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# AN-006

## Application Note

# AN INTRODUCTION TO 8-ELEMENT ADCOCK DF ANTENNAS

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## ***About RDF Products Application Notes...***

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 manufacturers' 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 shorter 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 a 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 history, technology, and application of 8-element Adcock DF antennas. Although 8-element Adcocks have existed for many decades, there is little published information that can be readily found via an internet search. Furthermore, the information available is mostly not in a format that is helpful to non-specialists in determining the capabilities and limitations of an 8-element Adcock in comparison to the simpler and less expensive 4-element alternative.

Although the 8-element Adcock is a more advanced and sophisticated implementation of Adcock technology than its simpler 4-element predecessor, the applications where its advantages are useful are somewhat narrow and limited. 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 funding.

## SECTION II - ADCOCK DF ANTENNAS - A BRIEF 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 (British Patent No. 130490) a new DF antenna that relied on two difference-phased vertical dipoles or monopoles (rather than loops) to obtain the necessary bi-directional characteristic. Since these Adcock element 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 bi-directional pattern distortion and therefore far better immunity to bearing errors in the presence of signals having horizontally-polarized components. The invention of this 4-element 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.

Various implementations of the 8-element Adcock were first developed after World War II. The concept went through considerable evolution and shake-out as the underlying science became better understood. The essential concept of the modern 8-element Adcock design was published in the 1964 paper "A Symmetrical Eight-Element Four-Phase Adcock Antenna" by N. Burtnyk (see Ref. 1), although the design implementation was subsequently improved.

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 Adcock/Watson-Watt DF technique has withstood the test of time and is arguably the most effective DF technique available for both mobile and fixed-site narrow-aperture DF applications from very low frequencies up into the UHF range.

## SECTION III - ADCOCK/WATSON-WATT DF SYSTEM SIMPLIFIED THEORY

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

In the most general sense, all non-rotating radio direction finding systems employ a DF antenna having an array of spatially-displaced elements (three or more are required for an unambiguous bearing presentation) that are illuminated by the received signal wavefront. The resulting voltages produced by these elements 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 element output voltages.

A single-channel Adcock/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

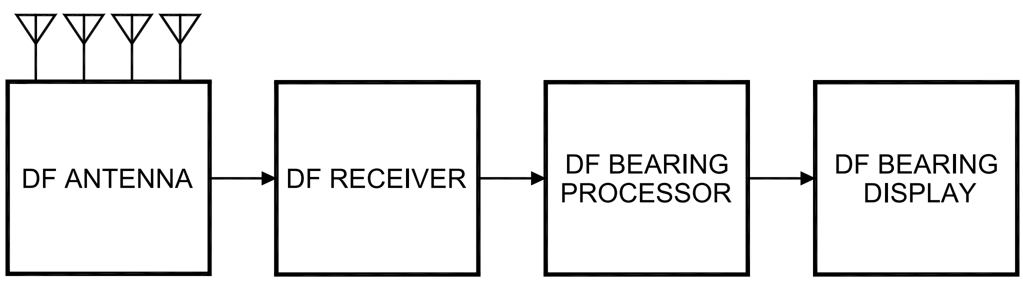



**Figure 1 - Adcock/Watson-Watt DF System Simplified Functional Block Diagram**

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 would 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 direction (compass point)*.

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.

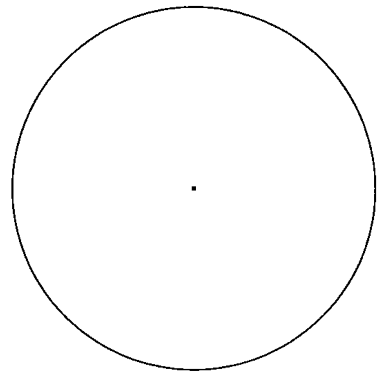


**Figure 2 - Omni-Directional Azimuthal Gain Patten Of Monopole Or Vertical Dipole**

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-8" gain pattern with circular lobes similar to those of Figure 3 results. This differenced-phased antenna array is referred to as an *Adcock element pair*.

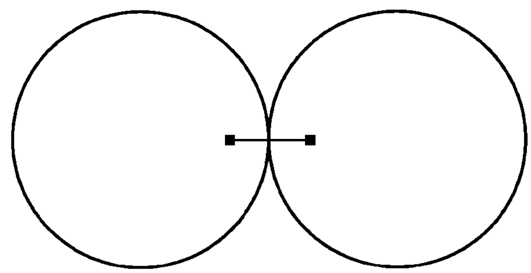


**Figure 3 - Bi-Directional Azimuthal Gain Pattern Of Adcock Element Pair**

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.

An Adcock 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 Adcock element pairs, (i.e., 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.

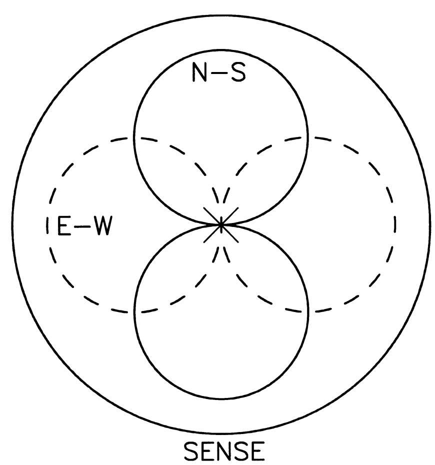



**Figure 4 - Required Azimuthal Gain Patterns For A Watson-Watt DF System**

An Adcock/Watson-Watt DF system is categorized as an *amplitude comparison* DF technique. Referring again to Figure 4, a wavefront arriving at an azimuth of 30° (as an example) results in a relatively high output voltage from the N-S Adcock element pair and a relatively low output voltage from the E-W pair (as can be seen by examining the Figure 4 gain patterns for a 30° azimuth).

By appropriately comparing these two voltages, the wavefront azimuth (bearing) can be ascertained. More specifically, if the pattern lobes are circular, this bearing is easily determined by simply computing a 4-quadrant arc tangent of N-S and E-W output voltages.

The omni-directional sense antenna output is required to resolve a 180 degree ambiguity that would otherwise result. The means by which this is accomplished is beyond the technical purview of this paper, but essentially it provides a "polarity" for the four lobes. To explain, the upper N-S and right-most E-W lobes of Figure 4 are caused (by the sense signal) to be "positive" output voltages while the lower N-S and left-most E-W lobes are caused to be "negative". (With no sense signal, all four lobes would have the same polarity with the result that the 4-quadrant arc tangent algorithm would not have sufficient information to compute the appropriate bearing quadrant).

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 elements.

