Raven Research Ltd

High Frequency Receiving Antenna System With Super Resolution Radio Direction Finding

For 1.5-30 MHz

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1 Introduction

This document describes the Raven Research Ltd Multiple Beam High Frequency receiving antenna system 'Taurus', designed for operation over the frequency band 1.5 to 30MHz and the integration of a Super Resolution DF onto the Taurus array. The DF system can be an integral part of the Taurus or it can be a *stand-alone system*. This document concentrates on the integration of the DF system into the Taurus antenna array.

The Taurus receiving antenna has been developed for use at locations where there is a need to receive high frequency signals from the entire 360 degrees of azimuth plane. This is a compact antenna system ideal for use where the available ground area prevents the use of rhombic antennas.

The system comprises two circular arrays of antennas connected by feeder cables to beam forming networks. The two arrays are deployed concentrically, making a valuable saving of ground area and the beam forming networks are housed in a small building at the centre of the array.

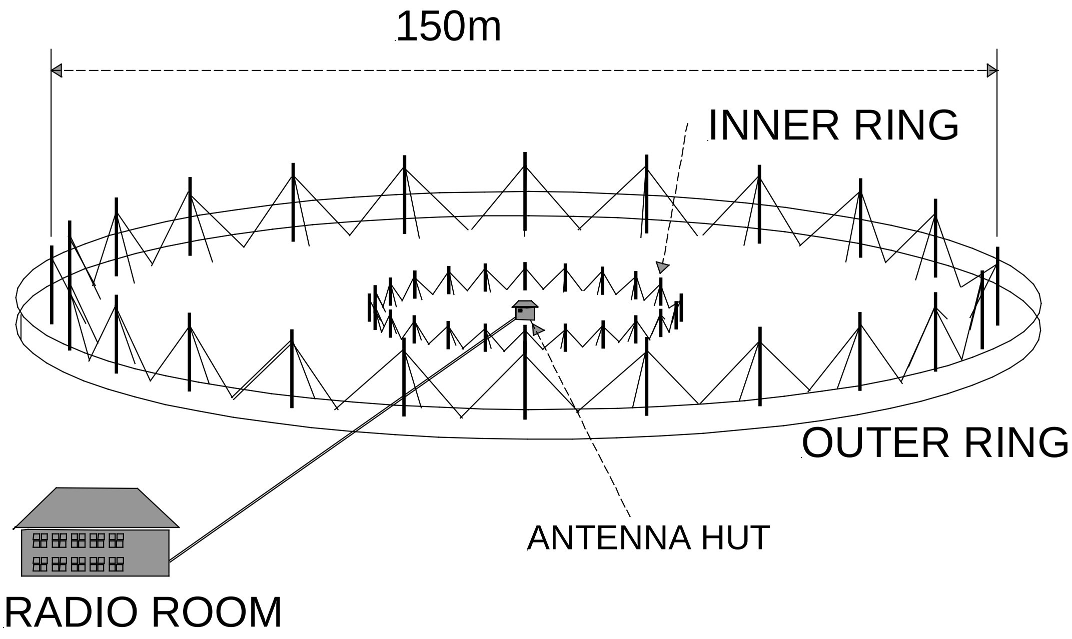

Figure 1 - Artist's Impression of the Taurus Site

The system gives 24 fixed beam outputs which are available simultaneously and which are spaced on 15-degree intervals in azimuth. The beams provide significant directive properties up to an elevation angle of 60 degrees.

The two arrays are very compact. For the same frequency coverage, they are occupying less than 10% of the area required for a corresponding array of rhombic antennas. The two arrays give a similar degree of all-around coverage over the same frequency band. Reception tests have indicated that the 'Taurus' system gives a performance equal to or better than such an array of rhombic antennas.

Each beam output may be used to feed a large number of receivers for various monitoring purposes by the use of the signal exchange equipment, which is widely deployed in NATO countries. The signal exchange equipment and the receiver banks would normally be installed in the main receiving station building at some distance from the antennas. (See Figure 1)

2 Direction Finding Equipment

2.1 General

This proposal addresses the issues around creating a Super-Resolution HF Direction Finding system and integrating this into the 'Taurus' Antenna Array. The advantages of using this direction finding technique will be highlighted; these include the ability to differentiate two different signals at the same frequency with different angles of arrival and also Single Site Location. The single site location facility allows the bearing and distance to target to be calculated.

