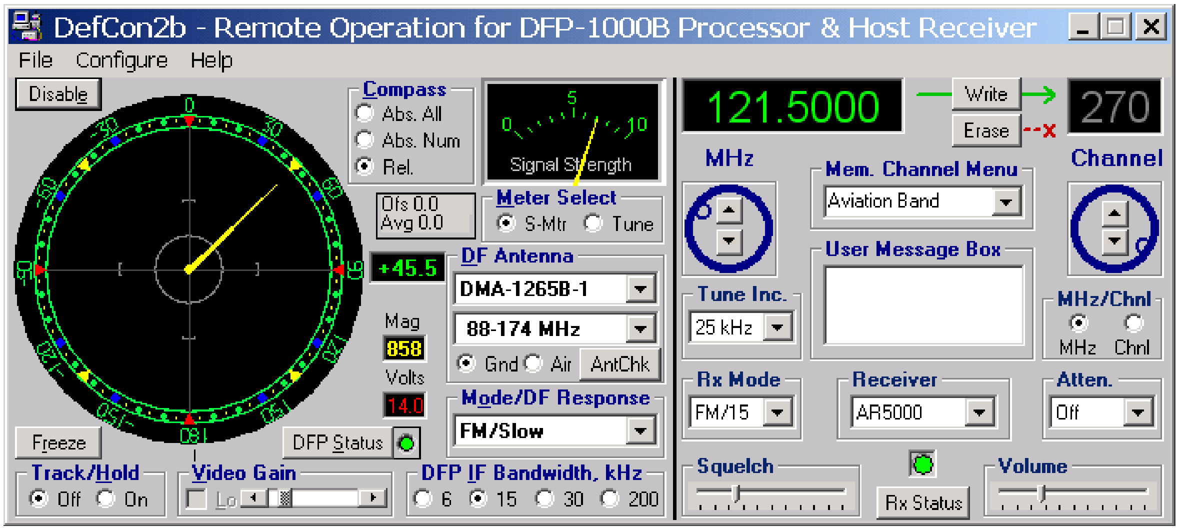

Figure 8 - **DefCon2b Main Screen**

SECTION IV - USING MOBILE DF ANTENNAS IN MAST-MOUNTED APPLICATIONS

A. INTRODUCTION AND OVERVIEW

Inquiries are frequently received by RDF Products from customers regarding the feasibility of employing mobile Adcock DF antennas (see Figure 5) for fixed-site applications by placing them atop masts or other high structures. Although this simple expedient may have a certain intuitive appeal (and in fact, some vendors actually attempt this), there are compelling technical reasons to avoid this practice.

When a monopole Adcock is mounted atop a tower or mast, serious performance anomalies occur that badly degrade performance. These anomalies include elevation gain pattern perturbations (which occur as a result of parasitic effects of the support mast) and also bearing errors induced by vulnerability to horizontal polarized signals (which occur as a result of the lack of an adequate ground plane). These issues are discussed in detail in the following paragraphs.

B. ELEVATION GAIN PATTERN PERTURBATIONS

An important attribute of antennas is their *elevation gain pattern*. The elevation gain pattern graphically represents the antenna gain over a prescribed range of elevation angles (at some specified azimuth). Again using a vertical dipole as an example, its elevation pattern (in free space) would appear as illustrated in Figure 9. Notice that the vertical dipole responds best to signals "on the horizon", with nulls directly above and below the dipole. For most DF and communications applications, best antenna gain is usually desired at or near zero degrees since most non-sky-wave signals are received at small positive or negative elevation angles (typically less than 30 degrees). A vertical dipole is thus well suited for DF applications. The elevation response of a vertical monopole working against an ideal infinite ground plane is the same as that of the vertical dipole, but with the

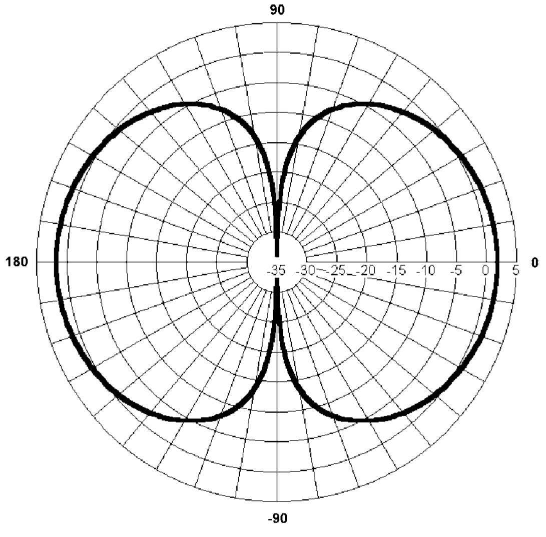

Figure 9 - **Vertical Dipole Elevation Response**

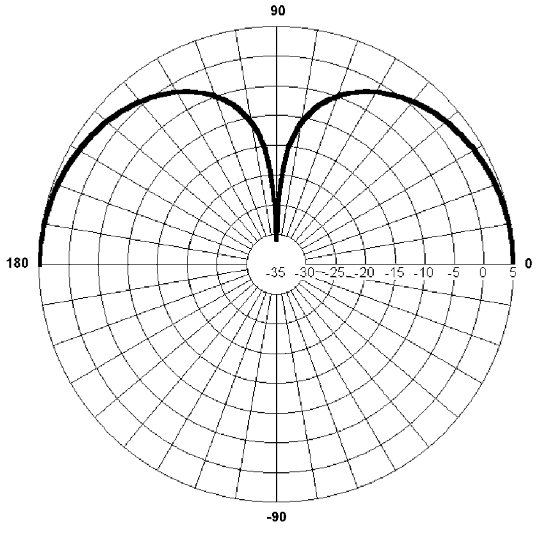

Figure 10 - **Monopole Elevation Response**

lower half of the pattern missing due to the presence of the ground plane as illustrated in Figure 10.