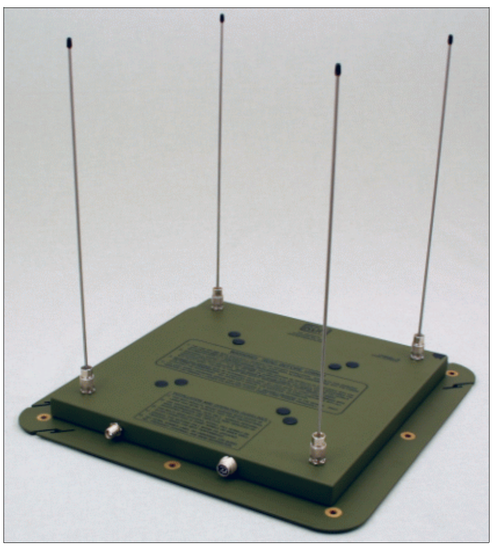


**Figure 5 - Mobile Adcock DF Antenna**

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

Existing 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 elements. 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 as elements 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 (audio frequency) and the E-W axis bi-directional output with another tone at a different audio frequency. 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 computer and 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.

In modern systems, bearings are 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”).

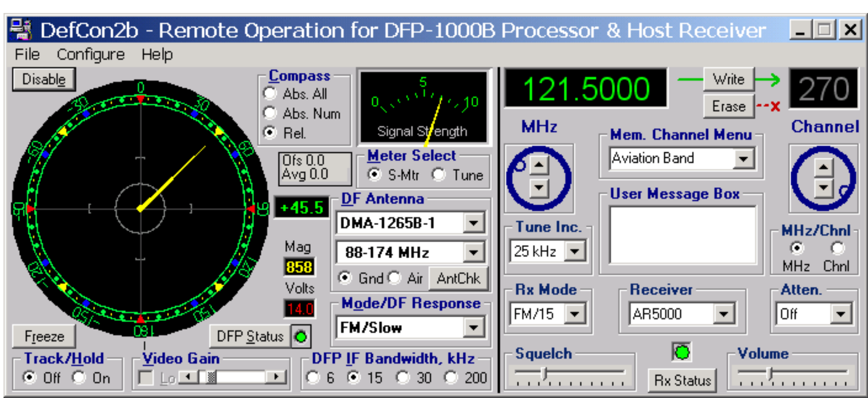



**Figure 8 - DefCon2b Main Screen**

## SECTION IV - 4-ELEMENT ADCOCK FREQUENCY COVERAGE LIMITATIONS

Most end-users prefer that their Adcock DF antennas cover wide frequency ranges. The two fundamental constraints that limit frequency coverage are related to the Adcock *spacing* (also referred to as *aperture* in the literature). Physically, this is the distance between opposing Adcock elements (conventionally expressed in meters). Electrically, this spacing is most conveniently referenced to a wavelength *at the operating frequency* and is expressed as follows:

$$\text{Spacing (electrical)} = d/\lambda \qquad (1)$$

where:

$d$ = distance between opposing Adcock elements (i.e., diagonal spacing for a 4-element array)
$\lambda$ = wavelength at the operating frequency (in same units of measure as $d$)

*Wavelength* in turn is defined as the distance an electromagnetic (radio) wave travels during the time interval of a complete (360°) cycle, and is calculated as follows:

$$\lambda = 300/f \qquad (2)$$

where:

$\lambda$ = wavelength (in meters)
$f$ = operating frequency (in MHz)

To illustrate by example, a 30 MHz radio wave in free space would have a wavelength ($\lambda$) of 300/30 = 10 meters, which is the distance that radio wave would travel during a complete (360°) cycle.

Electrical spacing can be expressed either as a wavelength ratio (where 1.0 is a full wavelength), or in electrical degrees referenced to a wavelength. As a case in point, an Adcock array with an electrical spacing ($d/\lambda$) of 0.25 could synonymously be referred to as having an electrical spacing of 90°. *In both cases, this must be referenced to the operating frequency since the wavelength $\lambda$ varies inversely with the operating frequency.*

At the risk of belaboring this issue, an Adcock array with a physical spacing of 10 meters would have an electrical spacing of 360° (or $d/\lambda = 1.0$) at 30 MHz, but only 90° ($d/\lambda = 0.25$) at 7.5 MHz.

For clarity, the term “spacing” is prefixed by the term “physical” or “electrical” in the remainder of this paper to minimize confusion. Electrical spacing is specified either in electrical degrees or as the wavelength ratio $d/\lambda$.

With the above explanation in mind, a 4-element Adcock has two fundamental constraints that limit frequency coverage:

1. Low-End Frequency Limitation - The primary factor determining a 4-element Adcock's useful low-end frequency boundary is the Adcock element pair spacing. As the operating frequency is decreased, the electrical spacing (relative to a wavelength at the operating frequency) becomes very narrow. This results in diminished Adcock element pair output (i.e., low gain), which causes low sensitivity.

   A secondary limiting factor is that network balancing becomes more difficult with narrower electrical spacing. Keeping in mind that an Adcock element pair employs a voltage differencing (subtracting) network to obtain the desired bi-directional gain pattern, and that at narrow spacings big numbers are effectively subtracted from big numbers to obtain small numbers, even slight network imbalances can result in significant errors that result in distorted gain patterns that in turn diminish bearing accuracy. Although network balancing is relatively easy to achieve in the HF range (i.e., 30 MHz and below), it becomes progressively more difficult to achieve in the VHF and UHF ranges.

   Although there is no hard and fast rule for minimum spacing, most designers would not want the electrical spacing to be too much less than 1/10 wavelength ($d/\lambda = 0.1 = 36°$) at the lowest operating frequency. Spacings down to 1/20 wavelength ($d/\lambda = 0.05 = 18°$) are manageable, although with some loss of DF sensitivity.

2. High-End Frequency Limitation - In order for the 4-quadrant arc tangent bearing computation algorithm discussed above to be accurate, it is necessary that the gain pattern lobes illustrated in Figure 4 be nearly perfectly circular. While these lobes maintain good circularity for electrical spacings up to 1/4 wavelength ($d/\lambda = 0.25 = 90°$) or so at the operating frequency, they become elongated as per Figure 9 for wider spacings.