2.2 System Architecture

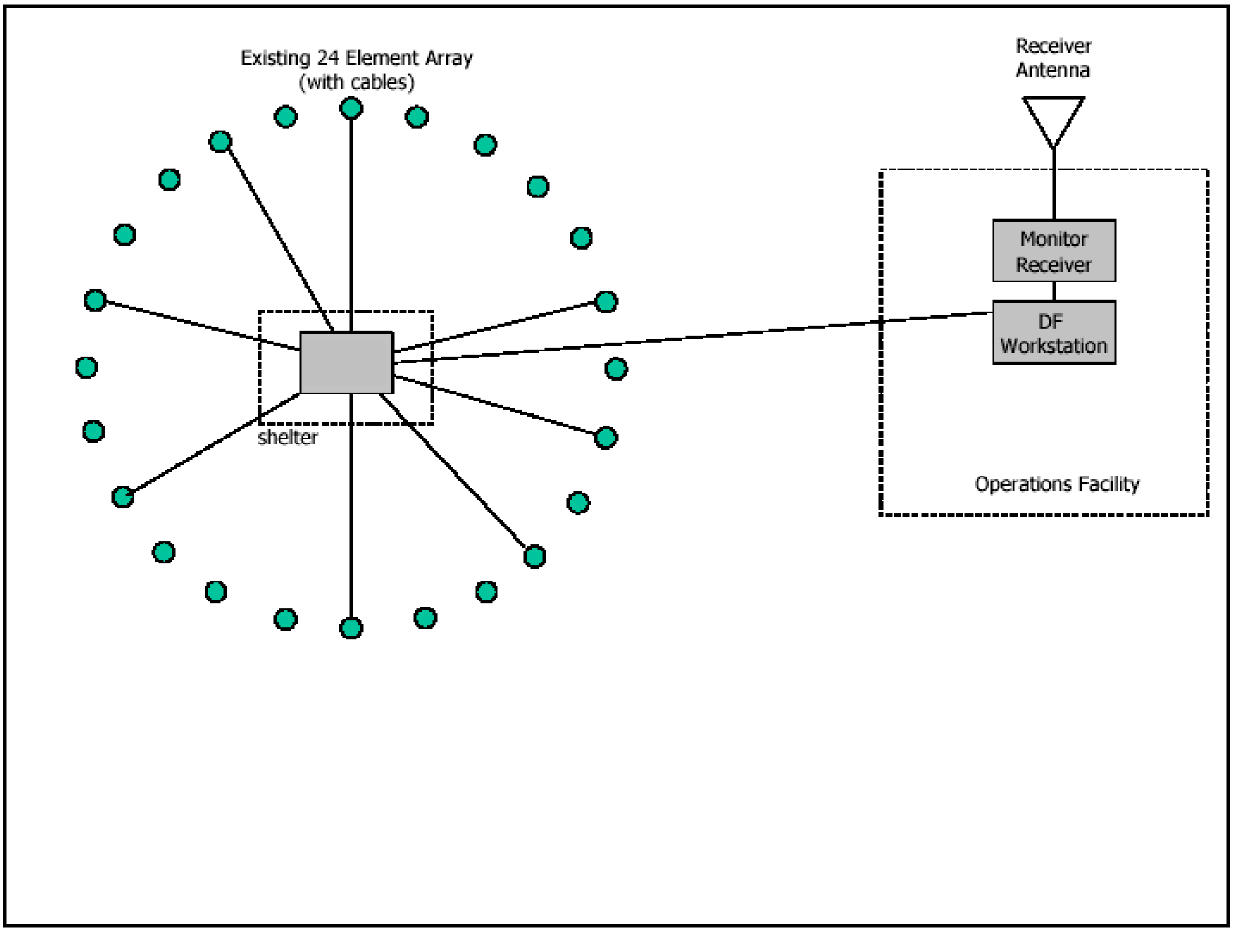

Figure 2: System Block Diagram

Figure 2 above delineates a high-level block diagram for the DF system upgrade. It will be the intent of this project to use eight of the existing antenna feeder elements and associated cables as shown.

2.3 Super-resolution DF at HF

Super-resolution DF processing is an excellent approach to DF in the HF band. At HF, multiple co-channel signals are very common and multi-path (multimode) propagation is prevalent. Super-resolution DF operates well in this environment, due to its multiple-signal handling capability. If the multimode signals are correlated then a maximum likelihood algorithm is required to resolve the modes. Frequently, however, the delay difference between modes provides adequate de-correlation for a standard super-resolution algorithm, e.g. MUSIC, to give good results.

It must be recognized that HF Direction Finding provides a number of significant challenges that do not generally apply at V/UHF.

The HF band (1 to 30MHz) represents a very wide percentage bandwidth. DF performance (both accuracy and resolution) is proportional to the array aperture. The requirement is to provide an array that will provide a useful aperture at the lowest frequency whilst not generating ambiguities at the highest frequency. In the Taurus array this has been achieved by employing two concentric circular arrays, for different parts of the band.