Various complications arise when monopoles are elevated and mounted atop finite ground planes. A very serious problem that arises is that the mast and feed cable become part of the antenna. In effect, the mast/feed cable combination act as the missing lower half of a vertical dipole. Since the mast/feed cable are very long, the net effect is to create an asymmetrical vertical dipole with characteristics much different than that of either the original ground plane monopole or a standard vertical dipole.

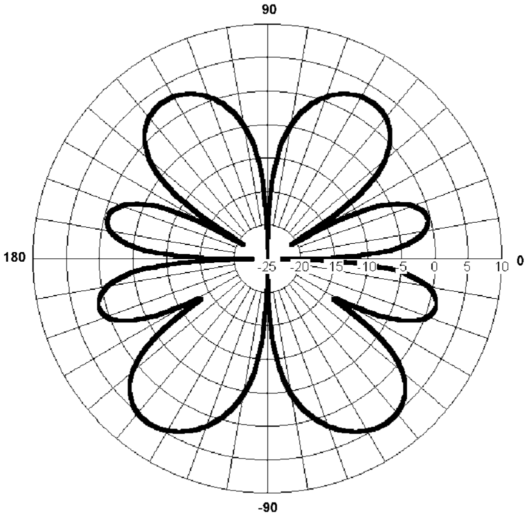

Figure 11 - Elevation Gain Pattern For 9" Monopole On 30" Dia. Metal Disc Elevated On 72" Metal Mast (345 MHz)

As an example, an ideal quarter-wave ground-mounted ground plane monopole would exhibit the elevation pattern of Figure 10 and would present a feedpoint impedance of 36 + j0 ohms at its resonant frequency. If this monopole was instead place atop and centered on a 30" diameter horizontally-oriented metal disc placed atop a 72" metal mast, the elevation pattern would be as illustrated in Figure 11.

Since an elevated ground plane monopole is really an alternative form of a vertical dipole, one would expect the elevation gain pattern to have lobes at negative as well as positive elevation angles (i.e., the elevated ground plane monopole is really a variation of a vertical dipole) and thus might expect an elevation pattern similar to that of Figure 9. The presence of the deep nulls in Figure 11, however, is caused by the presence of the long (72") mast. Note that one of these nulls occurs on the horizon (close to zero degrees elevation). The presence of this null would result in very poor antenna sensitivity for signals received at or near this elevation angle.

A further ill effect of the 72" mast would be its effect on the monopole feedpoint impedance. Rather than the normal 36 +j0 feedpoint impedance one would expect for an ideal ground-mounted monopole, the feedpoint impedance for the elevated monopole (at 345 MHz) would be 866-j1596 ohms. This would result in a severe mismatch loss (approximately 13 dB) that would seriously degrade sensitivity. An additional complication that would arise would be that the both the elevation pattern of Figure 11 and the feedpoint impedance would drastically change as a function of frequency and mast height. In short, this elevated monopole would yield both poor and inconsistent performance.

This may come as a surprise to many readers who might point out that large numbers of such elevated monopoles are widely employed in a broad range of radio communication services. Unfortunately, many of these function rather poorly. Although there is a very widely held perception that horizontal radials or a disc absorb all the missing lower-dipole current, thereby decoupling the elevated monopole from the mast/feed cable, this is incorrect. In the general case, significant amounts of antenna current flow down the mast/feed cable, thereby causing it to become part of the overall antenna and resulting in the afore-mentioned serious perturbations in the elevation pattern and feedpoint impedance. To obtain good performance for an elevated monopole, some means is required to decouple the monopole and its associated ground plane away from the mast/feed cable. Unfortunately, most designs do not address this issue.

Since a mobile DF antenna is typically just an array of monopoles, it is clear that elevating it on a mast (even in conjunction with an elevated ground plane of substantial size) is a certain prescription for generally poor and erratic performance for the reasons outlined above.

C. AZIMUTHAL GAIN PATTERN PERTURBATIONS

As mentioned, mobile Adcock DF antennas employ monopole aerials that must work against a sizeable ground plane. In practice, this means that the unit must be mounted directly atop a large metal surface (e.g., a vehicle roof-top) for good performance. When the ground plane is finite, distortion can occur to the desired bi-directional azimuthal gain pattern of Figure 3, resulting in bearing errors.

Succinctly stated, the problem is that undesired horizontally-polarized signal components induce currents in the horizontally-oriented finite ground plane that become part of the overall current at the monopole feedpoint. The net result is that the monopoles lose their ability to reject horizontally-polarized signal components (the premier feature of Adcock DF antennas). As it happens, *the azimuthal gain response for horizontally-polarized signals of two spaced monopoles configured as an Adcock aerial pair exhibits a peak at the azimuths where the response of this same Adcock aerial pair for vertically-polarized signals is a null*. This results in the nulls becoming “filled-in” when the incoming signal has both vertically- and horizontally-polarized components (the typical case), resulting in bearing errors.

