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# AN-007A

## Application Note

# AN INTRODUCTION TO THE AN/TRD-4B 1.5-30.0 MHz ADCOCK/WATSON-WATT TACTICAL HFDF SYSTEM

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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

The new AN/TRD-4B is a 1.5-30.0 MHz fixed-site monopole Adcock tactical HFDF system employing RDF Products' enhanced single-channel Adcock/Watson-Watt DF technique. The AN/TRD-4B is a highly modernized and refined 21st century successor to its Vietnam/Cold War era AN/TRD-4A predecessor.

Although the AN/TRD-4B has no official Army/Navy (AN) designation status as its name would appear to imply, this designation was chosen in recognition of the brave men of the U.S. Army Security Agency and other U.S. and Allied military personnel who used the original AN/TRD-4A systems with great skill and effectiveness during the Vietnam War. It was also chosen in recognition of the engineers who skillfully designed and competently implemented that original system despite the fact that the technology available in 1955 (the year the AN/TRD-4A was officially introduced) was so primitive by today's standards.

The AN/TRD-4B employs a ground-mounted 8-element (plus central sense) "U" (ground-mounted monopole) Adcock HFDF antenna designed for temporary or permanent installation in a large, flat field. The array spacing (diameter) is 32' (9.75m). The nine monopole towers are approximately 22' (6.7m) tall. The combination of this element spacing, element height, and the 8-element Adcock implementation yields excellent bearing accuracy and sensitivity throughout the entire 1.5-30.0 MHz range.

The operator console is located approximately 150' (45.7m) distant from the central sense monopole tower via a supplied interface cable set. The DF receiver/processor/display comprises an Icom R8600 or user-supplied receiver with the RDF Products' standard DFP-1000B DF processor/display unit.

The system can be powered by any standard +13.8 VDC vehicle power source or from any suitable AC power supply capable of supplying 11-16 VDC at up to 4 amperes. This relatively modest power consumption makes the system suitable for solar charged battery powered remote operation.

Although the system is designed for permanent installation, no concrete needs to be poured to install the system. Additionally, no special construction skills or equipment are required. While not portable, the system can be transported as required to different locations via a small truck or van.

The AN/TRD-4B is effective for direct, surface, ground, and sky-wave reception and has ultra-high signal handling capability suitable for dense signal environments. It is capable of intercepting signals of all reception modes commonly used in the HF range (AM/NFM/SSB/CW as well as narrow-band digital), and is capable of both manned and unmanned operation. Multiple sites can be networked using RDF Products' HuntMaster digital mapping and location software.

The DUA-1124B1 is intended for regulatory, law-enforcement, surveillance, signal intelligence, frequency management, interference location, and other applications requiring a professional-quality tactical grade HF radio direction finding system.

## SECTION II - ORIGINAL U.S. ARMY AN/TRD-4A HFDF SYSTEM

### A. INTRODUCTION

Since the AN/TRD-4B is a modernized replacement for the original U.S. Army AN/TRD-4A, the discerning reader will likely want to know the history and capabilities of this earlier system as a basis for better understanding the modernizations and enhancements that have been made in the new AN/TRD-4B. This background is presented in the paragraphs below.

### B. AN/TRD-4A OVERVIEW

The AN/TRD-4A was developed shortly after the Korean War to provide an improved HFDF capability at the tactical level. The front cover of its technical manual TM 11-688 (reference 1) is illustrated in Figure 1. Although compact cross-loop HFDF antennas had been deployed for this purpose during World War II and the Korean War, the U.S. Army Security Agency (USASA) determined that a larger and more effective Adcock HFDF antenna design was necessary to provide superior performance.

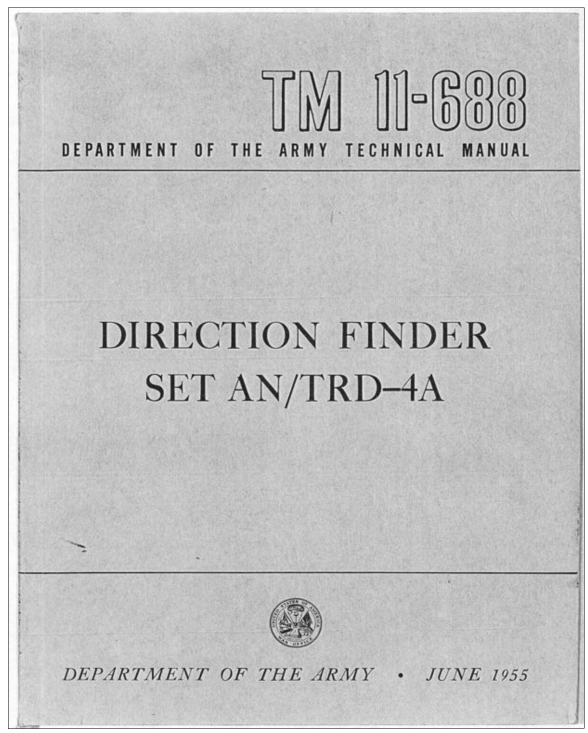

TM 11-688
DEPARTMENT OF THE ARMY TECHNICAL MANUAL
DIRECTION FINDER
SET AN/TRD-4A
DEPARTMENT OF THE ARMY • JUNE 1955

**Figure 1 - U.S. Army AN/TRD-4A Technical Manual TM 11-688 (June 1955)**

The AN/TRD-4A employed two co-located 4-element monopole Adcock arrays to cover its full 0.54-30.0 MHz range. The smaller (inner) array was 18.8' (5.74m) in diameter with 22.3' (6.8m) tall monopole towers and covered 8.0-30.0 MHz.

The larger (outer) array was 33' (10m) in diameter with 29' (8.8m) tall monopole towers and covered 0.54-10.0 MHz. These taller towers included top-loading radial capacitive hats to improve effective height (sensitivity). Figure 2 is a pictorial illustration of these two arrays from TM 11-688.

In many cases, only one of these two arrays (typically the larger 0.54-10.0 MHz array) was installed based on the signal frequency intercept requirements. For most of the Vietnam deployments, most signals of interest were below 10.0 MHz.

Since these were monopole arrays, a large "counterpoise" (conductive ground plane) was required for them to function effectively. The AN/TRD-4A employed a foldable 75' x 75' (22.9m x 22.9m) wire mesh structure for this purpose. Figure 3 is a pictorial illustration of this counterpoise from TM 11-688.

The system also included a rotatable cross-loop antenna array for close-in HFDF applications. This loop array was effective only for vertically-polarized ground wave reception and was not frequently used.

The AN/TRD-4A operator console was located inside a weather-protected shelter that housed the electronics equipment. This shelter also served as the container for the entire system for local transport and storage. (This shelter in turn was packed in a large crate for shipping.)

The pictorial drawing of Figure 4 (from TM 11-688) illustrates the entire system. This illustration depicts a single (larger) array with the top-loading capacitive hats covering 0.54-10.0 MHz. The rotatable cross-loop HFDF antenna can be seen atop the shelter.

The lower right cut-out detail in Figure 4 illustrates the operator console. The HF radio receivers were R-390s (later succeeded by the R-390A). This receiver (first manufactured by Collins Radio) was the most advanced military shortwave receiver of the 1950s and was used into the 1980s. It covered 0.5-32.0 MHz and employed 33 vacuum tubes. As per Figure 5, it was a large radio with many controls and features and had excellent performance.

As per Figure 4, one of these R-390 receivers was the dedicated HFDF receiver. The scope azimuth display unit can be seen atop that receiver. The two remaining R-390s were used for spectrum monitoring and listen-thru.