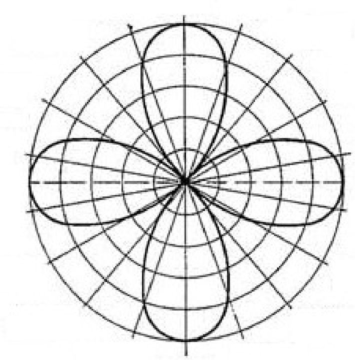
   

   **Figure 9 - Adcock Non-Circular Pattern Lobes for Wide Element Spacing**

   As the operating frequency increases, the Adcock array electrical spacing also effectively increases as discussed above. The resulting pattern distortions (i.e., the lobe elongations as illustrated in Figure 9) diminish the accuracy of the 4-quadrant arc tangent bearing computation algorithm causing bearing errors. This phenomenon is referred to in the literature as the Adcock *spacing error.*

   Spacing error increases rapidly with the operating frequency. Also, it is *octantal* in nature, peaking near the eight tertiary azimuths (i.e., 22.5, 67.5, 112.5, 157.5, 202.5, 247.5, 292.5, and 337.5 degrees). This spacing error is also *oscillatory* in nature (i.e., alternating successively between positive and negative values), diminishing to zero at the cardinal and inter-cardinal azimuths.

   For an electrical spacing of 1/4 wavelength ($d/\lambda = 0.25 = 90°$), the peak spacing error for a 4-element Adcock is a modest 1.54°. However, for an electrical spacing of 1/3 wavelength ($d/\lambda = 0.333 = 120°$), the peak spacing error rises to a more significant 2.85°.

Since this spacing error as a function of azimuth is nearly sinusoidal, the RMS spacing error can be accurately computed using the following approximation:

$$\text{Err (RMS)} \cong 0.707 \times \text{Err (peak)} \qquad (3)$$

where:

Err (RMS) = approximate RMS spacing error
Err (peak) = peak spacing error.

As a practical matter then, most designers would want the electrical spacing for a 4-element Adcock to be no greater than about 1/3 wavelength ($d/\lambda = 0.333 = 120°$) at the highest operating frequency.

Given these constraining low- and high-end frequency limitations (i.e., sensitivity and network balance as the low-end frequency limitation and spacing error as the high-end frequency limitation), 4-element Adcocks can be designed to function over a frequency range ratio of about 3- or 4-to-one for conservative designs. As cases-in-point, the DMA-1310B2 mobile and DFA-1310B1 H-dipole fixed-site 4-element Adcock DF antennas of Figures 5 and 6, respectively, both cover 75-300 MHz for a 4:1 frequency coverage ratio.

As discussed in the next Section, however, this ratio can be greatly extended using an 8-element Adcock.

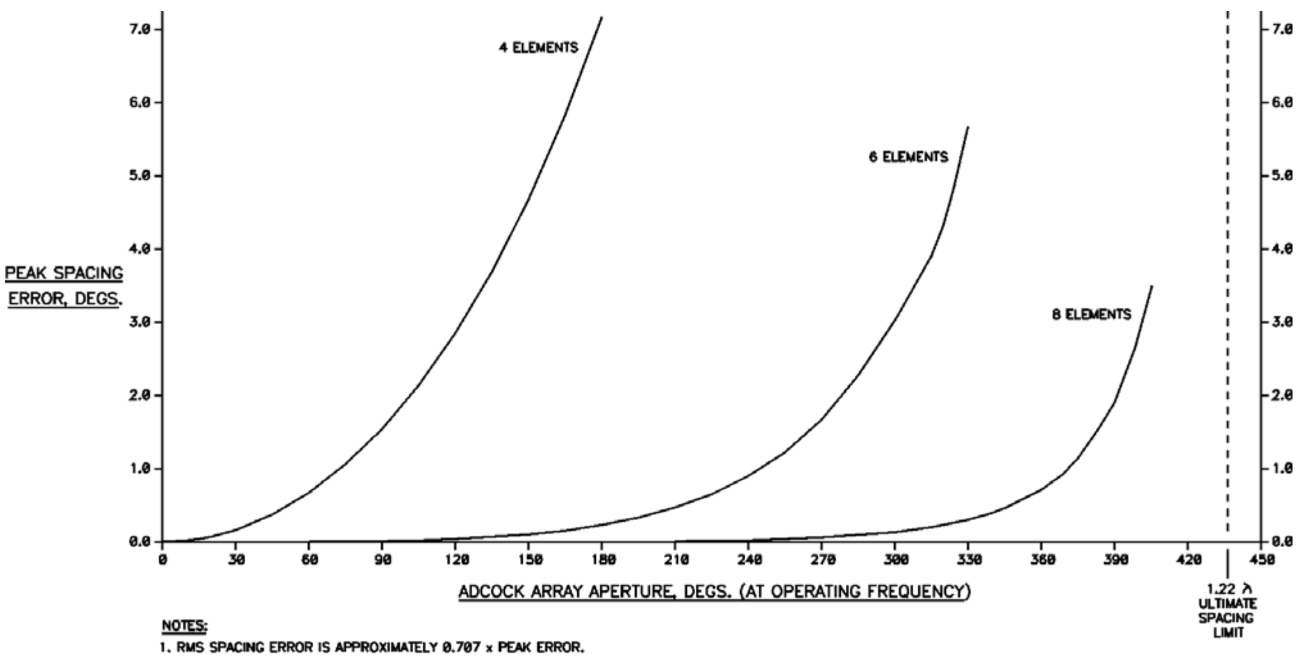
# SECTION V - 8-ELEMENT ADCOCK OVERVIEW

## A. INTRODUCTION

As discussed in the previous Section, a 4-element Adcock DF antenna's upper frequency limit is constrained by the spacing error, which limits its electrical spacing to approximately 1/3 wavelength ($d/\lambda = 0.333 = 120°$) at the highest operating frequency. By adding more Adcock element pairs, however, this electrical spacing limit can be extended up to a full wavelength ($d/\lambda = 1.0 = 360°$) for far wider frequency coverage as discussed in the following paragraphs.

## B. SPACING ERROR COMPARISON FOR 4-, 6-, & 8-ELEMENT ADCOCKS

Additional Adcock element pairs can be added to an Adcock array to reduce spacing error and thereby extend its upper frequency limit. As can be seen in the spacing error curves of Figure 10, this improvement is very significant. Note that this graph is applicable for *symmetrical* Adcocks only, which is to say that the angles between the Adcock element pair axes is constant (i.e., 90° for 4-element Adcocks, 60° for 6-element Adcocks, and 45° for 8-element Adcocks).




NOTES:
1. RMS SPACING ERROR IS APPROXIMATELY 0.707 x PEAK ERROR.
2. 4-ELEMENT ADCOCK PEAK SPACING ERROR IS OCTANTAL (22.5/67.5/112.5/157.5/202.5/247.5/292.5/337.5 DEGS. NOMINAL).
3. 6-ELEMENT ADCOCK PEAK SPACING ERROR IS TRIPLE-QUADRANTAL (15.0/45.0/75.0/105.0/135.0/165.0/195.0/225.0/255.0/285.0/ 315.0/345.0 DEGS. NOMINAL).
4. 8-ELEMENT ADCOCK PEAK SPACING ERROR IS DOUBLE-OCTANTAL (11.25/33.75/56.25/78.75/101.25/123.75/146.25/168.75/191.25/ 213.75/236.25/258.75/ 281.25/303.75/326.25/348.75 DEGS. NOMINAL).
5. SOURCES: ADCOCK DF ANTENNA MODELING PROGRAMS ADCOCK4A.BAS, ADCOCK6A.BAS, & ADCOCK8A.BAS.