HF direction finding is frequently required to provide both azimuth and elevation estimates. This requires a considerably higher computational load to search the array manifold over the full upper hemisphere. It also demands more careful attention to array geometry to avoid ambiguities.

HF sky wave propagated signals are far from stationary. The changing ionospheric propagation can cause very rapid apparent changes in DF bearing. Thus the DF signal processing must be capable of providing many DF's per second.

HF reception is generally external noise limited. This noise is not spatially white i.e. there is some correlation between the noise in the various array channels. Whilst this can be an advantage in conventional receiving systems attached to directional arrays, in the computing of noise and signal values, it makes the threshold between signal and noise more difficult to determine.

HF signals often have a low and fading signal-to-noise ratio. Super-resolution DF provides a beam forming gain compared to, say, interferometry. For example, an 8 element array would nominally provide 12 dB improved sensitivity. When this is coupled with coherent and non-coherent processing gain, DF can be achieved on signals several dB's below the noise level.

Polarization of sky-wave signals is quite undetermined. If the DF array employs antenna elements that respond differently to different polarizations then providing a simple array manifold is no longer adequate. An example would be a ship-based DF system employing simple loop antennas in different orientations. In this case the array manifold must be defined in two orthogonal polarizations and extra matrix computations performed in the super-resolution scan process.

The above complicating factors found at HF make an advanced DSP based super-resolution DF implementation highly desirable because it provides much improved operational performance.

2.4 HFDF System

The DF subsystem consists of three major components: the DF Processor, the DF Operator Workstation, and the 'Taurus' antenna array. As previously described, selected elements of the existing Taurus antenna array are utilized. The DF Processor is typically located in a small building at the centre of the antenna field. This building needs to be provided with electrical power (mains and backup), environmental conditioning, and workspace for maintenance.

The DF Workstation may be installed in the antenna field building with the DF Processor. In this case, the DF Workstation and DF Processor are connected using a 10BASE-T LAN. The equipment is installed in either a single 6-foot tall equipment rack or in two smaller racks mounted side-by-side.

In many cases, it is desirable to install the DF Workstation in separate facility located away from the antenna field in the same location as the monitoring receivers. There are a variety of reasons to do this including:

- Allow the DF operator to be located with operators of other systems;
- Provide easier access to communication network equipment;
- Minimize the number of personnel working in the antenna field;
- Connection of existing antennas to the monitoring receiver.

Figure 3 is a block diagram of a typical DF Subsystem installation, with a new DF antenna array installation. In this case, the DF Processor is installed in the antenna field and the DF Workstation is located in the nearby operations building. The DF Processor is connected to two types of antennas: a 16-element dual circular DF array and a single whip antenna used for radiating a test signal into the DF array.

The primary components of the DF operator's position are the DF Workstation processor, monitor, and keyboard, a monitor receiver for audio monitoring of the signal of interest.