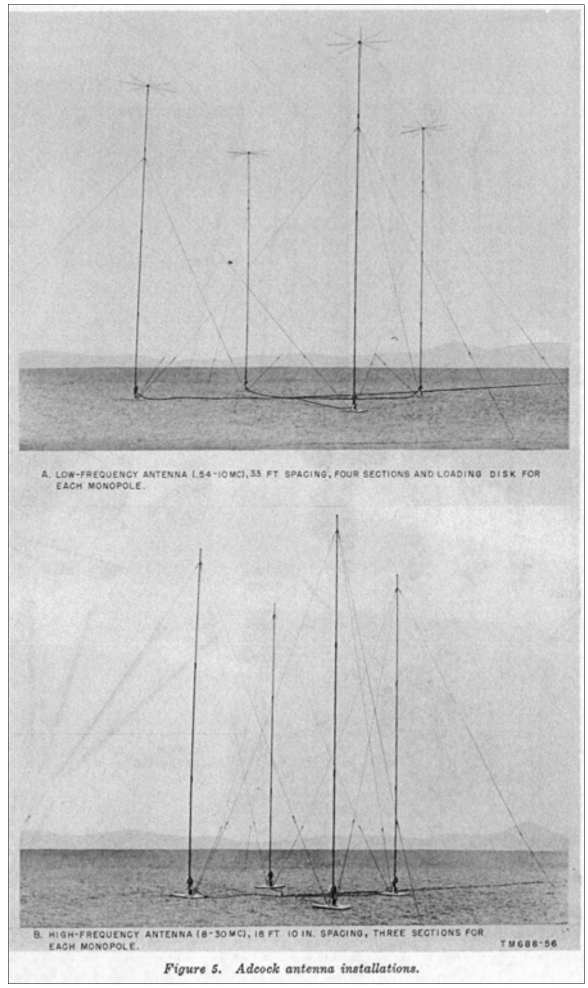



**Figure 2 - AN/TRD-4A Low- and High-Band 4-Element Adcock Arrays (from TM 11-688)**

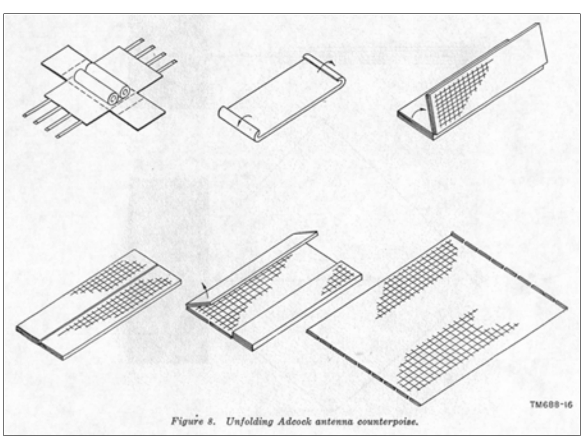



**Figure 3 - AN/TRD-4A Foldable 75' x 75' Wire Mesh Counterpoise (ground plane)**

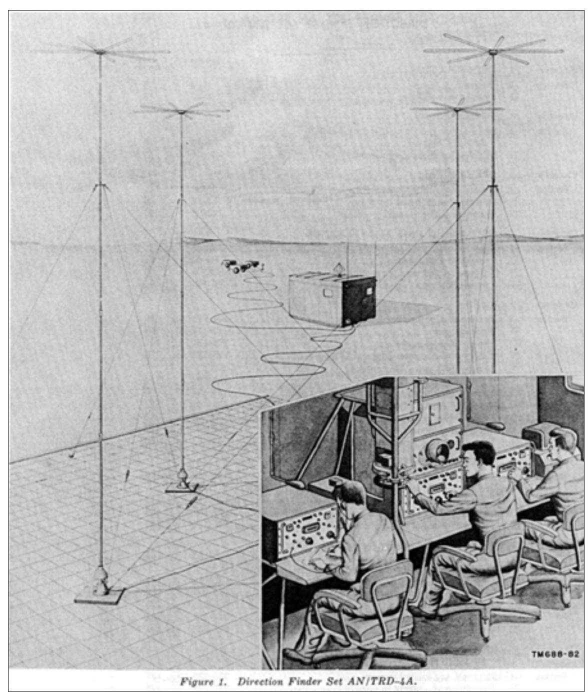



**Figure 4 - AN/TRD-4A HFDF System Overall Pictorial**

As can be seen from Figure 4, the overall system was quite large and expansive. Although difficult to discern from the pictorial, the system transport truck and AC generator trailer is also visible.

**Figure 5 - R-390A 0.5-32.0 MHz Receiver (courtesy of Wikipedia)**

Since all the electronic equipment employed vacuum tube circuitry, overall power consumption was high (nearly 2,000 watts). This included the power required for a heater and ventilation blower. Although some systems were run from AC power mains (115/230 VAC; 48-62 cycles), many were operated at remote locations that required a gasoline operated AC generator.

The overall system was also quite heavy and bulky. The total volume was 622 cu. ft with a weight of 3,800 lb/1727 kg (excluding the 3,200 lb/1455 kg shipping crate).

## C. OPERATION

Unlike the RDF Products DFP-1000B (and most modern DF bearing processors), the AN/TRD-4A bearing resolver/display was not automatic. As per Figure 6, the DFP-1000B DF processor unambiguously and almost instantaneously provides an unambiguous real-time polar bearing display of the intercepted signal. Very little operator skill or intervention is required provided that the bearing is stable.


**Figure 6 - DFP-1000B DF Bearing Processor (with unambiguous real-time polar bearing display)**

Resolving the bearing for a signal intercepted by the AN/TRD-4A was not nearly as simple or instantaneous. As per Figure 7, the intercepted bearing had the appearance of a propellor on the 5" (9.8cm) cathode ray tube (CRT) display. Referring to the "bearing" pattern to the left in Figure 7, the operator could tell at this point that the intercepted signal azimuth was either 0° or 180°, but did not yet know which (i.e., the bearing pattern inherently had a 180° ambiguity).

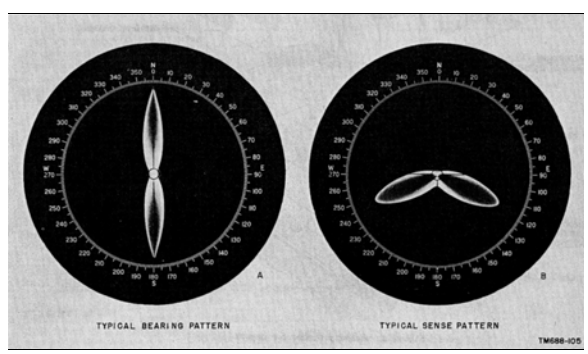



**Figure 7 - AN/TRD-4A Bearing (left) and Sense (right) Display Patterns**

To resolve this ambiguity, it was necessary to press a button that would add the omni-directional sense signal. This would result in the "sense" pattern that would cause the propellor "blades" to bend in one direction or the other to resolve the 180° bearing ambiguity. The sense pattern of Figure 7 (right) thus indicates a 180° (rather than 0°) received signal azimuth.

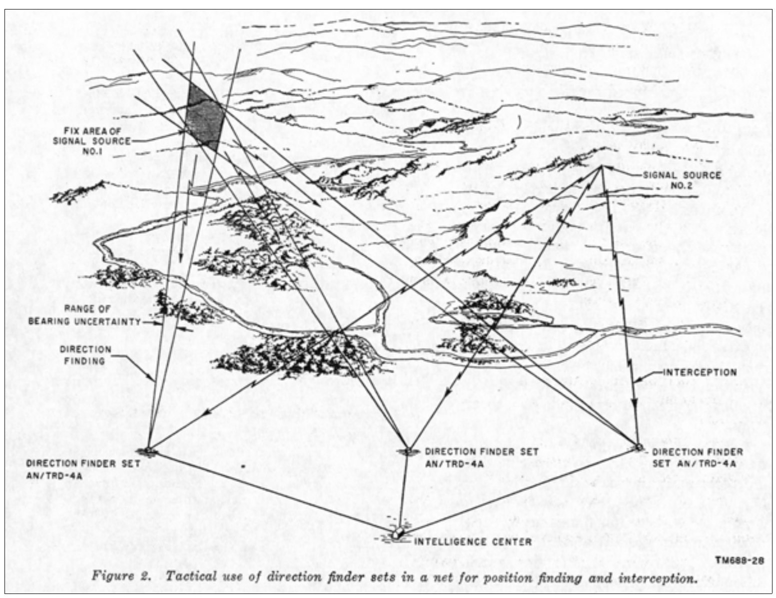
Unfortunately, the clean patterns in Figure 7 were obtainable only for near-ideal signals. Under more typical circumstance, the propellor patterns were often noisy, indistinct, would blossom, sway, and sometimes even spin. Obtaining useful bearings under such circumstances required a great deal of operator intervention (by appropriately adjusting the controls), interpretation, and skill.

The requirement for a two-step bearing resolution (reading first the bearing pattern and then switching to the sense pattern to resolve the 180° ambiguity) plus the need for skilled operator intervention and interpretation required significant time to obtain a line-of-bearing. In contrast, the DFP-1000B does most of this electronically resulting in much faster and more automatic bearing acquisition requiring far less skill and interpretation.

## D. <u>INTER-SITE COORDINATION</u>

Since a line-of-bearing from a single AN/TRD-4A HFDF site was only marginally useful, multiple sites were deployed that were then networked together with the results analyzed at the coordinating signal intelligence center. The general concept is illustrated pictorially in Figure 8 (from TM 11-688).

As depicted in Figure 8, three deployed sites are networked under the coordination of the signal intelligence center. In typical DF missions, the signal intelligence center would assign frequencies of interest to the sites, which in turn would obtain lines-of-bearing on the intercepted signals and then report this information back to the signal intelligence center.




**<u>Figure 8</u> - Networked AN/TRD-4A HFDF Sites**

Throughout much of the Vietnam War, this communication was frequently done manual Morse CW. (The AN/TRD-4A sites had CW transmitters and operators for this purpose.) One-time pads were used for encryption.

The signal intelligence center would then plot these lines-of-bearing on paper maps to estimate the locations of the intercepted transmitters. This information was then passed along for further analysis.

## E. SYSTEM MODERNIZATIONS AND IMPROVEMENTS

Using manual Morse CW with one-time pad encryption was both slow and cumbersome. In the later years of the Vietnam War, these manual Morse data links were replaced by much faster 60 wpm encrypted Teletype links using Model 28 Teletypes and fully electronic on-line tactical crypto machines to provide fast and secure real-time data links between the AN/TRD-4A sites and the signal intelligence center. In some cases, this signal intelligence center was located very close to one of the sites in the network.