To amplify on this, first consider a single vertical monopole aerial placed at the center of a circular elevated disc (i.e., a symmetrical finite ground plane). Although horizontally-polarized signal components induce currents in the ground plane, the symmetry of the ground plane with respect to the monopole causes these induced currents to cancel at the monopole feedpoint. The net result then is that the monopole does not respond to horizontally-polarized signals. (In fact, this antenna actually functions as a vertical dipole.) It is for this same reason that symmetrical capacitive hats placed atop vertical monopoles do not cause a susceptibility to horizontally-polarized signals.

If the vertical monopole aerial is moved away from the center of the circular disc, however, symmetry is lost. As a result, the currents induced into the disc by horizontally-polarized signal components no longer cancel at the monopole feedpoint. The monopole, even though vertically-oriented, now has a susceptibility to horizontally-polarized signal components that would not exist if the ground plane was symmetrical or very large.

The reader can confirm that although a 4-monopole Adcock DF antenna can be centered atop an elevated circular disc as a ground plane, *the four aerials individually are not symmetrical with respect to the disc and therefore are susceptible to ground plane currents induced by horizontally-polarized signals as a result.* To reduce this susceptibility to the point where it would not cause measurable bearing errors would require an impractically large ground plane.

Figure 12 is an azimuthal gain pattern illustrating the typical response of an Adcock aerial pair to horizontally-polarized signal components. Note that the two azimuths of peak response fall on the nulls of the ideal vertically-polarized bi-directional Adcock azimuthal gain pattern of Figure 3 for an Adcock aerial pair having the same orientation. When the received signal has both vertically- and horizontally-polarized components, this results in the nulls filling in as illustrated in Figure 13, thus causing bearing errors.

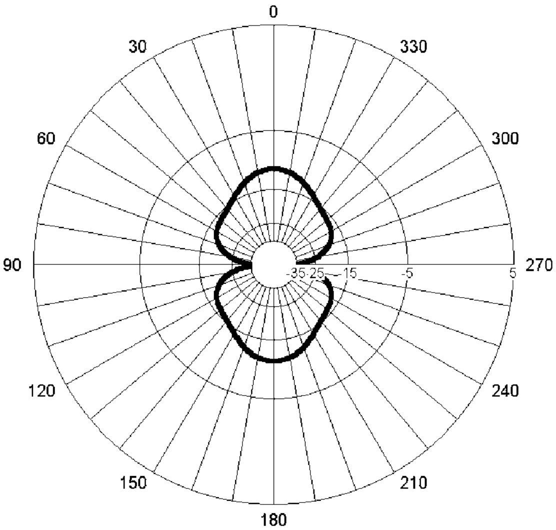

Figure 12 - Azimuthal Gain Response Of Monopole Adcock On Finite Ground PlaneTo Horizontally-Polarized Signal Components

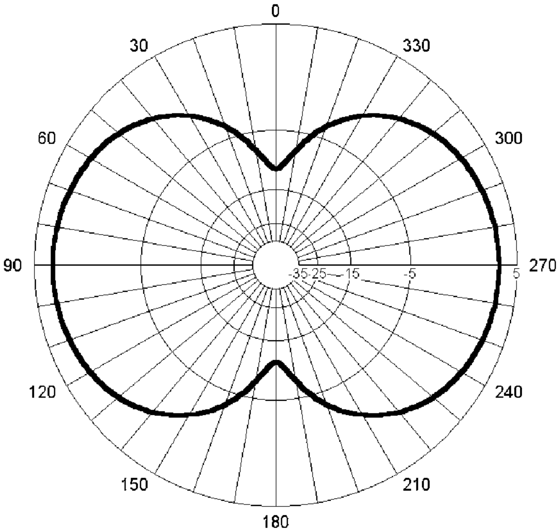

Figure 13 - Distortion To Monopole Adcock Bi-directional Azimuthal Gain Pattern Caused By Finite Ground Plane Response To Horizontally-Polarized Signal Components

D. SECTION IV SUMMARY

Mobile Adcock DF antennas in general are ill-suited for use in elevated fixed-site DF applications. Fundamentally, there are two very serious problems. First, the mast and feed cable become part of the antenna, causing the monopoles to become part of an asymmetrical vertical dipole, with the mast/feed cable effectively acting as the lower dipole half. The result is serious distortion to the elevation gain pattern and undesirable changes in the monopole feedpoint impedance, both resulting in diminished DF antenna performance.

Second, the finite ground plane used with the monopole causes susceptibility to horizontally-polarized signal components which in turn distorts the azimuthal gain patterns and causes bearing errors. To reduce these errors to acceptable levels would require the finite ground plane to be impractically large.

These problems are overcome by using mast-mounted dipole Adcocks for fixed-site DF applications as discussed in the following Section.

SECTION V - USING DIPOLE ADCOCKS FOR MAST-MOUNTED DF APPLICATIONS

A. DIPOLE ADCOCK INTRODUCTION

The fundamental requirement for each aerial of an Adcock aerial pair is that it be omni-directional in the horizontal plane. Although the aerials discussed so far have been vertically-oriented monopoles working against a ground plane, vertical dipoles also meet this fundamental requirement as well.