FILE: SPAERR_1.PCB

**Figure 10 - Spacing Error for 4-, 6-, and 8-Element Adcocks as a Function of Array Aperture (electrical spacing)**

To explain Figure 10 more formally, this is a graph of Adcock peak spacing error as a function of the array's electrical spacing (aperture) at the operating frequency (expressed in degrees where 360° is equivalent to $d/\lambda = 1.0$ as per the discussion in Section IV). Peak spacing error curves are plotted for 4-, 6-, and 8-element symmetrical Adcock arrays.

Even a cursory examination of Figure 10 reveals the stunning spacing error reduction achievable by incorporating additional Adcock element pairs. For a 4-element Adcock, spacing error begins to appear at $d/\lambda = 15°$. For a 6-element Adcock, spacing error doesn't appear until $d/\lambda = 120°$, while for an 8-element Adcock significant spacing error doesn't appear until $d/\lambda = 260°$.

To express this spacing error suppression more precisely, however, we can compute the array spacing at which the spacing error reaches some specified value. If we are willing to accept 1.5° peak spacing error, as an example, then the maximum $d/\lambda$ values are as follows:

4-Element - 89°
6-Element - 265°
8-Element - 383°

By any measure, the spacing error reduction obtained by including additional Adcock element pairs is enormous.

As per Note 1 in Figure 10, RMS spacing error is approximately 0.707 x peak spacing error. This is because the spacing error as a function of azimuth is oscillatory, alternating between negative and positive throughout the 16 half-octants. Since this function resembles a sinusoid, the 0.707 peak to RMS conversion factor is reasonably accurate.

As per Note 4 in Figure 10, the spacing error function is double-octantal in nature, peaking at 16 points around the compass rose.

## C. PRACTICAL AND MISCELLANEOUS ISSUES

First, although the maximum theoretical $d/\lambda$ limit for an 8-element Adcock is 1.22 $\lambda$ (just under 440°) as per Figure 10, practical issues limit $d/\lambda$ to about 1.0 (360°, or 1.0 $\lambda$) for conservative designs. Even so, this still allows an enormous frequency coverage improvement over 4-element Adcocks.

Second, to this author's knowledge, no one has ever implemented a 6-element Adcock. Although this is speculation, it is likely that the incremental effort and expense of an 8- as compared to a 6-element Adcock was judged to be a modest tradeoff for the significantly improved performance provided by the technically superior 8-element implementation.

Although this author designed a 10-element Adcock back in the mid- to late-1980s for an FAA project, this was done for a purpose unrelated to diminishing spacing error. (Although an 8-element implementation provides significant spacing error reduction as compared to a 6-element implementation, employing more than eight elements significantly increases cost for very marginal incremental improvement.) In reality then, the practical choice for an Adcock

DF antenna designer is either a 4- or 8-element implementation.

Finally, increasing the number of Adcock element pairs does not impair the lower end frequency limit. As a case in point, the RDF Products 1.5-30.0 MHz DUA-1124B1 covers a 20:1 frequency range with an electrical spacing of $d/\lambda = 0.049 = 17.5^\circ$ at 1.5 MHz and $d/\lambda = 0.976 = 351.2^\circ$ at 30.0 MHz. Although the electrical spacing of $d/\lambda = 0.049$ at the 1.5 MHz low-end frequency is very narrow, network balancing (and thus bearing accuracy) is very good.

# SECTION VI - 8-ELEMENT ADCOCK CIRCUITRY

## A. OVERVIEW

In this Section, the additional circuitry necessary for an 8-element Adcock as compared to its 4-element counterpart is presented in simplified functional block diagram format. Although many of the functional blocks are the same, the 8-element Adcock requires an additional 4-to-2 phase transformer to accommodate the two additional Adcock element pairs.

## B. 4-ELEMENT ADCOCK FUNCTIONAL BASICS

Figure 11 is a simplified functional block diagram of a typical 4-element Adcock DF antenna. For simplicity a central (rather than derived) sense antenna is illustrated.

Referring to Figure 11, the two outputs of the N-S Adcock element pair are applied to the N-S differencing network. This network outputs the vectorial difference of these two signals (which produces the bi-directional azimuthal “figure-of-8” gain pattern with circular lobes illustrated in Figure 3). This N-S output is then fed to the Y-axis (N-S) amplitude modulator.

Similarly, the two outputs of the E-W Adcock element pair are applied to the E-W differencing network. The resulting E-W output is then fed to the X-axis (E-W) amplitude modulator.

The specifics and details of the modulation process are somewhat beyond the technical purview of this paper. Suffice it to say, however, that these amplitude modulators allow the N-S and E-W signals to be subsequently combined in such a fashion that they can be processed by a single receiver, but then recovered and separated in the subsequent bearing processor circuitry with no loss of information.

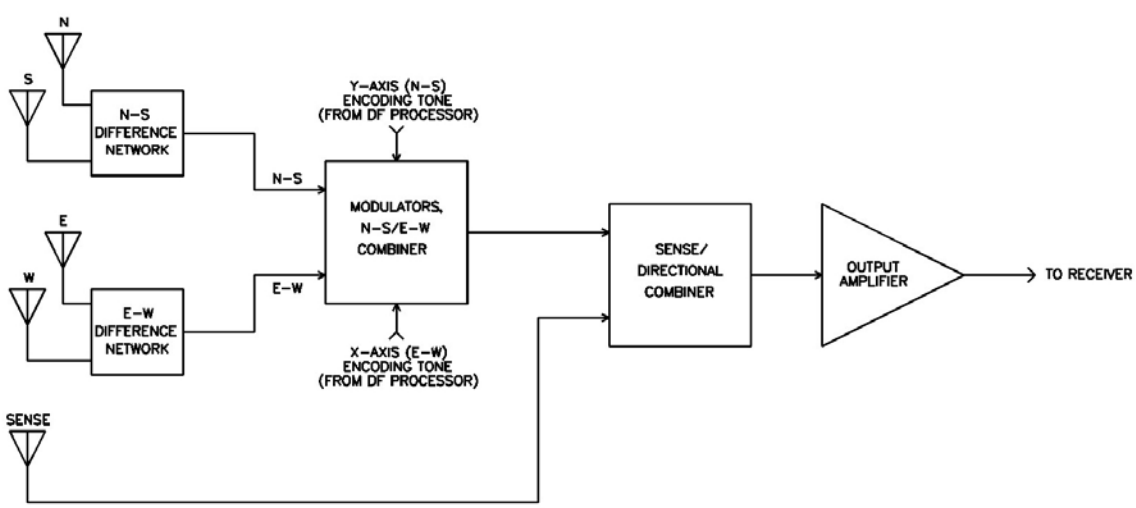



**Figure 11 - 4-Element Adcock Simplified Functional Block Diagram**

After being suitably modulated by the two axis encoding tones, the two modulator outputs are linearly summed and then applied to a sense/directional combiner where they are linearly summed with the central sense signal. This inclusion of the central sense signal resolves the 180° bearing ambiguity that would otherwise result.