A further modernization was the R-390A receiver "Auto-Tune" modification. These comprised motor-driven servo-controlled tuners that replaced the R-390A tuning knob. These auto-tuners were capable of automatically tuning to frequencies as received over the encrypted Teletype links from the coordinating signal intelligence center for fast signal acquisition. Although primitive by today's standards, these systems were quite advanced for 1960s-era technology.

## F. AN/TRD-4A SYSTEM COST ESTIMATE

Cost information is difficult to research for a product first built and deployed over 60 years ago. Also, 1955 dollars were worth many times current dollars. Even so, based on the equipment used and the elaborate nature of the AN/TRD-4A, this system would likely cost the equivalent of $300,000-$500,000 in current (2017) U.S. dollars as a rough estimate.

## G. SURVIVING SYSTEMS

The likely operational period of these AN/TRD-4A systems for the U.S. military was 1955-1976. As is the case for the cost estimate, it is similarly difficult to track the history of any post-Vietnam surviving systems.

When U.S. forces left South Vietnam in 1973, it is likely that some of the deployed systems were turned over to the South Vietnamese military (most likely trained and assisted by U.S. government civilian advisors). Following the fall of South Vietnam in April 1975, it is possible that some of these systems fell into the hands of the North Vietnamese.

It is unlikely that these systems were ever used operationally by U.S. forces after 1976, but it is almost certain that some of these systems continued in operation post-1976 in Thailand, some NATO countries, and possibly some other countries having bilateral defense arrangements with the U.S. Since the system employed mostly 1950s-era vacuum tube technology, they would have become increasingly difficult to maintain and repair after 1976. Also, the necessary institutional memory for such maintenance and repair would have quickly evaporated after 1976. In all likelihood, there are no surviving AN/TRD-4A systems in operation today.

# SECTION III - RDF PRODUCTS AN/TRD-4B HFDF SYSTEM OVERVIEW

## A. INTRODUCTION

The RDF Products AN/TRD-4B 1.5-30.0 MHz tactical HFDF system is the true 21st century successor to the original U.S. Army AN/TRD-4A. Although the “A” and “B” versions are both single-channel ground-mounted U-Adcock HFDF systems with similar capabilities, there are also major differences. Succinctly stated, the AN/TRD-4B is a highly modernized, refined, and evolved implementation of the original AN/TRD-4A made possible by over 60 years of technological advancement and field experience.

The AN/TRD-4B comprises two major components. The first of these is the DUA-1124B1 1.5-30 MHz 8-element U-Adcock DF antenna. As illustrated in Figure 9, this unit comprises an 8-element “U” (ground-mounted monopole) Adcock plus a central sense element. Each of the nine monopole towers are identical and have independent, ferrite-isolated radial wire ground planes.

**Figure 9 - RDF Products DUA-1124B1 1.5-30.0 MHz 8-Element U-Adcock HFDF Antenna**

An electronics signal processing hub is mounted near the base of the central sense element. This hub processes the signals from all nine elements to produce a single composite output that can be processed by the DFR-8600B DF receiver/processor/display (located at the operator position) to produce an unambiguous real-time DF bearing (in polar format) on the intercepted signal.

A 150' (45.7m) cable set interconnects the electronics hub with the DFR-8600B. This cable set comprises an RF coaxial signal output cable and a multi-conductor interface cable. This interface cable supplies the electronics hub with DC power, antenna axis encoding tones, and band switching information. Ferrite isolators are installed as required on all cables to maintain ground plane symmetry and prevent antenna pattern distortion and resulting bearing errors.

The array diameter (distance between opposite monopole towers) is 32' (9.75m), which is very close to that of the AN/TRD-4A low-band (0.54-10.0 MHz) array. The DUA-1124B1 monopole tower height is 22' (6.7m), which is somewhat less than the 29' (8.8m) tall towers employed by the AN/TRD-4A low-band array. As discussed in a subsequent Section, however, this shorter tower height does not compromise sensitivity.

The second major AN/TRD-4B component is the DFR-8600B DF receiver/processor/display. As per Figure 10, the DFR-8600B comprises the RDF Products DFP-1000B DF processor/display and the Icom R8600 host receiver. This very compact unit, measuring only 8.5"x8.6"x10.6" (21.6x21.8x26.9cm) HxWxD, and weighing only 15.9 lbs. (7.2 kg) replaces the very large and heavy R-390A receiver and the even larger and heavier DF processor/display unit employed in the AN/TRD-4A as illustrated in Figure 4.

While the DFR-8600B can be manually operated, it is also capable of full remote control operation via its bi-directional RS-232 interface. In fact, overall basic system power consumption is sufficiently low (under 60 watts) to allow solar powered operation for unmanned remote sites.

The DFP-1000B is RDF Products' flagship DF bearing processor/display. It provides real-time lines-of-bearing on its bright TFT polar bearing display for AM/FM/CW/SSB signals (and most other signal formats with a transmitted bandwidth that is within its selected 6/15/30/200 kHz IF bandwidth).


**Figure 10 - RDF Products DFR-8600B HF/VHF/UHF DF Receiver/Processor/Display**

The R8600 host receiver is Icom's new 10 kHz-3,000 MHz wide coverage communications receiver. It is the first ultra-wide coverage receiver that has been designed specifically for superb HF reception. Its features and performance are far superior to that of the original AN/TRD-4A R-390A receivers.

## B. OVERALL SYSTEM FUNCTIONAL BLOCK DIAGRAM

To facilitate more convenient reader understanding, the overall system functional block diagram is presented in Figure 11. Standard (supplied) system components are indicated by solid lines while optional or user-supplied system components are indicated by dotted lines.

Standard system components are the 8-element plus central sense "U" Adcock array (referred to but not illustrated in Figure 11), the antenna electronics hub, the DFR-8600B (comprising the DFP-1000B DF processor/display and the Icom R8600 host receiver), and the 150' (45.7m) ferrite-isolated interface cable set.

Supplemental system components include one or more separate listen-thru receivers (dedicated to signal monitoring only), a GPS-synchronized ultra-precise 10.00000 MHz frequency reference for absolute receiver frequency accuracy, and system operating and mapping software. Custom software is also available.

User-supplied components include the 11-16 VDC power source and the Windows PC (required for remote operation).

A fuller explanation of these system components is provided in the Sections that follow. Comparisons are also made with the original U.S. Army AN/TRD-4A HFDF system.