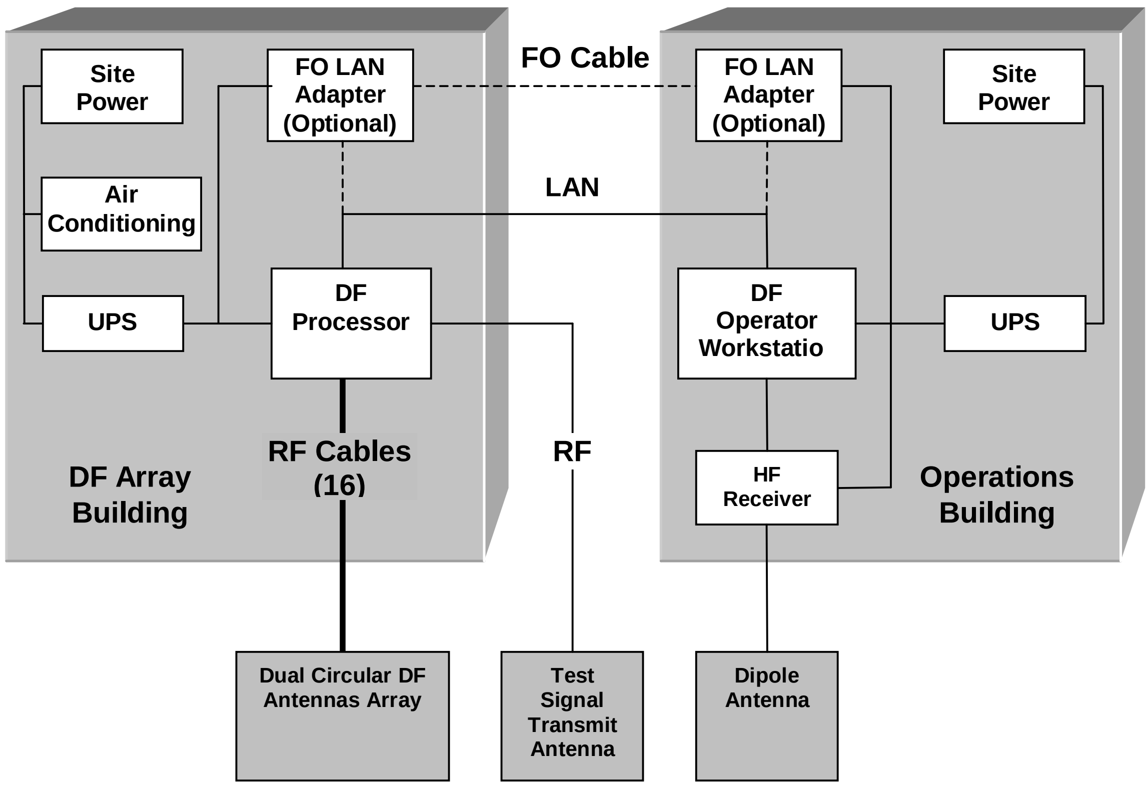

Figure 3: DF Subsystem Block Diagram

If the distance between the DF Processor and the DF Workstation exceeds the capability of the LAN, additional equipment will needed to interconnect these two components. Installing Fibre Optic LAN Adapters and fibre optic cable allows the DF Processor and DF Workstation to be separated by 2-10 kilometres (depending upon the type of fibre optic cable used).

The HFDF system is based on an N-channel HF receiving equipment, shown in Figure 4 and the System Software. The flexible Windows base software includes the Graphical User Interface, Database, Communications, Signal Analysis, Demodulation, equipment control, Mapping, Network Control, Collection and Reporting Software. This hardware and software have been proven in several locations around the world with results that show great accuracy advantages over the Interferometer and Watson Watt HFDF equipment. The open systems architecture can be easily expanded to increase the number of DF and collection sites, add single station location and integrate wideband-receiving equipment in the future.

Figure 4: HF DF Processor and MMI

The receivers used in the Direction Finder are VXI Digital HF Receivers (Figure 4). These receivers are capable of operating under external computer control of frequency, bandwidth, gain and detection mode. In addition, the DF operator can manually control the receivers. Eight coherent receivers are used to simultaneously receive the signals from the eight antenna elements utilised in the 'Taurus' antenna array. There is no switching of the receivers between antenna elements. This approach allows for very fast DF Line Of Bearings (LOB) in addition to the implementation of the Super-resolution DF algorithms. The eight receivers, the DF processor, the antenna switch, the signal generator and the slot zero controller fit into a single compact 9U 19 inch chassis. These small receivers provide high performance through the application of high dynamic range mixers, low noise amplifiers and digital filters.

The LOB accuracy is better than 1.5ºrms on skywave signals for frequencies ranging from 1.5 to 30MHz. Figure 5 shows the DF error measured on skywave signals on the an actual HFDF using the dual circular monopole DF array.