Finally, this composite signal is applied to an output amplifier. This amplifier serves primarily as a gain block to overcome the subsequent signal cable losses, and secondarily as an isolation amplifier. The signal is then sent to the receiver (and ultimately the bearing processor/display).

## C. 8-ELEMENT ADCOCK FUNCTIONAL BASICS

Figure 12 is a simplified functional block diagram of a typical 8-element Adcock antenna. For simplicity a central (rather than derived) sense antenna is illustrated. (Actually, a central sense antenna is the preferred implementation in most cases for reasons discussed below.)

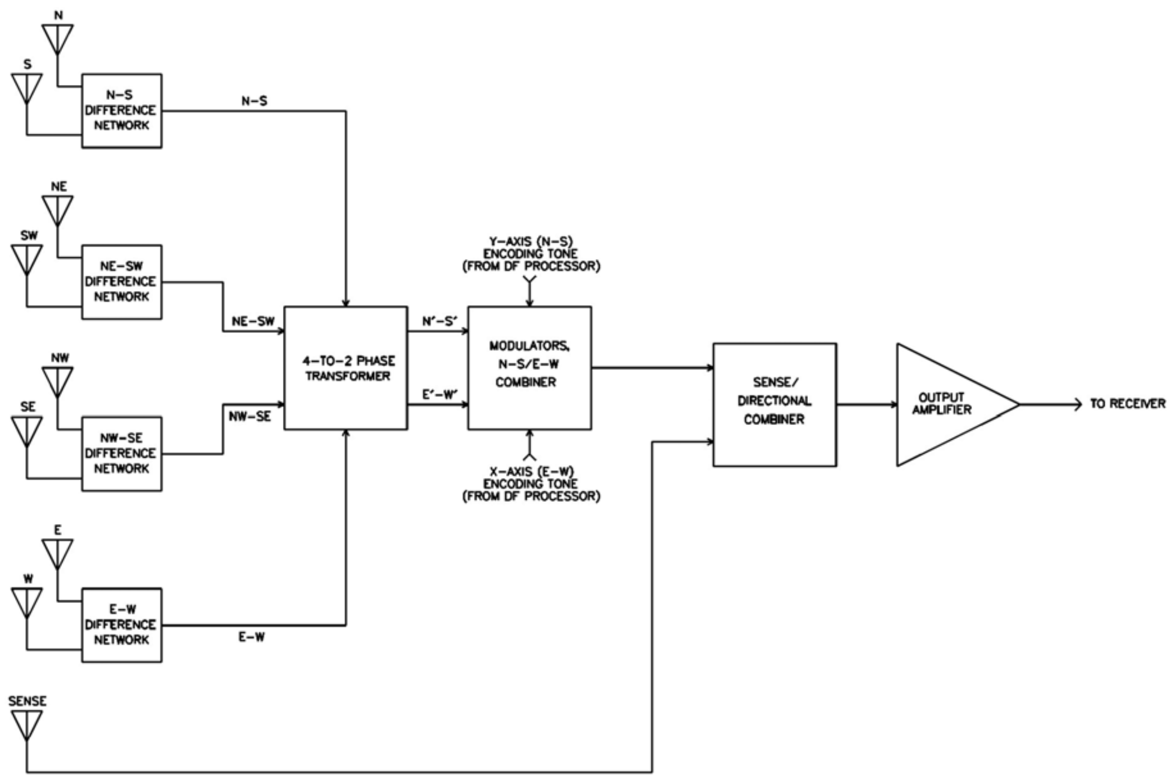



**Figure 12 - 8-Element Adcock Simplified Functional Block Diagram**

Although Figure 12 appears very similar to the 4-element Adcock simplified functional block diagram of Figure 11, there are two very important differences:

1. Additional Differencing Networks - In addition to the N-S and E-W differencing networks illustrated in Figure 11, two additional differencing networks are required to accommodate the added NE-SW and NW-SE Adcock element pairs.

2. <u>4-to-2 Phase Transformer</u> - An Adcock DF antenna is fundamentally a two phase (i.e., two axis) system that generates orthogonal bi-directional circular antenna gain patterns (i.e., the N-S and E-W outputs illustrated in the 4-element Adcock simplified functional block diagram of Figure 11). In contrast, an 8-element Adcock produces a four phase output (i.e., the N-S, NE-SW, NW-SE, and E-W bi-directional outputs illustrated in Figure 12).

   This 4-to-2 phase transformer is the key functional (and innovative) component of the 8-element Adcock. It is a fully passive network that accepts the four Adcock element pair differenced outputs and linearly combines them in such a fashion as to produce the desired two-phase output. These outputs are labeled N'-S' and E'-W' in Figure 12 to differentiate them from the N-S and E-W Adcock element pair outputs.

   The innovative feature of the 4-to-2 phase converter is that although the N-S, NE-SW, NW-SE, and E-W bi-directional outputs driving it exhibit severe pattern distortion (i.e., non-circular lobes) at operating frequencies where the electrical spacing d/λ is wide, the resulting N'-S' and E'-W' gain patterns are nearly perfectly circular. Stated differently, *the 4-to-2 phase converter restores pattern lobe circularity for the wide-spaced Adcock element pairs, even though the four Adcock element pair outputs individually have highly distorted (non-circular) gain patterns*.

As per Figure 12, the 4-to-2 phase converter N'-S' and E'-W' outputs are then processed in the same fashion as is the case for the 4-element Adcock. No changes are necessary in the receiver or DF processor to accommodate the 8-element Adcock.

## D. <u>CENTRAL VS. DERIVED SENSE ANTENNA</u>

As stated, Adcocks require an omnidirectional *sense* antenna to resolve the 180° bearing ambiguity that would otherwise result. Also as stated, this sense antenna can employ either a physical *central sense* element or the sense signal can be *derived* from the Adcock element pairs by successive summation. For 4-element Adcocks, a derived sense configuration offers some performance advantage, but becomes increasingly cumbersome to implement above 500 MHz. For this reason, RDF Products 4-element Adcocks employ derived sense designs in the VHF and low-UHF range and central sense designs in the higher UHF range.