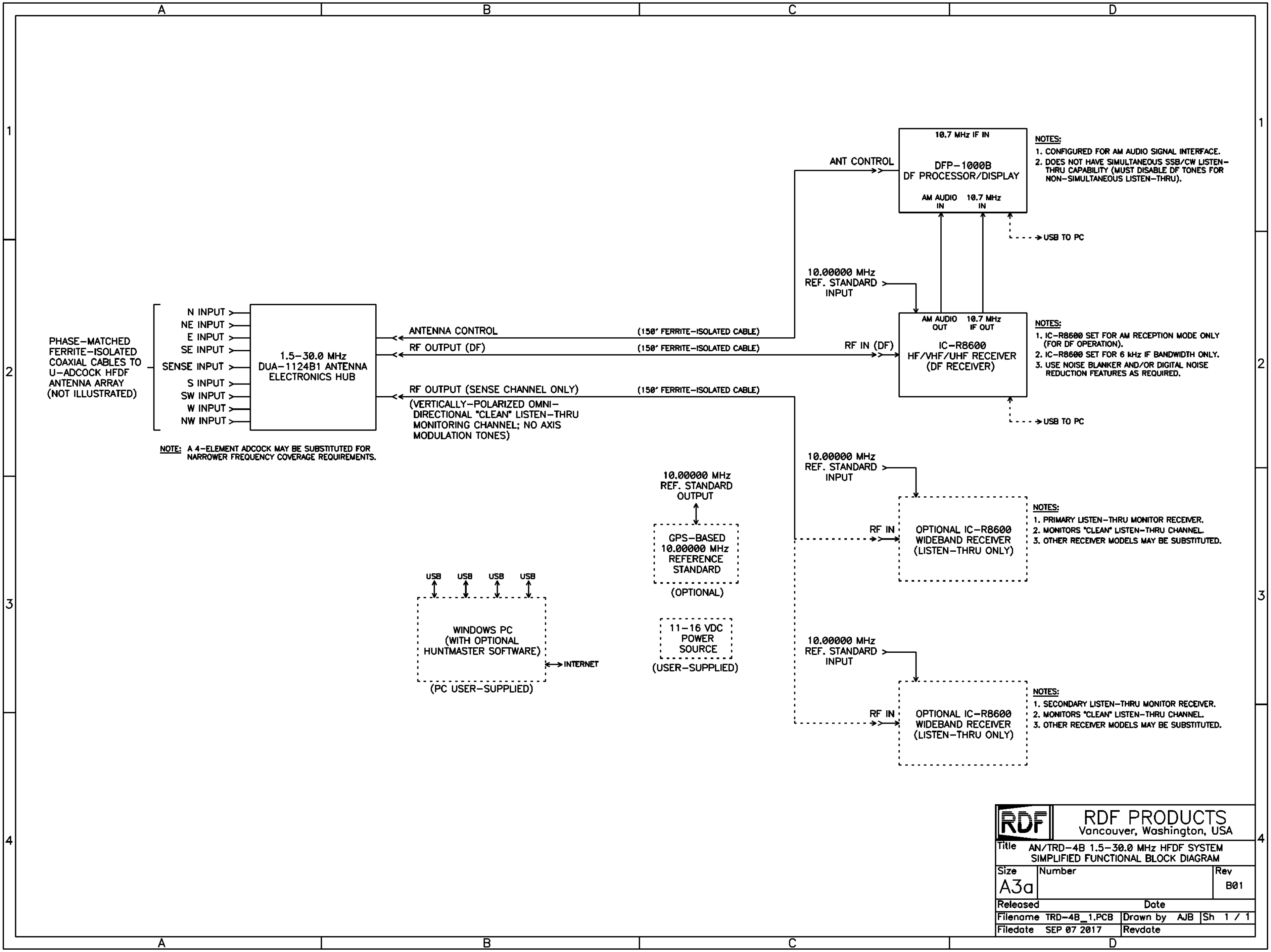



**Figure 11 - AN/TRD-4B HFDF System Functional Block Diagram**

## SECTION IV - RDF PRODUCTS DUA-1124B1 8-ELEMENT ADCOCK HFDF ANTENNA

### A. OVERVIEW

Referring to the Figure 9 photo and the Figure 11 functional block diagram above, the 1.5-30 MHz DUA-1124B1 component of the AN/TRD-4B comprises a ground-mounted 8-element (plus central sense) “U” Adcock monopole DF antenna array and a signal processing electronics hub. The nine monopole antenna towers are all 22' (6.7m) tall. The array aperture (distance between opposing towers) is 32' (9.75m).

The eight outer monopole towers are all connected to the electronics hub (located near the center of the array adjacent to the central sense tower) via 18' (5.5m) long precision-cut phase-matched double-shielded coaxial cables. The central sense tower is connected to the electronics hub via a precision-cut 5.0' (1.5m) double-shielded coaxial cable.

As per Figure 11, the DUA-1124B1 antenna electronics hub is connected to the DFR-8600B DF receiver/processor/display via a 150' (45.7m) interface cable set. As per the discussion in Section III-A, this cable set comprises a double-shielded coaxial signal output cable and a multi-conductor power/control cable.

This long cable set is necessary to allow the operator position to be located sufficiently far from the DF antenna array to prevent undesired interaction that could cause bearing errors. Also, the signal output coaxial cable is double-shielded (as are the monopole tower cables connected to the electronics hub) to prevent cable signal pickup that could cause bearing errors. As in all DF systems, it is extremely important that *only the antenna elements receive the incoming signal and that there not be unintended signal pickup on the output cables*.

### B. 8- VERSUS 4-ELEMENT ADCOCK ARRAY

The original Adcock DF antenna (patented by F. Adcock in 1919 in Great Britain) was a 4-element (plus central sense) design. As per the discussion in Section II, the original AN/TRD-4A likewise was a 4-element Adcock system.

Although 4-element Adcocks work very well, one of their limitations is their frequency coverage. In most DF applications, a 4-element Adcock can be designed to work satisfactorily over a frequency range of up to 4:1 or so (although this range can be extended somewhat with careful design). Attempting to operate it over a significantly wider frequency range results in serious compromises in bearing accuracy, sensitivity, or both.

Since the AN/TRD-4A was specified to cover 0.54-30.0 MHz, a single 4-element Adcock array was insufficient to cover the full frequency range without unacceptable performance compromises. Instead, two co-located 4-element arrays (covering 0.54-10.0/8.0-30.0 MHz) were required to cover the full range as per the discussion and illustrations in Section II.

Although in many cases only one of these two arrays was required at a given installation, there were also cases where both arrays were necessary. This was not an ideal solution since the larger outer array interacted significantly with the smaller inner array. This resulted in antenna pattern distortion which in turn caused significant bearing errors above 10 MHz (the frequency range of the inner array). Furthermore, these errors could not be mitigated using site calibration or algorithmic solutions. Since no technical solution was available to solve this problem in 1955 (the year the AN/TRD-4A was introduced), compromise performance had to be accepted.

An additional compromise also had to be accepted for the AN/TRD-4A 0.54-10.0 MHz low-band (outer) array. With a 4-element Adcock array, the array aperture (diameter) can be up to about 1/3 of a wavelength at the highest operating frequency. Since the spacing of the outer array was 10 meters and the wavelength at the 10 MHz high-end low-band frequency is 30 meters, this condition was met (i.e., 10/30 = 1/3).

However, using the 4:1 frequency coverage ratio cited above as the maximum for a 4-element Adcock, this would imply a 2.5 MHz minimum low-end frequency. Since the AN/TRD-4A low-end low-band frequency was specified as 0.54 MHz, its frequency coverage ratio was 10/0.54, or 18.5:1, which is far higher than what is usually considered acceptable for a well-designed 4-element Adcock DF antenna.

Since atmospheric noise levels tend to be high at these low frequencies, the sensitivity loss (resulting from the very narrow array aperture with respect to a wavelength at such low frequencies) could likely be tolerated (since signals had to be strong enough to overcome this noise). However, operating an Adcock DF antenna at such a narrow aperture also makes the system vulnerable to inter-element imbalances that can cause bearing errors. It is therefore possible that AN/TRD-4A bearing accuracy below 2.0 MHz or so may have been impaired as a result.

As a practical matter, this was probably irrelevant. It is doubtful that the AN/TRD-4A was ever required to operate below 2.0 MHz, so these performance issues likely never surfaced.

In 1964, a new Adcock DF antenna design employing eight symmetrical elements was introduced by N. Burtnyk in Canada (reference 2). The innovative feature of this new Adcock was that it could cover a much wider frequency range (over 20:1) than the 4-element version. An 8-element Adcock thus allows the full HF range to be covered with a single array without the aforementioned performance compromises of the co-located dual 4-element array.

Although the 8-element Adcock requires a much more complicated electronics hub than its 4-element counterpart, it is the ideal solution for a full-coverage Adcock HFDF system. It is for this reason that this design was selected for the DUA-1124B1. While the various issues underlying the differences between 4- and 8-element Adcocks are beyond the technical purview of this paper, interested readers can refer to RDF Products Application Note AN-006 (reference 3) as well as the Burtnyk paper (reference 2).

Although the DUA-1124B1 low-end frequency limit is 1.5 MHz (rather than 0.54 MHz for the original AN/TRD-4A), there are few, if any, DF requirements below 1.5 MHz (which is near top-end of the 0.54-1.7 MHz AM broadcast band). Also, since the AN/TRD-4A had questionable performance in this frequency range as per the discussion above, the DUA-1124B1 1.5 MHz low-end frequency limit is not a comparative disadvantage.

Although the 8-element Adcock is an elegant design and ideally suited for full HF range coverage, it is also true that in many instances end-users may require coverage of a narrower portion of the HF spectrum. For such applications, RDF Products can substitute simpler and less expensive 4-element Adcocks.

## C. SENSITIVITY

Despite some manufacturers' claims to the contrary, there is no significant difference in sensitivity between 4- and 8-element Adcocks. Even so, the AN/TRD-4A apparently exhibited diminished sensitivity due to losses in its input circuitry. This led the U.S. Army to commission the University of Michigan Research Institute electrical engineering department in 1960 to conduct a study to quantify this (reference 4).

In contrast, the DUA-1124B1 has been carefully engineered using modern components and circuitry to avoid such losses. Furthermore, low noise amplifiers with high signal handling capability are employed as required for best sensitivity.

## D. GROUND PLANE ISSUES

Monopole antennas require substantial conductive ground planes (alternatively referred to in the literature as "ground screens", "image planes", and "counterpoises") to function well. DF operation places even greater demands on the quality of the ground plane.

An ideal ground plane would be an infinitely large (or at least many wavelengths in radius at the operating frequency) flat conductive sheet directly under the monopole base (feed point). Since this is obviously impractical, more feasible implementations must be employed. The most commonly used techniques are as follows:

1. **Metal Stake** - The simplest implementation is just to drive a long metal stake into the ground at the monopole base (feed point). This is a very poor technique, however, since it is very lossy (inefficient). Also, the monopole resonant frequency is greatly influenced by soil characteristics.

2. **Buried Wire Radials** - This technique employs a large number of buried wires extending radially outward from the monopole base. For best results, these wire radials should be long, equal in length, and symmetrically placed. AM broadcast monopole towers typically employ this technique, using 120 symmetrically placed wire radials. Ideally, these radials are approximately 1/4 wavelength long at the operating frequency.

   A large number of radials is required for the monopole to be efficient. If only a small number can be laid, the ground system will be more lossy. Also, losses tend to be greater if the soil itself is not conductive. (AM broadcast stations often employ soil treatments to improve soil conductivity to reduce these losses.) Also, the monopole resonant frequency is significantly influenced by soil characteristics.

Since installing these buried wire radials is very tedious and labor intensive, this technique is suitable only for permanent installations. It would be impractical to redeploy an antenna system using buried wire radials to a different location.