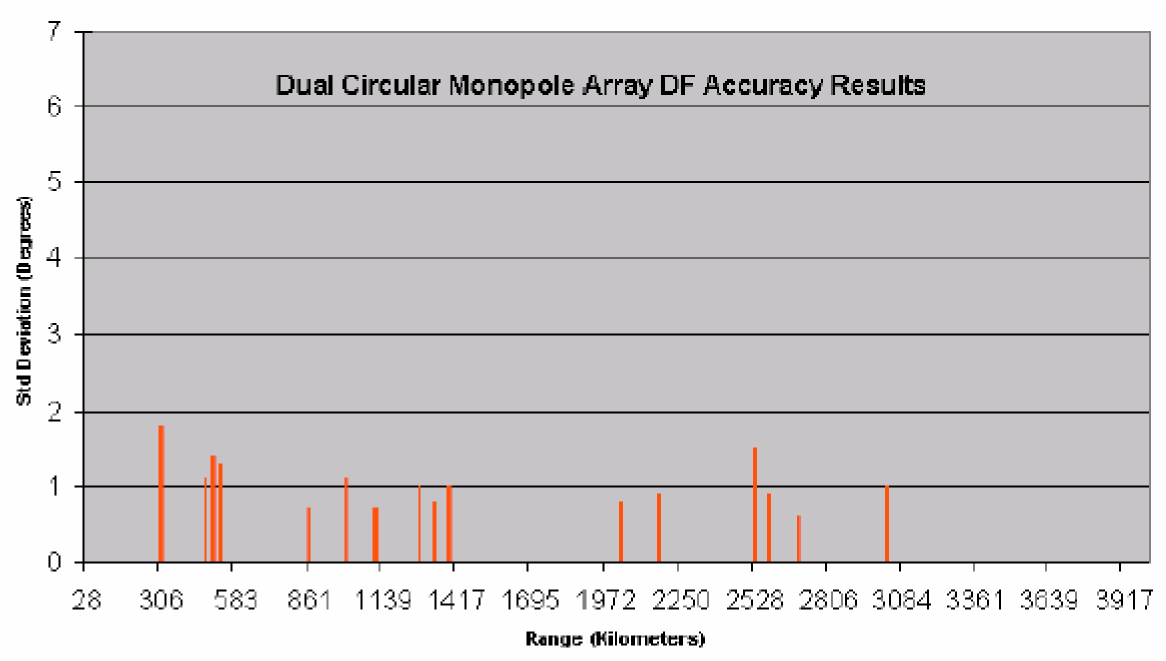

Figure 5: Measured HF DF Error on Skywave Signals

3 DF Equipment Building

The DF Processor is typically installed in a small building located at the center of the dual circular DF antenna array.

Electrical power is provided to the DF building by running underground cables from a nearby power source. The building is equipped with a commercial air conditioning unit to provide for heating and/or cooling of the equipment. The whip antenna mounted above the roof is used to radiate a low power test signal into the 'Taurus' and DF antenna array for testing and diagnostic purposes.

The DF equipment rack contains the DF Processor, an Uninterruptible Power Supply (UPS), and a Fiber Optic (FO) LAN adapter. The UPS regulates the mains power and provides for continued operation during brief power outages. The FO LAN adapter extends the LAN to the DF Workstation located in a nearby facility. The equipment rack includes a filtered blower (at the bottom of the rack) and a top-mounted fan to provide airflow within the rack assembly.

The sixteen RF cables from the DF antenna array enter the cellar of the DF building below ground level and are passed through an access opening for connection to the rear panel of the DF Processor equipment rack. Any excess cable is stored in the turning chambers of the DF building.

4 Software System

4.1 Mission Processing Display

The Mission Processing display is used while performing a manual DF mission. The target signal parameters are specified by the supervisor. The results from DF sites and the computed fix location are also shown. Finally, the DF Results Report is shown at the bottom of the Mission Processing display.

The DF sites, Line Of Bearings, and emitter fix location are plotted on a geographic map display. Note if the sites are Single Station Location (SSL) sites, both a LOB and a range estimate is generated. If the site does not have an SSL capability it will produce only a LOB.

The FIX algorithm is used for computing the emitter location fix and confidence ellipse parameters (semi-major axis, semi-minor axis, and orientation). The operator may select individual DF results for inclusion or exclusion in the fix calculation. The operator may include or exclude individual LOB's from the fix calculation. The operator may also manually add DF results for stations, which are not electronically connected to the workstation.

Individual target buttons are provided for prosecution of simplex DF missions. Selecting one of the Target buttons caused the LOB's, fix data, and DF Results Report for that simplex emitter to be displayed both textually and on the geographic map display.

The Mission Processing display is also used to review the results of previous DF missions for processing of late bearings, analysis, or quality control purposes. The operator selects a mission either from a list of recently performed missions or by performing a database query to retrieve the results for missions, which match specific parameters. The query parameters include call sign, frequency and date/time ranges.

4.2 Geographic Map Display

The Geographic Map Display allows the operator to overlay data from several sources on a map of the area of interest. The types of data that can be displayed on the map include:

- Plotting of the locations of the DF sites;
- Plotting of the LOB reported by each DF site;
- Plotting of the emitter fix location and confidence ellipse area;
- Annotation of the map with text at specific geographic locations;
- Plotting the location of check target emitters.

4.3 HF DF Results Database

The DF Results database contains all mission, fix, and LOB data for the DF missions performed by the Network Control Workstation. The database is made up of three tables: the Mission Table, the Fix Table, and the LOB Table.

One record is created in the Mission Table for each DF Mission performed by the DF Server. A record is added to the Fix Table for each emitter fix calculated for a DF mission (up to five per mission). A record is added to the LOB Table for each LOB generated during the DF Mission.

The Mission, Fix, and LOB records for an individual DF Mission are related to each other by a key consisting of the Mission date, two-character site identifier of the tasker requesting the mission, and the task sequence number (TSN). The TSN is reset to 0 at midnight each day. These three fields uniquely identify each DF mission prosecuted by the HF DF system.

The fields that comprise the tables in the DF Results database are listed below.