Derived sense designs are more difficult to implement for 8-element Adcocks. The problem is that the derived sense output amplitude is highly variable over any substantial frequency range. In fact, the derived sense signal output actually goes through a null and phase reversal at operating frequencies where the electrical spacing d/λ = 0.7652 = 275.5°. This phenomenon is illustrated graphically in Figure 13.

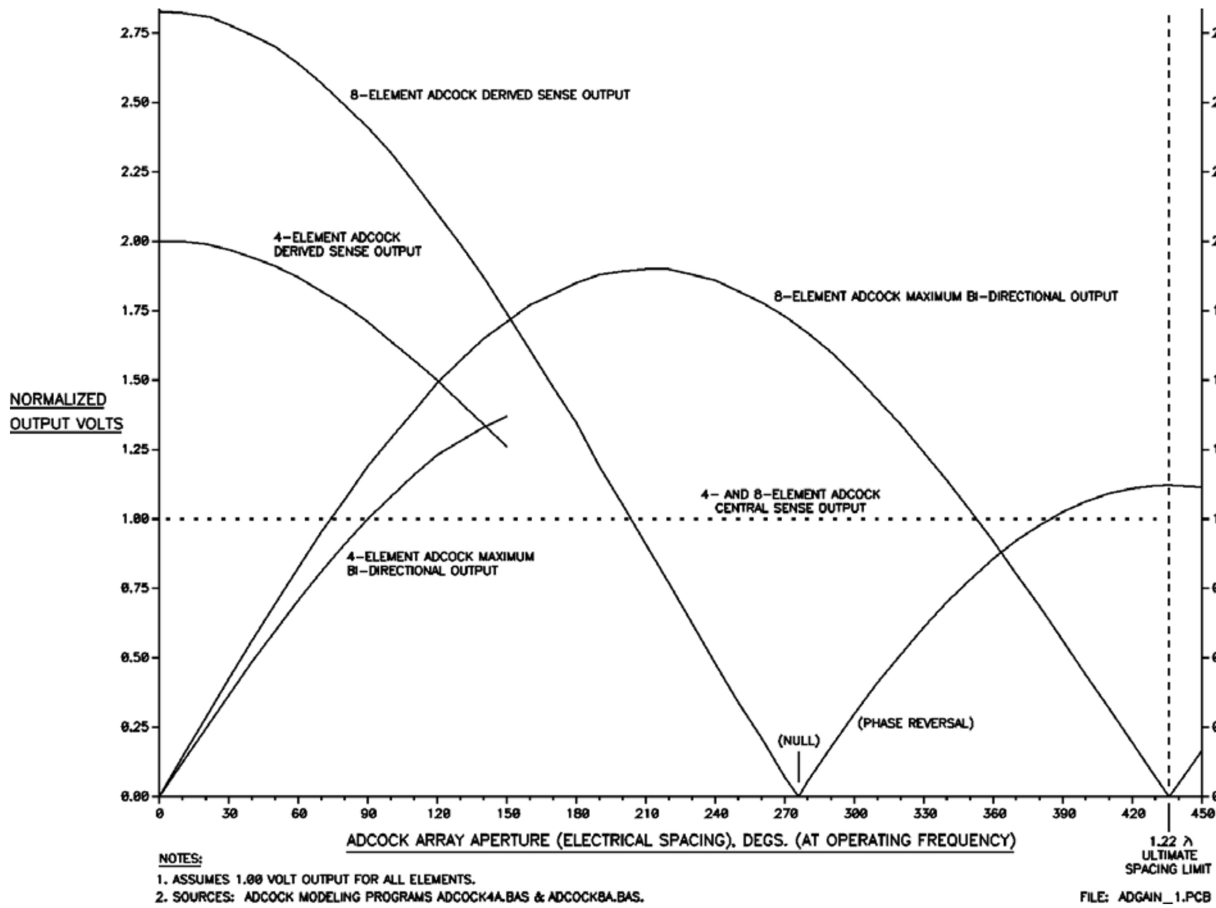



**Figure 13 - 4- & 8-Element Adcock Sense & Bi-Directional Output Curves**
**(normalized to a single element output = 1.00 volts)**

Since Figure 13 comes dangerously close to the "too much information" threshold for most readers, we break it down as follows:

1. X-Axis - The graph X-axis is the Adcock array aperture (electrical spacing, or d/λ as defined in Section IV-A), expressed in electrical degrees at the operating frequency.

2. Y-Axis - The graph Y-axis is output voltage *referenced to the output of a single element, which is normalized to 1.00 volts.* Stated differently we assume that the illuminating wavefront signal strength at the operating frequency is such that *the output of any single element by itself is 1.00 volts.* Results yielding outputs of >1.00 volt indicate *array gain*. As a case in point, *a central sense element would (obviously) have an output of 1.00 volt over the full frequency range* (as illustrated by the dotted horizontal line).

3. Element Interaction - The simplifying assumption is made that there is no inter-element shadowing or re-radiation. Although this assumption would be accurate only for very short elements, it is an appropriate starting point for analysis and facilitates easier understanding.

With these points in mind, Figure 13 provides the following information:

1. Central Sense - A central sense output for both 4- and 8-element Adcocks is a constant 1.00 volts across the entire operating frequency range (as illustrated by the dotted horizontal line.

2. Derived Sense (4-element Adcock) - For very narrow spacing, a 4-element Adcock derived sense signal approaches 2.00 volts output, which corresponds to an impressive sense array gain of 6 dB. This gain tapers off as the spacing increases, but is still significant at d/λ = 120° (the practical upper spacing limit for most 4-element Adcocks) with an output of 1.50 volts (corresponding to a sense array gain of 3.52 dB).

   A derived sense configuration thus offers a significant sensitivity advantage for 4-element Adcocks as compared to a central sense configuration. This is the reason most RDF Products 4-element Adcock DF antenna models use derived sense configurations.

3. Derived Sense (8-element Adcock) - For very narrow spacing, an 8-element Adcock yields even more sense array gain for derived sense configurations. As per Figure 13, its derived sense signal yields 2.82 volts output, which corresponds to a very impressive sense array gain of 9 dB.

   Unfortunately, this impressive array gain tapers off very rapidly as the spacing increases. Since an 8-element Adcock is useful for spacings as wide as d/λ = 360°, this is a serious issue. As per Figure 13, the derived sense output begins falling off sharply above d/λ = 60° or so until it reaches zero at d/λ = 275.5°. The output recovers at d/λ > 275.5°, but with a phase reversal.