3. **Non-Buried Wire Radials** - A wire radial system can also be laid on the ground rather than buried. This offers the benefit of a simpler installation than for buried wire radials, but also creates a maintenance issue in that it is difficult to mow a field with wire radials laying on the ground. As is the case with the buried wire radial system, the monopole resonant frequency is significantly influenced by soil characteristics (although significantly less so). Losses are also less than with buried radials.

4. **Elevated Wire Radials** - By elevating the wire radials and employing a raised feed to the monopole, greatly improved performance can be achieved. With even modest elevation, the antenna system becomes largely impervious to soil characteristics. This is extremely important in a DF installation where all the monopole towers must have nearly identical characteristics, and where these characteristics must remain constant regardless of where the system is deployed. A further advantage is that a large number of radials is not required.

As per the illustration in Figure 3, the AN/TRD-4A employed a 75' x 75' (22.9m) foldable wire mesh as its ground plane. Since the wire mesh was attached to plywood, it was at least slightly elevated above ground.

Although large, this ground plane was not very large compared to a wavelength at any operating frequency in the AN/TRD-4As 1.5-30.0 MHz range. The deficiencies of this ground plane (and the associated four monopole tower signal output coaxial cable feed lines ) can be summarized as follows:

1. **Ground Plane Asymmetries** - The innovative feature of the Adcock DF antenna is its ability to reject horizontally-polarized signal components. As per RDF Products Application Note AN-005 (reference 5) and the references cited in that paper, loop DF antennas work very poorly as a consequence of their inability to reject horizontally-polarized signals arriving at positive elevation angles. Since the desired loop bi-directional figure-of-8 gain pattern becomes distorted when receiving horizontally-polarized signals, bearing errors result.

   This was quickly recognized by the early 20$^{th}$ century HFDF users who noticed that loop DF antenna bearing accuracy was very poor at night due to sky-wave reception. (This was referred to as the “night effect”.) These sky-wave signals (which are predominant at night), tend to have large horizontally-polarized signal components.

   Since Adcock DF antennas provide excellent rejection of horizontally-polarized signal components (due to their vertical orientation) when properly constructed, bearing accuracy is greatly improved for sky-wave reception. However, it is important that an Adcock array be constructed in such a fashion so as to not compromise its ability to reject horizontally-polarized signals.

   For best horizontal polarization rejection, it is important that the monopole ground plane be symmetrical. Keeping in mind that the ground plane is part of the monopole antenna and a horizontally-oriented structure, it can receive horizontally-polarized signal components if it is not symmetrical. (Although a symmetrical ground plane also receives horizontally-polarized signal components, the induced currents cancel due to the ground plane symmetry. Thus, there is no resulting output voltage from the monopole feed point).

If the monopole tower, however, is located off-center on the ground plane, the resulting ground plane asymmetry upsets this cancellation with the result that the antenna no longer exhibits the desired horizontal polarization rejection and thus loses some of its advantage over a loop DF antenna.

This asymmetry was an issue for the AN/TRD-4A. Although its four monopole towers were located symmetrically ***as an array*** on its 75' x 75' (22.9m) wire mesh ground plane, the individual towers themselves were off-center. Therefore, each tower ***individually*** had an asymmetric ground plane, thus compromising their ability to reject horizontally-polarized signal components. (This problem could have been mitigated by using a much larger ground plane, but this would have been impractical.)

2. **Monopole Tower Feed Lines** - Each of the AN/TRD-4A four monopole towers had a coaxial cable signal feed line that ran horizontally from each antenna base to the operator position. These cables were thus effectively part of the overall ground plane and further contributed to ground plane asymmetry that compromised horizontal-polarization rejection.

The DUA-1124B1 employs a much improved ground plane that overcomes all of the shortcomings of the AN/TRD-4A. To summarize these improvements and referring to the prototype DUA-1124B1 monopole tower photos of Figures 12 and 13:

1. **Symmetrical 8-Radial Ground Plane** - Since it is impractical, as discussed above, to construct a ground plane sufficiently large to avoid asymmetries for a multiple monopole tower array, the DUA-1124B1 employs a compact symmetrical 8-radial ground plane for each tower. With this improved symmetry, excellent horizontal polarization rejection is achieved. Since all nine towers require their own ground plane and the radial wires overlap between adjacent towers, insulated wires are employed to ensure isolation.

2. **Raised Feed** - Rather than being buried or laid on the ground, these eight radials (and the monopole tower base) are elevated approximately 18" (0.46m) above the ground. As discussed above, by elevating the wire radials and employing a raised feed to the tower, greatly improved performance can be achieved. With even modest elevation, the antenna system performs very consistently over a wide range of soil characteristics.

3. **Isolated Feed Cables** - Each monopole tower is fed with a coaxial feed cable that connects to the antenna electronics hub (located adjacent to the central tower). Since the shield side of these coaxial cables is connected to the radial ground plane (at the tower feed points), these cables effectively become part of that ground plane.

   Since these cables would otherwise upset the ground plane symmetry and reduce immunity to horizontally-polarized signals as discussed above, ferrite isolators are employed on these coaxial cables to prevent antenna currents from flowing into the cable shields. Similarly, the 150' (45.7m) interface cable set connected between the electronics hub and the operator position also employs ferrite isolators.

**Figure 12 - DUA-1124B Monopole Tower & Elevated Ground Radials**

**Figure 13 - DUA-1124B1 Elevated Ground Radials (close-up; photo edited for illustration)**

## E. NEC-4 COMPUTER MODELING

Back in the mid-1950s when the AN/TRD-4A was developed, design engineers mostly had no access to computers. Antenna design, being very complex, had to be accomplished mostly with pencil and paper design techniques aided by tables, nomographs, imprecise rules-of-thumb based on historical experience, and difficult and tedious outdoor far-field test measurements conducted with crude equipment (by today's standards). This was all very difficult, labor intensive, and tedious work that was hard to validate and yielded imprecise results. In most laboratories, the most advanced computational devices available were slide rules and electro-mechanical calculators that could do little more than add, subtract, multiply, and divide. Although primitive computers did exist in some very high-end laboratories, these computers would not have had the processing power or memory to conduct sophisticated antenna modeling and analysis even if software had been available for this purpose at that time.

With the benefit of modern personal computers with their enormous computing power and advanced antenna modeling and analysis software, modern antenna designs can be accomplished far more easily, rapidly, precisely, and with far fewer tedious outdoor far-field measurements. It is no overstatement to claim that this has been a huge paradigm shift in antenna design, analysis, and development.

The most advanced such software is the Numerical Electromagnetics Code, or NEC (reference 6). The two authors originally wrote NEC in FORTRAN for mainframe computers back in the 1970s. Since that time, NEC has become highly evolved. Its current implementation (NEC-4) is far more sophisticated than the original version and can even model buried antenna ground radials with specified soil characteristics. NEC has also been re-coded into more current programming languages so that it can be run more conveniently on modern PCs.

In its native format, NEC is somewhat difficult to use, but an entire cottage industry has emerged with enhanced versions employing modern Windows-compatible graphical user interfaces. These modern versions are far better human engineered, offering much easier data entry and output, graphics, and many other features that greatly enhance convenience and flexibility to the core product.

Once such enhanced version is EZNEC (reference 7). EZNEC was originally written approximately 25 years ago by Roy Lewallen (W7EL) as a modestly priced antenna software product for the amateur radio market. This product is now very highly evolved and refined, having benefitted from the feedback of its many users over many years. The standard version employs the NEC-2 algorithm, while the far more capable professional version employs the highly advanced NEC-4 algorithm. This professional version was extensively employed in the DUA-1124B1 design with great benefit, particularly for the ground radial design modeling.

## SECTION V - RDF PRODUCTS DFR-8600B HFDF RECEIVER/PROCESSOR

### A. INTRODUCTION

The DFR-8600B is an HF/VHF/UHF DF receiver/processor/display that receives the signal from the DUA-1124B1 antenna electronics hub, appropriately tunes, demodulates and processes it, and then indicates the azimuth of that signal on its real-time polar bearing display. It also supplies 11-16 volt DC power, X/Y axis encoding tones, and band switching information to the DUA-1124B1.


**Figure 14** - **RDF Products DFR-8600B HF/VHF/UHF DF Receiver/Processor/Display (replicated from Figure 10 for convenience)**

As per Figure 14 (replicated from Figure 10 for convenience of reference) the DFR-8600B comprises the new Icom R8600 wide coverage communications receiver and a standard RDF Products DFP-1000B DF processor. This very compact DF receiver/processor/display effectively replaces the very large and heavy R-390A receiver and its even larger and heavier companion DF processor/display unit in the AN/TRD-4A as illustrated in Figure 4.

In addition to providing a real-time polar bearing display, the DFR-8600B also has a bi-directional RS-232 interface for full remote operation. With its companion interface software, the real-time polar bearing display can also be displayed in real-time on a host computer.

In the following paragraphs, the R8600 receiver and DFP-1000B DF processor are further discussed in detail. Refer to the Figure 11 functional block diagram as required to facilitate this discussion.

### B. ICOM R8600 RECEIVER

As mentioned, the DFR-8600B employs the new Icom R8600 wide coverage communications receiver as the DFR-8600B host receiver component. This model replaces the earlier R8500 that was used for many years for signal monitoring and DF applications.