Table 1: Mission Table

MISSION Table				
Key	**Field Name**	**Type**	**Size**	**Format/Range**
Y	Mission Date	Date/Time	8	Date (Year, month, day)
Y	Tasker Site Ident.	Char	3	ASCII
Y	Mission Sequ. Num.	Numeric	5,0	00000 to 99999
	Operator Position	Char	8	ASCII
	DF Start Time	Date/Time	8	Date/Time
	DF Stop Time	Date/Time	8	Date/Time
	Call sign	Char	3	ASCII
	Case Notation	Char	14	ASCII
	Priority	Char	2	ASCII
	Last Modified	Date/Time	8	Date/Time
	Late Bearings	Boolean	1	True/False
	Frequency	Numeric	7,5	0.50000 to 30.00000
	Detection Mode	Char	3	ASCII (AM, CW, etc.)
	Comment	Char	64	ASCII

Table 2: Fix Table

FIX Table				
Key	**Field Name**	**Type**	**Size**	**Format/Range**
Y	Mission Date	Date/Time	8	Date (Year, month, day)
Y	Tasker Site Ident.	Char	3	ASCII
Y	Mission Sequ. Num.	Numeric	5,0	00000 to 99999
Y	Target ID (Simplex)	Char	1	A, B, C, D, or E
	Latitude	Numeric	8,6	90.000000 to –90.000000
	Longitude	Numeric	9,6	180.000000 to –180.000000
	SemiMajor	Numeric	5,0	00000 to 99999
	SemiMinor	Numeric	5,0	00000 to 99999
	Orientation	Numeric	4,0	0000 to 9999
	CEP	Numeric	5,0	00000 to 99999
	Number of LOBs	Numeric	5,0	00000 to 99999

Table 3: LOB Table

LOB Table				
Key	**Field Name**	**Type**	**Size**	**Format/Range**
Y	Mission Date	Date/Time	8	Date (Year, month, day)
Y	Mission PDDG	Char	3	ASCII
Y	Mission Seq Num	Numeric	5,0	00000 to 99999
Y	Bearing Number	Numeric	2	0 to 99
Y	DF Site PDDG	Char	3	ASCII
	DF Site Latitude	Numeric	8,6	90.000000 to –90.000000
	DF Site Longitude	Numeric	9,6	180.000000 to –180.000000
	Bearing	Numeric	4,1	-359.9 to 359.9
	Elevation	Numeric	3,1	0.0 to 90.0
	Range (for SSL)	Numeric	5,0	00000 to 99999
	Confidence	Numeric	2,0	00 to 99
	Nil Heard (N Code)	Char	4	ASCII
	Time	Date/Time	8	Date/Time
	Quality Factor	Char	1	A, B, C

LOB Table				
Key	**Field Name**	**Type**	**Size**	**Format/Range**
	Height (for SSL)	Numeric	5,0	00000 to 99999

4.4 DF Data Analysis Software

The HF DF Data Analysis application provides the capability to perform statistical analysis of HF DF data collected against emitters at known locations (check targets). The primary purpose of this facility is to monitor the DF accuracy of the individual HF DF sites and the emitter fix accuracy of the overall network. A variety of textual, graphical and geographic map displays are used to present the raw DF and the resulting statistical data.

The facility comprises five major functions:

- Data Retrieval;
- File Access and Maintenance;
- Data Selection and Filtering;
- Graph Generation;
- Geographic Map Interface.

The Data Retrieval function is used to select data for analysis from the various subsystem databases. Specific data is requested using the database Query Form shown in Figure 6. The data to be retrieved is selected using combinations of call signs, site identifiers, and date, time, and frequency ranges.