Vertical dipoles are physically awkward for mobile DF applications as a result of their height and the requirement for a support structure. An inspection of Figures 5 and 6 (which show a monopole and dipole Adcock side-by-side) clearly confirms this. This additional height is no disadvantage in a mast-mounted fixed-site DF application, however, where there is sufficient room both for the dipole Adcock and its supporting mast.

As the reader will recall from the previous Section, one of the two fundamental causes of the poor performance of elevated monopole Adcock DF antennas is their anomalous behavior that occurs as a result of the associated finite ground plane. Since dipole Adcocks do not require ground planes, this shortcoming is substantially eliminated. As a result, dipole Adcocks exhibit a virtually undiminished ability to reject horizontally-polarized signal components. (The reader will recall from the previous Section that susceptibility to such horizontally-polarized signal components causes azimuthal gain pattern distortion that in turn results in bearing errors.)

The other cause of poor elevated monopole performance that was discussed is the tendency of the supporting mast to become part of the antenna, in effect acting as the missing lower half of a vertical dipole. Although dipole Adcocks also have supporting masts, they are not directly connected to the vertical dipoles and therefore cause far less performance degradation. Since the mast is in the close vicinity of the vertical dipoles, however, its impact on performance is not negligible and must be addressed as will be discussed.

B. DIPOLE ADCOCK PERFORMANCE ADVANTAGES

Dipole Adcocks offer several advantages over ground-mounted monopole Adcocks. In most cases, the primary advantage is that the dipole Adcock can be mounted on a high mast that can elevate it above nearby local obstructions. This greatly reduces multi-path reception that would in turn result in bearing errors. Monopole Adcocks, in contrast, would need to be mounted in the middle of a very large, flat, unobstructed field to obtain similar results.

Another advantage of the dipole Adcock's elevation is that it can "see" much farther than a monopole Adcock, resulting in much greater reception range. In contrast, the line-of-sight distance of a ground-mounted monopole Adcock is far more limited due to its lower elevation.

A final advantage of the dipole Adcock is that it inherently has better sensitivity than a comparable monopole Adcock when receiving space waves with a local ground reflection or surface waves. This sensitivity advantage can be as high as 9 dB (Ref. 3).

C. DIPOLE ADCOCK PERFORMANCE DEGRADATION CAUSED BY THE HORIZONTAL SUPPORT BOOM ("BOOM EFFECT")

Dipole Adcock aerial pairs employ a horizontal support boom to mechanically connect the two vertical dipoles. A problem exists in that horizontally-polarized signal components induce currents along the boom that in turn cause re-radiation. Some of this re-radiated signal is then intercepted by the dipoles.

If the dipoles are well-balanced, the resulting induced voltages cancel and therefore have no effect. In practice, however, the dipoles may be imperfectly balanced, thus resulting in incomplete cancellation. Even if the dipoles are perfectly balanced, the presence of the vertical support mast (being closer to the lower dipole halves) results in an asymmetry that degrades this balance. The end result is that the dipole Adcock exhibits an undesired susceptibility to horizontally-polarized signal components that ultimately causes bearing errors.

The problem is compounded by the fact that the azimuths of maximum response to such horizontally-polarized signal components occur at the nulls of the desired vertically-polarized azimuthal gain pattern, thus having the effect of reducing the depth of these nulls. This tends to magnify the bearing errors.

Fortunately, the magnitude of the bearing error caused by this "boom effect" is usually very small. In most designs, the resulting overall increase in DF antenna bearing error is not noticeable. A far more serious performance degradation occurs as a result of the presence of the vertical support mast as discussed below.

D. DIPOLE ADCOCK PERFORMANCE DEGRADATION CAUSED BY THE VERTICAL SUPPORT MAST ("MAST EFFECT")

Very serious performance degradation can occur as a result of the presence of the dipole Adcock vertical support mast. Essentially, an incoming signal illuminating the vertical dipoles also unavoidably illuminates the mast as well. The resulting induced mast currents cause re-radiation from the mast. As a consequence, the vertical dipoles are illuminated by both the desired incoming signal as well as the re-radiated signal from the mast. The net result is that the elevation gain patterns of the vertical dipoles become distorted.

Figure 14 is the elevation gain pattern for the two summed dipole outputs (i.e., the sense output) of a vertical dipole Adcock aerial pair with no mast present (note that this gain pattern is identical to that of the single vertical dipole illustrated in Figure 9). Maximum gain is achieved "on the horizon" (i.e., at zero degrees elevation), with the gain very gradually and smoothly decreasing at progressively higher positive or negative elevation angles. This is a very favorable elevation gain pattern for most radio direction finding applications where most incoming signals arrive at small to moderate elevation angles.

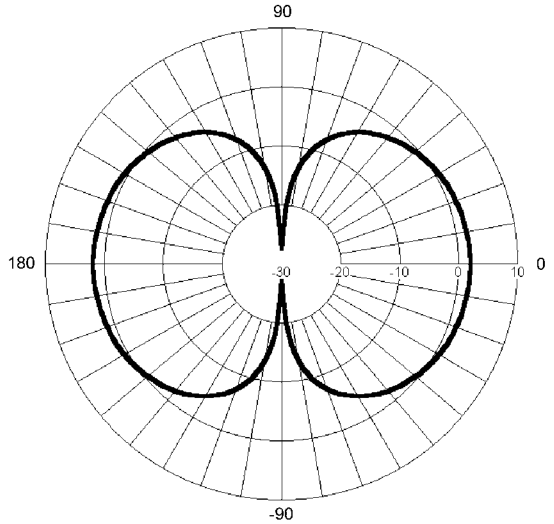

Figure 14 - Elevation Gain Pattern For Adcock Aerial Pair, No Mast (Summed Vertical Dipole Outputs)