A unique feature of the R8600 (as compared to competing wide coverage communications receivers) is that it was designed for excellent HF performance. To explain, while the earlier R8500 and similar wide coverage communications receiver offer HF coverage, they were not specifically designed for the rigorous and demanding requirements of HF reception. To explain, signal levels in and near the HF range can be very high with the result that the receiver front-ends can overload and suffer intermodulation distortion. Since previous wide coverage communications receiver included very little front-end preselection in the HF range, their HF performance was mostly sub-standard.

A particular advantage of the R8600 its inclusion of ***sub-octave input bandpass filters*** in the HF range. To explain, well-designed HF receivers (including all modern amateur radio HF receivers in particular) employ sub-octave input pre-selector filters. These filters reject strong AM broadcast, FM broadcast, TV, and other out-of-band signals that would otherwise compromise receiver performance by causing receiver front-end overload, intermodulation, and other performance ills.

The term "sub-octave" literally means that the ratio of the bandpass filter upper cutoff frequency to its lower cutoff frequency is less than 2:1. Although the significance of this is somewhat technical, the plain-language explanation is that if a receiver front-end is preceded by a sub-octave filter, ***there is no combination of input signal frequencies that can cause 2$^{nd}$-order intermodulation distortion in the following active stages (e.g., the amplifiers and mixers)***.

To expand on this point a little further, intermodulation distortion creates spurious signals that appear at frequencies on the receiver tuning dial where no such signals should exist. As an example, suppose that a radio operator is attempting to monitor a weak signal. If the receiver is prone to intermodulation distortion, two strong off-frequency signals can mix together in the receiver active circuitry to produce spurious signals at new frequencies that could fall on the weak signal frequency (and thus interfere with reception).

The inclusion of sub-octave filters ***thus provides the receiver with a high degree of immunity to an entire category (i.e., 2$^{nd}$-order) of intermodulation distortion***. This is an important performance advantage, and is the reason all modern amateur radio transceivers employ sub-octave filters in their receiver front-ends.

Figure 15 illustrates the input pre-selector filters that are typical of well-designed modern HF receivers (an Icom IC-7300 in this case). Although implementation details vary between different HF receivers, the essential technique is fundamentally the same.

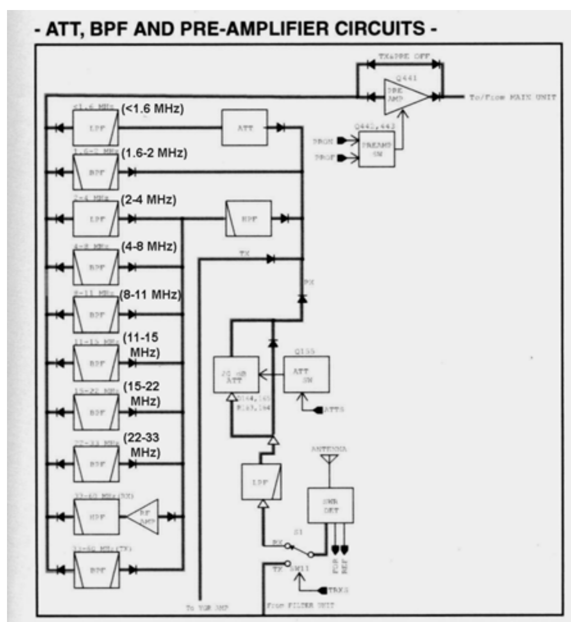



**Figure 15 - Typical HF Receiver Sub-Octave Input Pre-Selector Filter Functional Block Diagram**

As per Figure 15, seven selectable input bandpass filters are employed to cover the HF range (from 1.6-33 MHz). As per the added annotations, these ranges are 1.6-2 MHz, 2-4 MHz, 4-8 MHz, 8-11 MHz, 11-15 MHz, 15-22 MHz, and 22-33 MHz. These input filters are switched automatically whenever the receiver is tuned across a band-edge frequency boundary.

A simpler lowpass filter is employed below 1.6 MHz. (Since the only significant radio activity below 1.6 MHz is AM broadcast, less elaborate input filtering is employed for reasons of economy).

In contrast, other wide coverage HF/VHF/UHF communications receiver (e.g., the AOR AR5001D and the Icom R8500) do not employ sub-octave filters in the HF range for reasons of economy. ***As a result, these receivers lack the immunity to 2nd-order intermodulation distortion in the HF range enjoyed by the R8600, thus placing these receivers at a distinct HF performance disadvantage.***

## C. RDF PRODUCT DFP-1000B DF PROCESSOR/DISPLAY

The DFP-1000B DF processor/display is the culmination of nearly 40 years of continuous design evolution, field validation, and unbroken institutional memory. It was designed specifically to meet the demanding dynamic requirements of mobile VHF/UHF DF applications. More specifically, mobile DF systems must operate in dense signal urban environments in the presence of noise, multi-path reception, signal fading, and the various other ills encountered where both the DF station and the signal source can be in motion. The DFP-1000B thus has superb credentials for the similarly demanding requirements of HFDF.


**Figure 16 - DFP-1000B DF Bearing Processor (replicated from Figure 6 for convenience)**

The DFP-1000B succeeded the original DFP-1000 and its successor the DFP-1000A, both of which were developed in the early- and mid-1990s. These units in turn were evolved and refined versions of earlier DF processors this author designed for OAR Corp. in San Diego in the 1970s and 1980s.

The DFP-1000B is a mature and field-validated product that has been in continuous production since 2005 and has been frequently upgraded since that time. It has been a very successful product and will remain in production for many years to come. See the DFP-1000B operators manual (reference 9) for a fuller discussion of the DFP-1000B's features and capabilities.

## D. HUNTMASTER DIGITAL MAPPING & LOCATION SOFTWARE

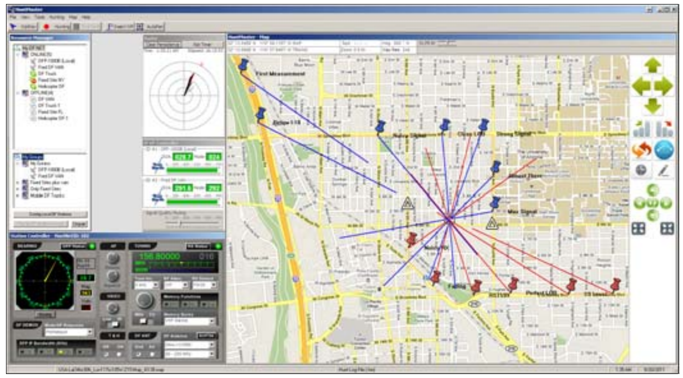


**Figure 17 - HuntMaster Windows User Screen**

HuntMaster is a Windows-based digital mapping and location software package that is a powerful adjunct to RDF Products' HF/VHF/UHF radio direction finding products. HuntMaster was originally written for mobile DF mapping and triangulation applications, both for single and multiple vehicle applications. Multiple sites (both fixed and mobile) can be networked together in real-time via the internet for optimum inter-site coordination. This product can also operate unmanned DF sites remotely via the internet.

HuntMaster is widely used by RDF Products' law enforcement, search-and-rescue, and national security end-users. As a result, it has the benefit of many years of evolution based on feedback from these highly skilled and experienced operators.

A full discussion of HuntMaster's features and capabilities is beyond the scope of this paper. For more information, visit the HuntMaster website at www.huntmasterpro.com.

# SECTION VI - RDF PRODUCTS AN/TRD-4B HFDF SYSTEM MISCELLANEOUS

## A. OVERVIEW

This Section addresses certain AN/TRD-4B topics that are somewhat subtle but important just the same. The first topic is the thought process that was associated with the selection of the monopole tower heights. The second topic is the system's "clean" listen-thru feature. The final topic is the ability of the AN/TRD-4B's R8600 receiver to be locked to an ultra-precise GPS-based 10.00000 MHz frequency standard for near-absolute frequency accuracy and stability.

## B. DUA-1124B1 ANTENNA MONOPOLE TOWER HEIGHTS

End-users sometimes ask how the DUA-1124B1 monopole tower heights were determined. This is a very important question, so it is addressed here even though the answer is somewhat technical.

Since only one Adcock array is employed to cover the full 1.5-30.0 MHz range, discerning end-users sometimes ask how the monopole tower height was chosen and what trade-offs had to be accepted. More to the point, they ask how the same monopole tower can be efficient over the full 1.5-30.0 MHz range, what compromises have to be accepted for such a wide frequency coverage, and the dimensions of the associated trade-offs.

First, to state the obvious, a monopole antenna (e.g., the tower and its associated radial ground plane) clearly cannot be efficient at all frequencies in the 1.5-30.0 MHz range. Fortunately, there are mitigating factors that are extremely favorable for HF applications. More specifically:

1. Receiving antennas do not need to be as efficient as transmitting antennas. As a case in point, AM broadcast band receivers employ miniature internal ferrite loop-stick antennas that are extremely inefficient, yet are still very effective for their intended purpose. Likewise, portable shortwave radios function well with a very inefficient telescoping whip antenna.