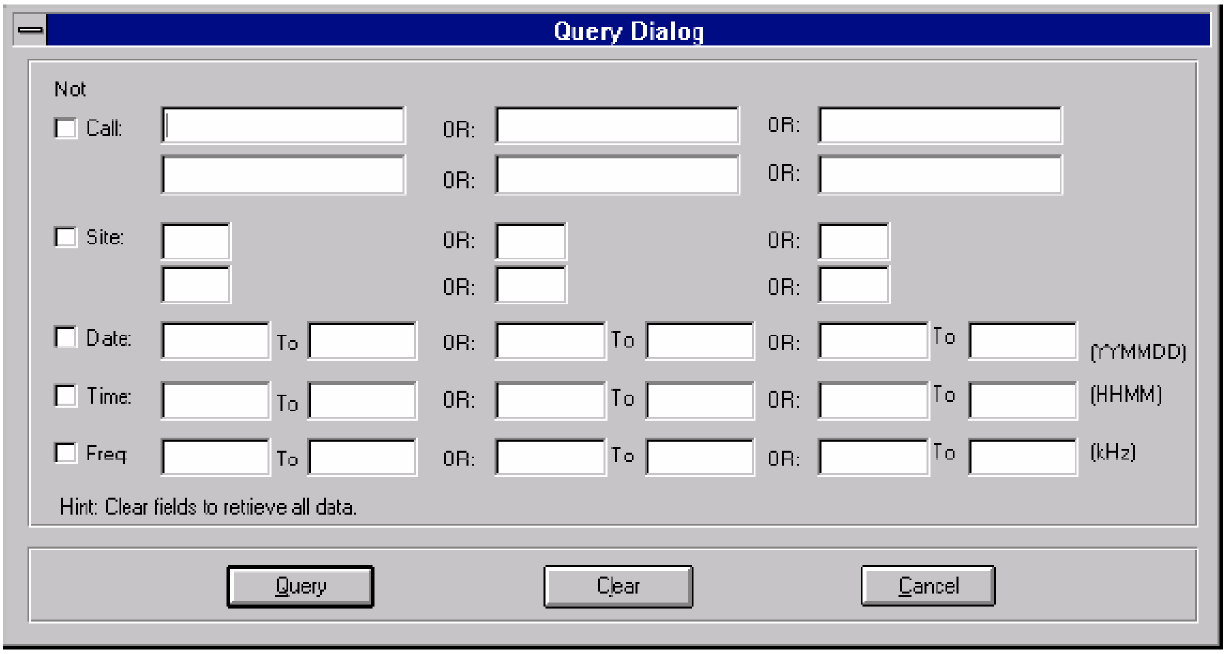

Figure 6: Query Form

The file access and maintenance function is used to create, save, and load the three types of data files: the Target Identification Table, the Tracker Location Table, and the Results files.

The Target Identification Table contains the geographic locations and identification of the target transmitters. The Tracker Location Table contains the locations and identifications of the DF sites. The Results files are subsets of the collected DF data from the subsystem databases saved as individual files for easy retrieval.

The querie functions allow the operator to select the target emitters, DF sites, and collected data to be used in the DF accuracy analysis calculations. This function is also used to match each DF data record to the corresponding emitter in the Target Identification Table.

The graphical functions perform the DF accuracy statistical calculations using the filtered data selected by the operator. A variety of graphical presentations are available including:

- Histograms
- Cumulative Plots
- Running Plots
- Scatter Plots

An example of the Azimuth Error Histogram display is provided in Figure 7.