   Since the fundamental rationale for considering an 8-element Adcock is its ability to operate over very wide frequency ranges with spacings as high as d/λ = 360°, this derived sense extreme output variability is unacceptable. It is for this reason that central rather than derived sense outputs are employed in most 8-element Adcock designs.

## E. BI-DIRECTIONAL OUTPUTS

Once again referring to Figure 13, gain curves for both 4- and 8-element bi-directional signal outputs are plotted. As per the graph notations, these are peak gains (i.e., that achieved in the figure-of-8 gain pattern most favorable direction, or 90° offset from the nulls).

For both 4- and 8-element Adcocks, these bi-directional output magnitudes are very small for very narrow spacings. This is to be expected since at very narrow spacings, the outputs from the two Adcock element pair antennas are almost the same in magnitude and phase, so subtracting them in the differencing network will yield very low output.

As the spacing increases, these outputs increase sharply (more so for the 8- versus the 4-element Adcock). This output magnitude increases smoothly and monotonically for the 4-element Adcock as per Figure 13. Although this curve would eventually turn over and decline at wider spacings, this does not occur at the spacings that are practical for 4-element Adcocks. (As per the discussion above, 4-element Adcock spacing cannot be more than 1/3 λ or so at the highest operating frequency due to rapidly increasing spacing error.)

Bi-directional output for the 8-element Adcock, in contrast, is non-monotonic over its useful spacing. As per Figure 13, this output increases monotonically up to d/λ = 220°, after which the curve turns over with this output decreasing monotonically. Although the bi-directional output falls to zero at d/λ=436° (or approximately 1.22 λ), this is well outside the 8-element

Adcock's useful spacing range. (d/λ should not exceed 360° at the highest operating frequency to be consistent with good design practice.)

## F. SENSE/BI-DIRECTIONAL GAIN COMPENSATION

As per Figure 13, the sense and bi-directional output amplitudes vary widely, both with respect to each other and over frequency. Since it is necessary that the ratio of the sense as compared to the bi-directional outputs stay within a reasonable range, this inherent variability requires that gain compensation networks be employed for this purpose. This is also an issue with 4-element Adcocks, but the task is more difficult with 8-element Adcocks due to the increased variability.

## G. DF SENSITIVITY

As per Section VI-B, a single-channel Adcock DF antenna (both 4- and 8-element types) employs an amplitude modulation (AM) technique to encode the N-S and E-W bi-directional outputs with two different tone frequencies so that these bi-directional outputs can be separated and recovered in the DF receiver/processor with no loss of information. In this composite AM signal, the sense signal serves as the carrier while the tone modulated N-S and E-W bi-directional signals are the sidebands. In the frequency domain, this would appear as a carrier with two pairs of sidebands (one pair for each modulation tone).

To prevent "over-modulation", these tone sidebands must be significantly lower in magnitude than the sense signal carrier. (This is the more specific reason for the gain adjustment requirement discussed in Section VI-F above.) For good design practice, the tone modulation index should not be much higher than 50%, which corresponds to the tone sidebands being 12 dB lower in amplitude than the carrier (sense signal).

As is the case for any AM signal, it is the "carrier-to-noise ratio" (CNR) that ultimately establishes system sensitivity. To a first approximation then, since the sense signal serves as the AM carrier, its amplitude determines DF system sensitivity. Since the bi-directional signal output amplitude must be 12 dB or more lower in amplitude than the sense signal to prevent over-modulation as explained in the previous paragraph, this bi-directional signal must often be attenuated to meet this constraint. Therefore, even though the bi-directional output can be high in an 8-element Adcock as per Figure 13, much of this array gain must be "thrown away" to prevent over-modulation. In contrast to some claims in the literature and some manufacturers' advertisements, the increased 8-element Adcock bi-directional gain does not significantly improve sensitivity as compared to its 4-element counterpart.

## SECTION VII - 8-ELEMENT ADCOCK APPLICATIONS

Although the 8-element Adcock is elegant and sophisticated, there are surprisingly few applications where it is preferable to its "lesser" 4-element counterpart. Inflated manufacturers' claims notwithstanding, its only true benefit is that it can operate over a frequency range 3-4 times wider than that of a 4-element version as discussed in Section V.

Unfortunately, it is impractical to design elements that work efficiently over 10- or 20-to-1 frequency range. Thus, greatly diminished sensitivity inevitably occurs in the lower portion of an 8-element Adcock's frequency range due to element inefficiency.

For this reason, it is often better practice to co-locate two 4-element Adcock arrays to cover a wide frequency range. As a case in point, the RDF Products model DMA-1306B1 mobile Adcock (see Figure 14) employs two co-located and co-planar 4-element monopole Adcock arrays to cover 65-1,000 MHz.

Referring to Figure 14, the taller outer elements cover the VHF range while the shorter inner elements cover the UHF range. An 8-element implementation for this same frequency coverage would require elements sufficiently short for good performance in the UHF range which would result in diminished VHF sensitivity.

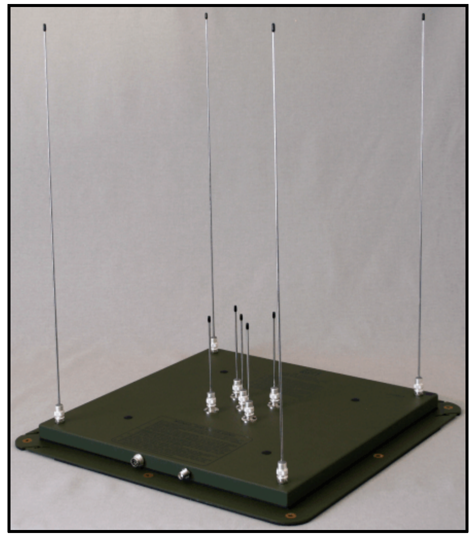


**Figure 14 - RDF Products 65-1,000 MHz DMA-1306B1 Dual 4-Element Adcock**

**Figure 15 - RDF Products 60-1,000 MHz DFA-1325B2 Dual Stacked 4-Element Adcock**

For a fixed-site (mast-mounted) array, the same sensitivity benefit can be achieved by stacking two 4-element Adcock arrays as is done with the RDF Products model DFA-1325B2 covering 60-1,000 MHz. The VHF array (employing the taller elements) is mounted underneath the UHF array (employing the shorter elements).

A further difficulty with the 8-element Adcock is that the added 4-to-2 phase transformer (see Figure 12) is complicated and requires additional precision manufacturing processes that are difficult to control. As a practical matter then, bearing accuracy likewise becomes more difficult to control. This problem becomes more acute at higher frequencies.