2. The lower portion of the HF range is inherently very noisy as a result of static crashes, ionospheric disturbances, and various other atmospheric phenomenon (all of which are collectively referred to here as "atmospheric noise"). This is particularly the case below 12 MHz. Given this reality, effective radio communications in the lower HF range require that transmitters have sufficient power to overcome this atmospheric noise (i.e., high atmospheric noise levels require strong signals in order achieve the high signal-to-noise ratios necessary for reliable communications).

   Since signals must be very strong in the lower HF range to overcome these elevated atmospheric noise levels, receiving antennas do not need to be efficient (i.e., they can be small). Although this results in diminished signal pick-up, ***it also results in identically***

***diminished noise pick-up. As a result, the signal-to-noise ratio (the true figure-of-merit for radio communications) does not diminish. This is the reason why an AM broadcast band receiver with a miniature internal ferrite loop-stick antenna functions well****.* (This highly favorable circumstance exists as long as the noise internally generated by the antenna electronics hub and receiver is low compared to the atmospheric noise.)

3. The ability to be able to use a relatively short antenna in the lower HF range without compromising sensitivity is very favorable for HFDF. This allows the monopole towers to be modest in height (and thus also modest in cost, both for the towers themselves and their installation since it is not necessary to pour concrete).

   The DUA-1124B1 monopole towers are resonant near 12 MHz (i.e., this is the frequency at which the towers are most efficient and most sensitive). At frequencies below resonance, sensitivity falls off rather sharply. At frequencies above resonance, however, the sensitivity initially diminishes only modestly, then increases as the frequency approaches the 3rd-harmonic resonance near 36 MHz.

   This is illustrated graphically in Figure 18. (Although this curve is conceptual for illustration only and not based on specific calculations, it is an accurate portrayal of the behavior of monopole antennas in general.)

   This behavior is extremely favorable for an HFDF system. Above the 12 MHz monopole tower resonance where atmospheric noise diminishes and good antenna sensitivity is required, the monopole towers exhibit only a modest loss in sensitivity. ***Although sensitivity drops off sharply below 12 MHz, this is largely forgiven by the fact that good sensitivity is not required in this noisy lower portion of the HF range since signals must be inherently strong to overcome this atmospheric noise as discussed above***.

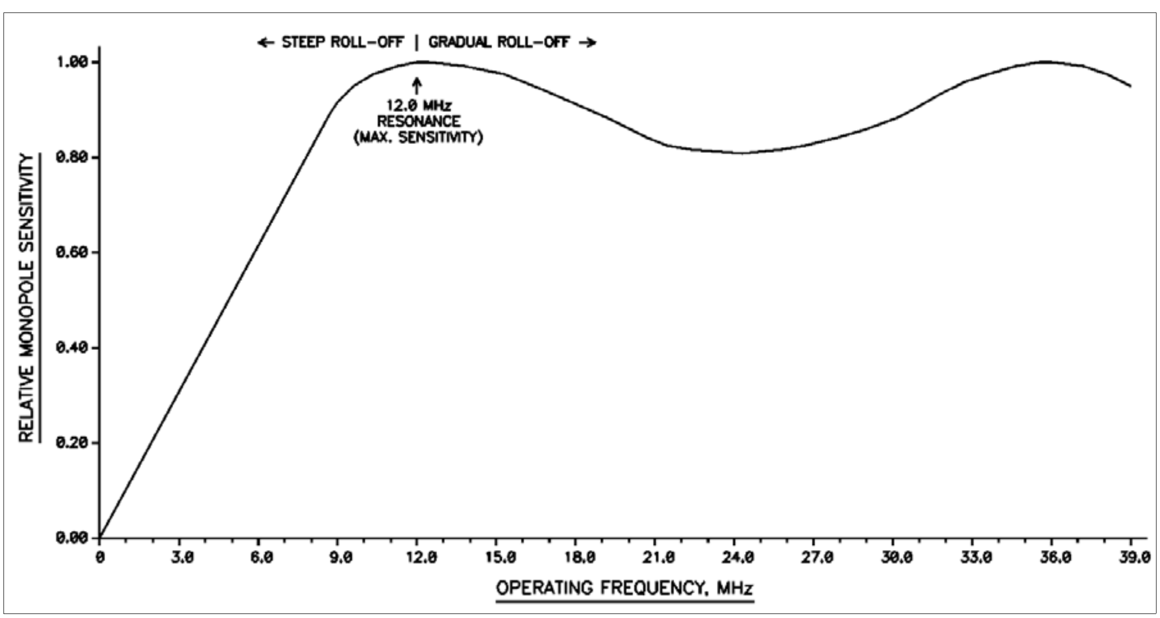



**Figure 18 - DUA-1124B1 Monopole Tower Relative Sensitivity**

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a re

On a related note, an AA-30 0.1-30 MHz hand-held network analyzer is supplied with the DUA-1124B1. This analyzer allows the end-user to conveniently measure the monopole tower resonant frequencies and is thus a powerful installation and troubleshooting instrument. With the AA-30, the end-user can easily diagnose and troubleshoot almost any antenna problem.


**Figure 19 - AA-30 0.1-30 MHz Antenna Analyzer**

## C. DUA-1124B1 "CLEAN" LISTEN-THRU OUTPUT

Single-channel DF systems (i.e., those employing only one receiver for DF purposes) rely on various modulation techniques at the DF antenna to facilitate the DF process. In a single-channel Adcock/Watson-Watt DF system (i.e., that employed for the AN/TRD-4B), two ***axis encoding tones*** are sent from the DFP-1000B DF processor to the DUA-1124B1 electronics hub to facilitate this modulation process. A fuller explanation can be found in RDF Products Web Note WN-002 (reference 10).

The compelling advantage of a single-channel DF technique is that ***only one receiver is required***. Multi-channel DF techniques, on the other hand, require multiple very expensive custom receivers. Although multi-channel DF systems avoid the antenna modulation process required for single-channel DF systems, the requirement for multiple custom receivers elevates system costs to extreme levels that are usually unacceptable to most end-users.

Although single-channel DF systems are much more economical, this economy is achieved at the expense of some performance trade-offs. One of these trade-offs is that the antenna tone modulation process ***can compromise DF system listen-thru capability***.

To explain, a desirable feature of any DF system is having ***simultaneous DF and listen-thru capability***. In other words, it is a distinct advantage for the operator to be able to simultaneously obtain a line-of-bearing ***and*** monitor any audio modulation on the intercepted signal. The problem is that the antenna axis encoding tone modulation can interfere with the intercepted signal resident audio modulation (i.e., the antenna modulation tones are also heard on the received signal, thus obscuring or distorting the desired listen-thru audio).

RDF Products DF systems feature good listen-thru capability for most signal formats. For AM and FM signals, listen-thru capability is very good. For SSB signals, however, the antenna modulation tones interfere with signal intelligibility. Although this is seldom a problem in the VHF/UHF range (where most signals are FM or AM), it is a distinct disadvantage in the HF range.

To help mitigate this, ***the DFP-1000B has the provision to disable the modulation tones to the DF antenna to allow clean listen-thru***. However, this also disables system DF capability. Even so, this feature is very useful in situations where listen-thru capability temporarily becomes more important than DF capability.

A technically superior and more sophisticated approach is to have a separate receiver fully dedicated to signal monitoring (listen-thru) only. To facilitate this, the DUA-1124B1 features a clean listen-thru channel output as per Figure 11. This output is taken from the vertically-polarized omni-directional central-sense antenna (via a buffer amplifier) prior to the antenna tone modulators and thus is not modulated by the axis encoding tones. This output is then connected to the dedicated listen-thru receiver at the operator position. As per Figure 11, this requires a ferrite-isolated signal output cable.

Another approach (not illustrated in Figure 11) is to employ local antennas at the operator position for listen-thru purposes. This has to be implemented with some caution, however, since these local antennas are also unintended parasitic re-radiators that can impair DF antenna bearing accuracy.

This is particularly an issue for vertically-polarized antennas. To avoid bearing errors, any local antennas should be no taller than 1/8 wavelength at the highest frequency of interest. For most installations, this constraint would require that this antenna be very short, which could impair sensitivity. In nearly all cases, using a local vertically-polarized listen-thru antenna would be less effective than relying on the DUA-1124B1 clean listen-thru output.
A better argument can be made for having a local horizontally-polarized listen-thru antenna (i.e., a flat-top horizontal dipole). Since a horizontally-polarized antenna would not respond to vertically-polarized signals, it would not diminish DF antenna bearing accuracy.

The primary advantage of having a local horizontally-polarized listen-thru antenna is that there are some instances where a horizontally-polarized antenna would be more sensitive than a vertically-polarized antenna. To explain, HF signals typically contain both vertically- and horizontally-polarized components (which continuously vary in relative magnitude as a result of changing propagation conditions). As a result, a horizontally-polarized antenna can offer better sensitivity in instances where the received signal is primarily horizontally-polarized.

In the majority of cases, however, the most cost-effective and streamlined approach is to simply rely on the DUA-1124B1 clean listen-thru channel vertically-polarized output. It is therefore recommended that end-users not attempt to install a separate horizontally polarized listen-thru antenna unless there is some compelling reason.