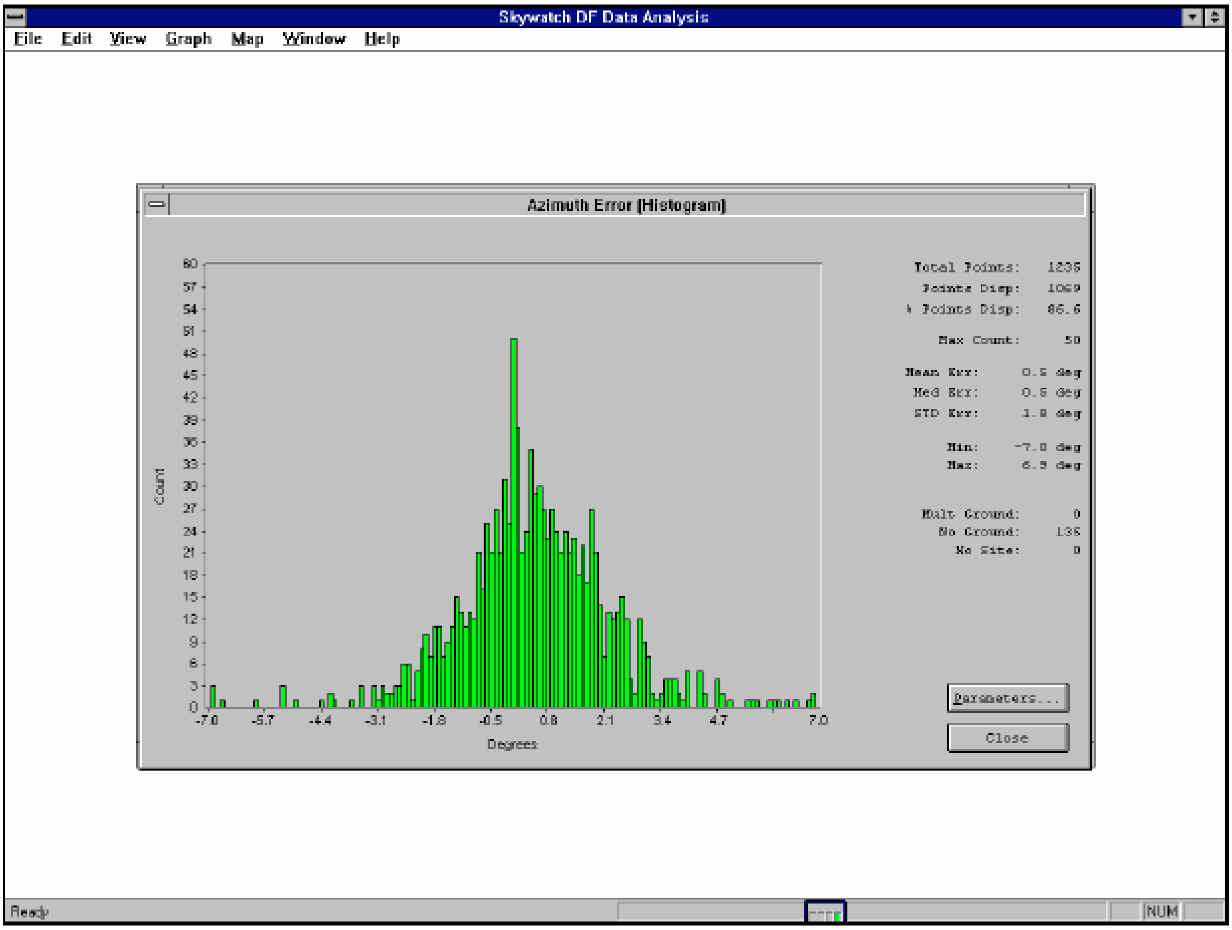

Figure 7: Azimuth Error Histogram

This application is interfaced to the map displays for showing the DF data, site locations, and emitter fixes on geographic maps. The map display interface is also used to compute composite target fixes using data collected for a target over a period of time.

5 Enhanced Copy

Co-channel interference is a common problem in HF DF operations. Interfering signals make it difficult to monitor and determine the correct bearing for the signal of interest. However the super-resolution signal processing algorithms implemented in the DF Processor provides for the separation of multiple signals (up to seven signals for the 8-element antenna array). Azimuth and elevation angle of arrival data is produced for each of the individual signals detected in the receiver pass band.

Although the DF Processor will produce DF data for each of the multiple signals, it can be difficult for the DF operator to determine the azimuth and elevation associated with each signal. As a result, the operator may unknowingly report an incorrect bearing.

The interfering signals may also prevent the DF operator from confirming that the signal of interest is being received at the DF site. If the operator cannot hear the signal, this confirmation cannot be accomplished even though the DF Processor may be producing valid DF data for the signal of interest.

The signal augmenting capability digitally forms a “beam” on one signal and forms “nulls” on the other signals in the passband. The beam and nulls are specified using the azimuth and elevation angles of arrival. This specification is accomplished using the azimuth/elevation plot in the DF Control display of the DF workstation.

When the beams and nulls have been formed this allows the operator to easily monitor the audio of the signal coming from the direction where the beam has been formed. The operator can interactively move the beam and nulls to monitor different signals while determining which angle of arrival is associated with each signal. This is accomplished by clicking on the azimuth/elevation clusters in the display.

6 Project Implementation

6.1 Site Survey

In order to facilitate proper installation of the DF and SSL subsystems, a Site Survey at the proposed facility is required. A systems engineer will travel to the site to perform this task. The engineer will work with the end user’s personnel to finalise the installation details in the site survey report. The report will detail:

- Physical locations of the ‘Taurus’ Array, DF Processor and the DF operator workstation.
- Identification of the Radio room for the monitoring receivers and the DF controller.
- Identification of any civil works to be performed by the customer
- LAN interface requirements.
- Mains power requirements.
- Other site-related installation considerations.

6.2 System Integration

Raven Research Limited can integrate all required hardware and software for this project at its UK facility for pre-installation deployment and testing.

6.3 System Testing

Raven Research Limited can prepare a factory acceptance test plan to verify proper operation of the system prior to deployment. It is anticipated that representatives of the end user organisation will participate in this testing.

6.4 System Installation and Testing

Following Factory Acceptance testing, Raven Research Limited can arrange for the packing and shipment of the system. Upon equipment arrival in country, Raven Research Limited can deploy engineers to perform system installation and Site Acceptance testing.

6.5 Training

Raven can provide on-site training to end user personnel. This training will encompass operation and maintenance of the system. All training and training materials will be in English.

6.6 Deliverables

Raven Research Limited can deliver the following services and equipment:

Services:

- Site Survey
- Factory Acceptance Test
- System Installation and supervision
- Training
- System Commissioning

Systems and Equipment:

- HF DF System
- HF RF Distribution System
- Work Station Terminals
- System Racking
- System Interconnect Cables (RF cables, to antennas, are part of the existing system)
- System and Equipment Manuals.