The most favorable application for an 8-element Adcock is for wide frequency coverage fixed-site HFDF antennas. Such antennas typically cover 2-30 MHz, which is well within the frequency coverage capabilities of a single 8-element Adcock array.

The HF range is favorable for 8-element Adcocks for the following reasons:

1. Electrically Short Elements - As a practical matter, the elements employed for HF Adcocks usually must be electrically short at the lower end of the HF range. Even physically tall elements can be very short electrically at 2 MHz.

   To elaborate on this, the element heights for a ground-mounted monopole Adcock cannot be much taller than 20' or so to still function well at 30 MHz (the upper frequency boundary for most HFDF antennas). For most installations, however (and especially for transportable installations), elements much taller than 20' would be impractical anyway. Thus, practical considerations already constrain the element heights such that they have to be electrically short at the lower end of the HF range.

2. Practical Sensitivity Issues - Although a 20' tall monopole is very short electrically at the low end of the HF range, this short electrical height surprisingly does not impose a practical limitation on sensitivity. Although electrically short antennas are inefficient, the practical limitation on sensitivity is the high level of atmospheric noise that is encountered in the low HF range.

   Since received signals must be strong enough to overcome this atmospheric noise, short antenna inefficiency is effectively forgiven. In other words, the sensitivity “bottleneck” is the external (atmospheric) noise rather than antenna efficiency.

3. 4-to-2 Phase Transformer Practicality Issues - As mentioned, one of the difficulties encountered with 8-element Adcocks is the complexity of the 4-to-2 phase transformer and the difficult-to-control manufacturing processes that affect network precision and bearing accuracy. While these issues are very formidable in the V/UHF range, they are far more manageable below 30 MHz. Although this transformer requires skillful design and careful adjustment in the HF range, it is practical to implement.

**Figure 16 - OAR Corp. 0.5-30 MHz UA-282 8-Element Adcock**

There are very few 8-element Adcock HFDF antennas still in production. Figure 16 is a photo of the UA-282 HFDF antenna that was designed and built by the former OAR Corp. in San Diego, California back in the mid-1980s. The UA-282 nominally covered 0.5-30 MHz and was designed for man portable or small vehicle transport. It employed collapsible short elements (approximately 10' tall) with base preamplifiers to partly overcome the diminished sensitivity associated with these short elements. Its element spacing (aperture) was approximately 33'.

Although nominally specified to operate down to 0.5 MHz, the UA-282 did not work well below 1.5 MHz or so (probably as a result of network balancing issues). Although the preamplifiers at the element bases partially overcome the diminished sensitivity inherent in the short elements, they were prone to intermodulation from strong signals. Another problem was that the wire ground screen was inadequate. The UA-282 has been out of production for about 25 years.

The RDF Products model DUA-1124B1 illustrated in Figure 17 is a more modern HFDF 8-element Adcock. Covering 1.5-30 MHz, the DUA-1124B1 employs 20' tall elements so as to provide good sensitivity without the need for intermodulation prone preamplifiers at the element bases. Its element spacing (aperture) is 32'.

**Figure 17 - RDF Products 1.5-30 MHz DUA-1124B1 8-Element Adcock**

The DUA-1124B1 employs are more extensive and better isolated wire ground screen than the DUA-1124B. This in turn results in far better immunity to variations in soil conductivity and permittivity and also superior rejection of horizontally-polarized signal components.

The DUA-1124B1 is effective for direct, surface, ground, and sky wave reception and has ultra-high signal handling capability. It is effectively a modernized replacement for the U.S. Army AN/TRD-4A that was used extensively (and effectively) during the Vietnam War.

Notice that both the UA-282 and DUA-1124B1 employ central (as opposed to derived) sense antennas. In both cases, this was done to avoid the derived sense output amplitude variability issues discussed in Section VI-D.

## SECTION VIII - SUMMARY AND CONCLUSION

The symmetrical 8-element Adcock is the most elegant and sophisticated implementation of Adcock radio direction finding antenna technology. Although it has been in use for over 50 years, there is still some confusion and misinformation regarding its advantages.

As per the discussion in Section IV-B (and especially the spacing error graph of Figure 10), the 8-element Adcock's fundamental (and sole) advantage is that a single array can cover frequency spans 3-4 times greater than that of its simpler 4-element counterpart. Aside from that, it offers no other benefits and is more costly to implement.

Despite this sole advantage, some misconceptions (and outright misinformation) have been promulgated by some manufacturers. These are listed and debunked as follows:

1. Improved Bearing Accuracy - There is a certain element of truth to this claim, but the 8-element Adcock's improved bearing accuracy is limited solely to its reduced spacing error at wider spacings. Since no astute user would attempt to use a 4-element Adcock beyond its narrower frequency range capabilities, the 8-element Adcock's "improved bearing accuracy" claim is really just double-counting its wider frequency coverage advantage.

   Actually, an argument can be made that the 8-element Adcock has less bearing accuracy on a practical level due to the additional process control errors in the added 4-to-2 phase transformer as discussed in Section VII. While these added errors can be minimized in the HF range, they become progressively more serious in the V/UHF range.

2. Multi-Path Bearing Error Reduction - The claim has been made that since an 8-element Adcock is a medium- to wide-aperture DF antenna over much of its frequency range, it has an inherent ability to reduce bearing errors caused by multi-path reception. The basis for this claim is the demonstrated ability of pseudo-Doppler DF antennas of similar medium- to wide-aperture spacing to suppress multi-path bearing errors via the mechanism of wavefront averaging. (See Ref. 3.)

   Unfortunately, this wavefront averaging mechanism is non-functional for Adcocks. Regardless of their aperture, Adcocks (both 4- and 8-element) inherently perform as narrow-aperture DF antennas with no ability to suppress multi-path bearing errors. Any claim to the contrary is spurious.

3. More Professional-Quality - The claim is sometimes made that the 8-element Adcock is somehow more "professional-quality" than its 4-element counterpart. While it is true that the 8-element Adcock does offer the advantage of being able to function over a wider frequency range with low spacing error, this speaks to a specific performance advantage (though with limited applications and at increased cost as discussed above) rather than to any standard of professionalism. Both types are professional-quality units when designed and manufactured to professional standards. <>

## REFERENCES

1. N. Burtnyk, “A Symmetrical Eight-Element Four-Phase Adcock Antenna”, Transactions of the Engineering Institute of Canada, February 1964.

2. Alex J. Burwasser, “Basics Of The Watson-Watt DF Technique”, RDF Products Web Note WN-002, December 1998.

3. Alex J. Burwasser, “A Comparison of the Watson-Watt and Pseudo-Doppler DF Techniques”, RDF Products Web Note WN-004, April 1999.