As a final thought on this topic, some readers may wonder if having a separate listen-thru receiver in itself might be an unnecessary sophistication. Although this added receiver is not essential, it does add an important capability to the HFDF system at a very modest incremental cost and is therefore recommended.

## D. GPS FREQUENCY STANDARD

Referring to the Figure 11 AN/TRD-4B system functional block diagram, an optional GPS-based 10.00000 MHz reference standard is illustrated. This frequency standard is actually a specialized GPS receiver that locks onto the GPS signal's ultra-precise one pulse per second output. A digital frequency multiplier then produces an equally precise 10.00000 MHz frequency reference . This frequency reference is then used to synchronize the R8600 receiver(s) so that the selected receive frequency has the same ultra-precise frequency accuracy and stability.

To explain, the GPS satellites employ an ultra-precise Cesium beam frequency standard to obtain the precise timing necessary for GPS. GPS receivers in turn output a one pulse per second timing signal with the same precision (i.e., the one second pulse period is effectively synchronized to the satellite Cesium beam frequency standard with typical frequency accuracy of 1 part in $10^{11}$.

This one pulse per second thus as a frequency of exactly 1 Hz. This 1 Hz signal can then be digitally multiplied up to any practical desired frequency and used as an ultra-precise frequency reference. The R8600 has a 10.00000 MHz reference frequency input so that its frequency accuracy and stability can be established by an external precision frequency reference in applications where greater frequency precision is required.

Modestly priced GPS frequency standards are now available for this application, and one such unit is offered as an extra-cost option as illustrated in Figure 11. The advantage of this option is that it can synchronize multiple DF sites on the same frequency to ensure that there are no inter site frequency errors when triangulating a signal.

## SECTION VII - OTHER POST-VIETNAM TACTICAL HFDF SYSTEMS

### A. INTRODUCTION

Very few tactical HFDF systems have been designed and produced since 1976 when the last of the U.S. Army AN/TRD-4A systems were retired from service (aside from a small number of legacy units that remained deployed in the years that immediately followed) . Also, none of these successor systems were produced and deployed in any comparable quantity. Some of these successor systems are discussed in the paragraphs that follow.

### B. OAR CORP. UA-282 HFDF ANTENNA

One such successor system was the OAR Corp. UA-282 HFDF antenna. As per Figure 20, this antenna was an 8-element (plus central sense) ground-mounted monopole Adcock DF antenna similar in many respects to the RDF Products DUA-1124B1. The UA-282 was used in conjunction with a compatible DF receiver/processor also built by OAR Corp.

**Figure 20 - OAR Corp. UA-282 0.5-30.0 MHz Tactical HFDF Antenna (photo shot by author in 1985)**

While not a direct participant in this program, this author was present at OAR Corp. when the UA-282 was designed and developed and observed this effort as it progressed. This program was funded by the U.S. government. Although it did not occur to this author at the time, the UA-282 was likely intended as a replacement for the discontinued AN/TRD-4A for some applications.

Unlike the AN/TRD-4A (and its true successor, the AN/TRD-4B), the UA-282 system was designed to be sufficiently compact and light weight so as to be truly man-portable. The antenna elements were thus shorter, constructed from light weight materials, and were telescoping so that they could be packed into duffel bags.

Since the UA-282 antenna elements had to be short for compactness, sensitivity was diminished in the lower HF range. This was partially offset by employing “active” elements (i.e., these elements employed special pre-amplifiers at their base feed points).

Unfortunately, this resulted in performance compromises. These pre-amplifiers were vulnerable to intermodulation distortion that diminished performance in strong signal environments. Also, the presence of these pre-amplifiers resulted in antenna inter-element balancing problems that diminished bearing accuracy.

Another problem was that the ground radial system was inadequate. In addition to being sparse and non-isolated from the DF receiver/processor, it was also mounted directly on the ground (as can be seen in Figure 20). As per the discussion in Section IV-D, non-elevated ground radial system performance is influenced (and often degraded) by soil characteristics (unlike the DUA-1124B elevated ground radial system which is largely impervious to soil characteristics as confirmed by NEC-4 computer modeling).

All-in-all, the UA-282's performance was marginal, and it did not work well under 1.5 MHz. Only a very small number were produced (probably under 10). Cubic Corp. (also located in San Diego, California), discontinued this product shortly after it bought out OAR Corp. in 1995.

## C. ALARIS DF-AA015

The South African company Alaris (formerly Poynting) DF-A0015 is a current tactical HFDF antenna with similarities to both the RDF Products DUA-1124B1 and the OAR Corp. UA-282. Like the DUA-1124B1 and the UA-282, the DF-A0015 is an 8-element (plus central sense) ground-mounted monopole Adcock HFDF antenna.

Covering 1.0-30.0 MHz, the DF-A0015 is similar to the UA-282 in that it employs short elements that include base pre-amplifiers to help offset the resulting loss in sensitivity. It is also similar to the DUA-1124B1 in that it employs an extensive and symmetrical isolated ground radial system for each element. (The Figure 21 DF-A0015 photo, taken from Alaris' website, appears to be missing the central sense monopole tower and the ground radials.)

**Figure 21 - Alaris DF-A0015**
**1.0-30.0 MHz Tactical HFDF Antenna**

While the DF-A0015 appears to be a more skillfully designed and competently implemented version of the UA-282, it is not sufficiently light weight at 275 lbs. (125 kg) to meet the man-portable design goal of the UA-282.

The DF-A0015 designers apparently recognized the intermodulation susceptibility issues associated with the element base pre-amplifiers as evidenced by the fact that they included a provision to bypass them. This provides users the option to disable these pre-amplifiers and operate the system in a "passive" mode in strong signal environments where intermodulation is an issue, although with diminished sensitivity.

All-in-all, there appears to be much to admire about the DF-A0015. A very serious issue, however, is that Alaris does not offer a compatible DF receiver/processor that works with the DF-A0015. Even more surprising, Alaris does not even specify a compatible DF receiver/processor from another DF vendor.

As is the case with all DF antennas, this product is not useful by itself. Buyers would therefore have to assume the responsibility for designing and producing their own DF antenna signal processing unit, DF receiver, and DF processor. Since these are tasks that would require highly specialized engineering skills, it is hard to imagine who would purchase the DF-A0015. As of 2015, pricing for this unit was quoted at $106,000 (USD), which seems to be a very steep price for an incomplete HFDF system.

Since this product would appear to be unmarketable on its own, it is possible that the DF-A0015 was designed as a custom DF antenna for a customer who already had the other necessary HFDF system components (i.e., their own DF receiver/processor). Although it is possible (and likely) that this program was non-recurring, it appears that Poynting (Alaris' predecessor) decided to leave this unit in the catalog despite the fact that very few prospective customers would likely be able to absorb the follow-on engineering and development tasks.

## D. ULTRA-COMPACT HFDF SYSTEMS

Finally, there are some current HFDF systems employing very compact antennas that are designed for vehicle, tripod, or mast mounting. These typically employ compact cross-loops or annular slot antennas. While such HFDF antennas are useful in some applications, the designers had to accept extreme performance trade-offs in exchange for such a small footprint. These trade-offs include greatly diminished sensitivity and the inability to obtain accurate bearings on sky-wave and other signals with significant horizontally-polarized components.

**Figure 22 - Ultra-Compact Tripod-Mounted HFDF Antenna**

The best of these compact HFDF antennas are the mast-mounted shielded cross-loops traditionally used in maritime applications. These loops are typically just under 1m in diameter and cover 2-30 MHz. The Japanese company Taiyo has been the prominent supplier for this market.

All of these compact HFDF antennas are a very pale imitation of a true Adcock HFDF antenna and do not come close to matching Adcock performance. Compact HFDF antennas should be used only in applications where compactness is the is the overriding necessary feature and where extreme performance compromises can be accepted in return.

## E. CONCLUSION

The U.S. Army AN/TRD-4A was the only free-world (i.e., non-communist bloc) tactical HFDF system that was ever produced and deployed in large quantities and operated extensively over a long period (20+ years). It is thus the benchmark tactical HFDF system standard of comparison for all succeeding systems.

Although these succeeding systems had the benefit of more modern technology and thus were capable of better performance in many respects, they all had various deficiencies that resulted in significant performance compromises, many of which were overcome by the original AN/TRD-4A simply as a result of its very large size and the exceptional skill of its operators. Also, none of these successor systems appeared to be designed with modern antenna modeling software, thus depriving the designers of the enormous benefits of a powerful design tool that is considered indispensable today.

Perhaps the most important disadvantage those designers faced was not having the benefit of the experience and institutional memory associated with the AN/TRD-4A program. In this respect, this author is very fortunate to have been an active player in the AN/TRD-4A program back in 1970-71 in Southeast Asia as a young U.S. Army Security Agency enlisted man, including time actually spent on-site. Subsequently, this author became a DF system designer and has continued down this career path ever since.

The AN/TRD-4B design thus has the benefit of 40+ years of direct DF design experience and unbroken institutional memory that goes all the way back to the original AN/TRD-4A, and is thus the true modernized 21st century replacement. <>

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Note: References 3, 5, 9, and 10 can be found on the RDF Products website at www.rdfproducts.com.