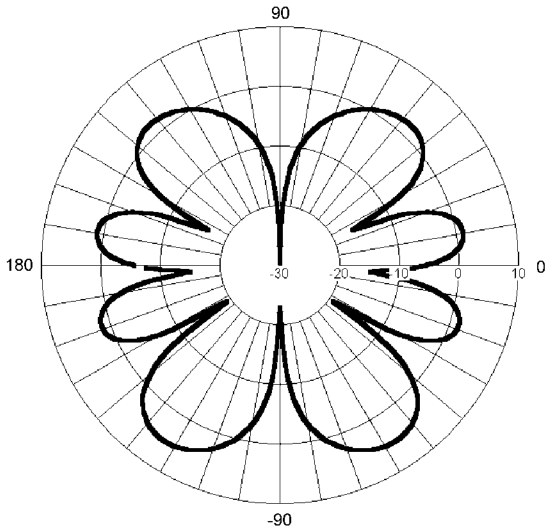

Figure 15 - Elevation Gain Pattern For Adcock Aerial Pair, With Mast (Summed Vertical Dipole Outputs)

Figure 15 is the elevation gain pattern for the two summed dipole outputs of the same vertical dipole Adcock aerial pair, but with the presence of a support mast. Note the appearance of the severe nulls, one of which is very close to zero degrees elevation. This antenna would provide highly erratic performance, with very poor sensitivity for signals arriving at elevation angles corresponding to the pattern nulls.

Although the elevation gain pattern of Figure 15 is a more extreme case, it well illustrates what can happen when the effect of the mast is ignored (as is usually the case for most designs). The severity of this “mast effect” depends upon a number of factors, including operating frequency, height of the mast and its support structure, and vertical dipole spacing. The problem is most noticeable with wide frequency coverage DF antennas and most acutely manifests itself as frequency "holes" (frequency bands where severe performance degradation is experienced). In addition, these holes tend to shift in frequency when the mast height is changed or the antenna is installed at a different location. Furthermore, *these holes are actually just the extreme manifestation of the broader problem that some degree of performance degradation exists over all or most of the DF antenna's frequency range as a consequence of inadequate mast decoupling.* Users are often unaware of these problems, however, attributing them instead to site anomalies or the vagaries of radio direction finding in general. The problem is further compounded by the reluctance of most manufacturers to fully meet their duty of candor to customers to disclose this serious performance shortcoming (or perhaps more likely, their lack of understanding of this important issue).

There are certain misconceptions regarding this mast effect that should be dispelled. One of these is that the necessary decoupling can be achieved by the simple expedient of employing a non-metallic mast. Unfortunately, this substitution is completely ineffective since the metallic feed cable inside the mast is no less troublesome.

Some manufacturers claim that if the support mast is sufficiently tall, these mast effects are somehow attenuated to the point where they are no longer troublesome. This is also a misconception that completely flies in the face of reality. Taller masts are no more forgiving than shorter masts in this regard. The only difference is that they produce more elevation gain pattern nulls as illustrated in Figure 15.

Another misconception is that 8-aerial dipole Adcocks are not vulnerable to this problem because the vertical dipoles can be spaced further from the mast. Although this contention is not true, it does contains a certain element of truth. As will be discussed, 8-aerial dipole Adcocks do allow the vertical dipoles to be spaced further from the mast *for a given high-end frequency band edge*. It is also true that, other factors being equal, greater dipole spacing from the mast mitigates the mast effect. At the lower end of the DF antenna frequency range, however, *the spacing of an 8-aerial dipole Adcock is no different than that of a 4-aerial unit*. The 8-aerial dipole Adcock is thus equally vulnerable to the mast effect at the lower end of its frequency range. Since for the same dipole spacing the 8-aerial dipole Adcock can operate much higher in frequency that a 4-aerial unit, it is less vulnerable to the mast effect in this extended high-end frequency range (keeping in mind that although the *physical* distance of the vertical dipoles from the mast is the same at all frequencies, the *electrical* distance in terms of percentage of a wavelength increases with frequency).

Rather than just ignoring this issue, RDF Products has specifically designed its dipole Adcock DF antennas so that the aerials are properly decoupled from the mast, thus eliminating the above mentioned mast-induced performance degradations. DF antenna performance is thus substantially unaffected by the mast and there are no frequency holes.

RDF Products has addressed this issue by supplying a special isolation mast with all of its dipole Adcock DF antennas. This iso-mast is sufficiently tall (typically 3 to 8 feet) to decouple the dipole Adcock from the tower or other support structure upon which it will ultimately be mounted. Fundamentally, the iso-mast is designed such that mast currents induced by the illuminating wavefront are sufficiently suppressed to minimize re-radiation.

Figure 16 graphically illustrates the enormous magnitude of improvement that is achieved using the iso-mast. In this illustration, the same dipole Adcock and mast combination used for the elevation gain pattern of Figure 15 is employed, but with an added iso-mast. Notice how the violent nulls of Figure 15 have become smoothed-out into very gentle ripples as a result of the iso-mast's ability to suppress re-radiation. Resulting Adcock performance is essentially the same as would be obtained with an Adcock having no mast at all as per the ideal elevation gain pattern of Figure 14.

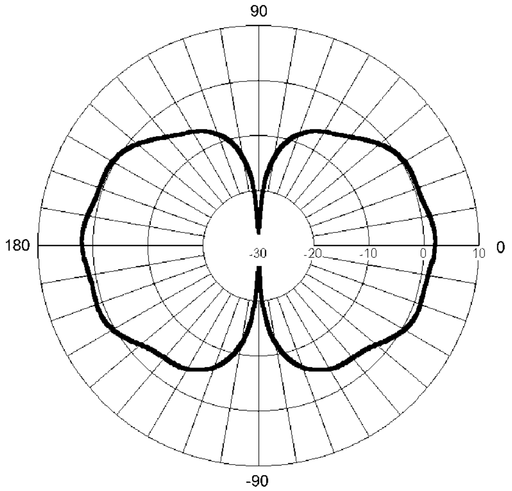

Figure 16 - Elevation Gain Pattern For Adcock Aerial Pair With Iso-Mast (Summed Vertical Dipole Outputs)

As a final point, the reader should note that this mast effect affects *only the Adcock aerial pair summed-sense output rather than the differenced bi-directional outputs*. Referring to the discussion in Section III, the reader will recall that a 4-aerial Adcock produces three separate outputs (the N-S bi-directional, E-W bi-directional, and sense). The reader will also recall that the bi-directional outputs are obtained by vectorially *differencing* (subtracting) the voltages produced by diagonally opposing aerials, while the sense output is obtained by vectorially *summing* these voltages. Because of the symmetry of the mast with respect to the vertical dipoles, *dipole voltages induced by mast re-radiation cancel at the bi-directional outputs as a result of the differencing action.* As a result, *the elevation gain pattern distortion caused by the mast for the summed-sense output as illustrated in Figure 15 is not present at the bi-directional outputs*.

An unfortunate consequence of this is an increase in *phase miscorrelation* between the sense and bi-directional outputs. To briefly explain, the sense and bi-directional output voltages must be approximately in phase for good DF antenna performance. If these voltages become too far out of phase, bearing accuracy and sensitivity are diminished. In extreme cases, such phase miscorrelation can even cause bearing reversals.

When mast re-radiation is severe enough to cause significant sense signal elevation gain pattern distortion, sense phase perturbations also occur. Since similar phase perturbations are not also experienced by the bi-directional output, phase miscorrelation increases.

E. 8-AERIAL ADCOCKS

The discussion so far has been focused primarily on 4-aerial Adcock DF antennas. One of the limitations of 4-aerial Adcocks is that bearing accuracy degrades if the antenna spacing (the distance between diagonally-opposing aerials) becomes too great (in terms of percentage of a wavelength at the operating frequency).

This phenomenon is known as *spacing error*, and occurs as a result of the fact that the circularity of the bi-directional lobes (see Figure 3) degrades as aerial spacing increases (these lobes tend to elongate). This error is octantal in nature, peaking at the tertiary compass points (22.5E, 67.5E, 112.5E, etc.) The magnitude of this spacing error for 0.125, 0.25, 0.33, and 0.5 wavelength spacing is 0.3, 1.1, 2.0, and 3.3 degrees RMS, respectively. For this reason, good 4-aerial Adcock design practice generally dictates that the unit not be operated at frequencies higher than where the corresponding spacing exceeds 1/3 of a wavelength or so.

At the low end of the Adcock frequency range, the primary limiting factor becomes reduced sensitivity (the reduced aerial spacing as a percentage of a wavelength results in less of the incoming wavefront being sampled). Good Adcock aerial pair balancing also becomes more difficult, resulting in increased bearing error. For this reason, good Adcock design practice generally dictates that the unit not be operated at frequencies lower than where the corresponding spacing is less than 1/10 of a wavelength or so (although this limitation can be overlooked if performance degradation can be accepted at the lower end of the band). For an Adcock design to conform to these conservative design practices, maximum frequency coverage for a 4-aerial Adcock should not exceed a ratio of 3- or 4-to-1.

The dimensions of this trade-off can be extended by employing additional Adcock aerial pairs. Although there have been a number of different implementations of this concept described in the literature, the implementation that has survived the test of time is the symmetrical 8-aerial Adcock. This 8-aerial Adcock is very similar in appearance to its 4-aerial cousin, simply having two additional Adcock aerial pairs.

The advantage of adding two more Adcock aerial pairs is that spacing error is greatly diminished. Whereas the spacing error constraint for 4-aerial Adcocks permits a maximum spacing of about 1/3 wavelength at the highest operating frequency, *8-aerial Adcock spacing can be as wide as a full wavelength at the highest operating frequency*. *The 8-aerial Adcock can therefore operate over three times as wide a frequency range as a comparable 4-aerial Adcock under the same constraints*.

Although this may appear at first glance to be an enormous advantage, there are a number of offsetting practical constraints that, more often than not, make the 4-aerial Adcock a better choice. Perhaps the most serious of these is the fact that although the 8-aerial Adcock can theoretically provide accurate bearings over a frequency range of 10 to 1 or greater, the individual vertical dipoles (or monopoles for a mobile version) cannot be very efficient over much of this range (this is an issue even for 4-aerial Adcocks covering a much narrower range). The consequence of this is extremely poor sensitivity in the lower portion of the frequency range. As a result, most designers are reluctant to attempt to use a single array to cover so wide a frequency band.

Another difficulty is that if a derived sense configuration is employed (usually the preferred technique) where the sense signal is derived by summation of all the aerial outputs, the magnitude of the sense signal goes through a null at the frequency where the spacing is 0.76 wavelength and reverses phase at higher frequencies. As a practical matter, the common solutions are to either restrict the highest operating frequency so that the corresponding spacing remain well below 0.76 wavelengths (thereby reducing frequency coverage by 40 % or so), or employing a central sense antenna rather than the derived sense configuration. Although the central sense antenna is practical for a mobile DF antenna employing monopoles, it is very awkward to implement with a dipole Adcock due to the presence of the mast.

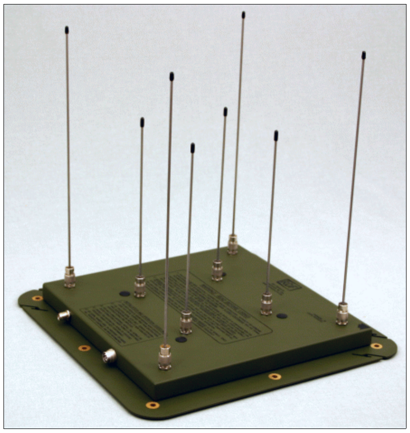

Figure 17 - DMA-1315B1 80-520 MHz Dual 4-Aerial Mobile Adcock DF Antenna

A final difficulty is that the antenna electronic circuitry required to process the dipole or monopole outputs is more complicated with more precision manufacturing processes that are difficult to control. As a practical matter then, bearing accuracy similarly becomes more difficult to control. This problem becomes more severe at higher frequencies.

As a consequence, better results are often obtained by simply co-locating two 4-aerial Adcocks. Figure 17 illustrates the RDF Products 80-520 MHz DMA-1315B1. As can be seen, the DMA-1315B1 is a dual 4-aerial array, with the outer aerials covering 80-250 MHz and the inner aerials 220-520 MHz. Note that the inner and outer array aerials are different in length to optimize sensitivity in their respective bands. This would not be possible with

Figure 18 - DFA-1315R0 80-520 MHz Dual 4-Aerial Stacked Dipole Adcock Array

a single 8-aerial array.

To co-locate two 4-aerial dipole Adcock arrays, the arrays can be stacked as illustrated in Figure 18. Note that an isolation mast must be used between the two arrays.

Since the advantages of 8-aerial Adcocks are somewhat questionable and their cost of production high, manufacturers sometimes tout their 8-aerial Adcocks as somehow being of more "professional-quality" than 4-aerial Adcocks (even though they also sell these "non-professional-quality" 4-aerial Adcocks). This is, of course, nonsense. The 8-aerial Adcock is not inherently more accurate. It is not more sensitive. It does not provide immunity to bearing errors induced by multi-path reception. Its sole advantage, as stated above, is its ability to cover a wider frequency range (as limited by the constraints cited above).

F. SITE CALIBRATION

Site calibration is a means by which the bearing accuracy of a fixed-site DF antenna can be improved by carefully positioning a test transmitter at various known azimuths around the DF antenna, recording the actual measured bearings, and then constructing a calibration "look-up" table that can be used to correct subsequent bearing readings. For a DF system employing a computer interface, this look-up table would normally be constructed in software and would employ automatic interpolation to allow corrections to be applied to bearing readings between calibration points. Site calibration is rarely applied to mobile DF systems

Although site calibration can be a useful tool, it is subject to many limitations. Some of the issues associated with site calibration are as follows:

1. Multi-Path Limitations - Site calibration is totally ineffective as a means of reducing bearing errors caused by multi-path reception (i.e., reflections). Generally speaking, a reflection has the effect of altering the apparent angle-of-arrival of the incoming wavefront, and the very best one can ask of a narrow-aperture DF antenna is to correctly report this *apparent* angle-of-arrival. More specifically, the reason for this is that the amount of bearing error caused by a reflection is dependent not only upon the *magnitude* of the reflected ray, but also upon its *phase* relationship to the direct ray. Depending upon this phase relationship, the bearing error induced by a reflection can be either positive, negative, or even zero. Since there is no *a priori* knowledge of this phase relationship in the general case, site calibration cannot offset the error. A corollary to this point is that site calibration in general is ineffective if the DF site is poor and most of the bearing errors are caused by multi-path reception. When considering site calibration then, always keep in mind the all-important point that only DF system *instrument error* can be reduced, and that it is ineffective in reducing *site error* caused by multi-path reception. Since multi-path reception is usually the predominant source of error in mobile DF applications, site calibration is rarely employed for mobile DF systems.

2. Number Of Calibration Azimuths - In general, a large number of calibration azimuths are necessary to construct an effective calibration look-up table, particularly if linear interpolation is employed to estimate and correct for errors between the calibration azimuths. Non-linear interpolation (if skillfully implemented) is somewhat more forgiving

in this regard and in general demands fewer calibration azimuths for the same corrected bearing accuracy. Typical site calibrations are conducted using 36 calibration points (i.e., at 10E azimuth increments).

3. Frequency Dependency - A site calibration is theoretically valid only at the frequency at which it was conducted. It is therefore necessary to repeat the calibration procedure at a number of different frequencies throughout the antenna frequency range. Once again, interpolation can be used to compute corrections for intermediate frequencies.

4. Elevation Angle Dependency - A site calibration is theoretically valid only at the elevation angle at which it was conducted. In practice, however, since most signals intercepted by fixed-site DF antennas are received at or near 0E elevation angle, site calibrations are similarly performed at or near 0E elevation angle. Another mitigating factor is that DF antenna bearing accuracy does not usually change much over a modest range of elevation angles centered around 0E.

5. Distance Between DF Antenna And Test Transmitter - For best results, the test transmitter should be located close to the DF antenna since this increases the magnitude of the desired direct ray in relationship to any reflected rays (thus minimizing any bearing errors due to multi-path reception). The test transmitter should not, however, be closer than a wavelength or so at the lowest test frequency.

6. Error Contribution Of Other DF Components - Although the DF antenna is usually the dominant DF system component with regard to bearing errors, the error contribution of the DF receiver/bearing processor may not be negligible (especially after a well-implemented site calibration). It is therefore good practice to first measure and record the bearing accuracy of the DF receiver/bearing processor so that these errors can be subtracted out from the measured composite system bearing errors to determine the error contribution of the DF antenna alone. Using this procedure, the calibration look-up table constructed for the DF antenna is still valid if a different DF receiver/bearing processor is later substituted. Of course, the bearing accuracy of the new DF receiver/bearing processor should be measured and the calibration look-up table appropriately modified to accommodate these errors if they are significant.

Site calibration is an involved topic and a more detailed discussion is beyond the purview of this Application Note. Also, as a practical matter, most users would be unwilling to invest the time and effort required of this tedious and demanding procedure.

G. DIPOLE ADCOCK CONFIGURATIONS

RDF Products supplies dipole Adcocks in two fundamental configurations. The first is the classical “H”-dipole Adcock as illustrated by the RDF Products 75-300 MHz DFA-1310B1 in Figure 19. H-dipole Adcocks employ a weather-sealed chassis that mounts the aerials and contains the necessary signal processing electronics. A coaxial RF output and multi-conductor antenna control cable are run down the mast to the DF receiver/processor. The multi-conductor antenna control cable typically carries DC power, axis encoding tones, and band selection control lines as required. The DFA-1310B1 employs an 8' iso-mast section that is in turn mounted on the user-supplied support mast or tower. As discussed in depth above, this iso-mast decouples the DF antenna so that its performance is independent of the characteristics of the supporting structure.

Although the H-dipole Adcock configuration is effective and widely used up through the VHF range, it becomes awkward for use in the UHF range for several reasons. First, the dipoles become much smaller at UHF and therefore less forgiving of the physical separation between the two dipole halves imposed by the height of the chassis. Second, the narrower spacing between the four dipoles results in the lower halves of the dipoles being physically too close to the mast. Finally, the smaller overall physical dimensions force the chassis to be very small, resulting in inadequate space for the necessary electronics.

To overcome these issues, RDF Products developed the "sleeve"-dipole Adcock. Rather than employing conventional vertical dipoles as used in the H-dipole Adcock, sleeve-dipoles are employed that can be mounted atop collinear masts as illustrated in Figure 20. The weather-sealed chassis can then be mounted at the base of the sleeve-dipole masts, and can be as large as necessary to accommodate the required electronics. This chassis is in turn mounted atop a short iso-mast.

Figure 19 - DFA-1310B1 75-300 MHz H-Dipole Adcock

Figure 20 - DFA-1405B1 300-1000 MHz Sleeve-Dipole Adcock

H. SECTION V SUMMARY

Dipole Adcocks are far better suited for fixed-site mast-mounted DF applications than mobile monopole Adcocks primarily because there is no requirement for the troublesome elevated ground plane that causes mobile Adcocks to perform so poorly. Elevating the dipole Adcock on a high mast also provides dipole Adcocks with much further line-of-sight than ground-mounted units, and also greatly reduces bearing errors from multi-path reception since the unit can be elevated well above nearby reflecting obstacles.

Dipole Adcock performance can be adversely affected by the “boom effect” and the “mast effect”. With regard to the boom effect, the dipole Adcock horizontal support boom creates a susceptibility to horizontally-polarized signal components that cause bearing errors. In most cases, however, the resulting error contribution is very small.

The mast-effect is far more serious. Since incoming signals illuminate the vertical support mast as well as the dipoles, resulting mast re-radiation can seriously distort the dipole elevation gain pattern and cause poor performance. RDF Products dipole Adcock DF antennas employ special isolation masts that effectively decouple the antenna from the supporting structure to eliminate this problem.

8-aerial Adcocks offer a means to extend frequency coverage. While 4-element Adcocks employing conservative design practices can cover a frequence range of 3- or 4-to-1, 8-element Adcocks can, in principle, cover frequency ranges in excess of 10-to-1. Unfortunately, there are a number of problems associated with 8-aerial Adcocks that are often best overcome by relying instead upon dual co-located 4-aerial Adcocks.

Site calibration is a means by which the bearing accuracy of a fixed-site DF antenna can be improved. Site calibration is capable only of correcting for instrument error, however, and cannot correct for bearing errors induced by multi-path reception for narrow-aperture DF antennas. As a practical matter, however, most users would be unwilling to invest the time and effort required of this tedious and demanding procedure.

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3. John W. Ames and William A. Edson, “Gain, Capture Area, and Transmission Loss For Grounded Monopoles And Elevated Dipoles”, p. 44-55, RF Design Magazine, Cardiff Publishing, November/December 1983. <>