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Roke Manor Research Ltd
a Siemens company

Superresolution Direction Finding (SRDF) & Adaptive Digital Beamforming (ADBF)

Features and benefits

- DF multiple signals within receiver bandwidth
- Real-time Azimuth and Elevation results
- Network enabled Client/Server operation
- Accurate Position Fixing of HF transmissions
- Single Site Location (SSL) Position Fixing techniques
- Supports numerous receiver hardware configurations via dedicated data servers
- Advanced published DF and signal separation algorithms
- Extensive display options - field proven accuracy
- Strategic and Tactical operations
- Discrimination between groundwave and skywave

Introduction

Over the last decade Roke has established itself as a world leader in advanced Superresolution DF (SRDF) systems and associated Adaptive Digital Beamforming (ADBF) techniques for enhanced signal reception (E-Copy). Recent developments in Higher Order Statistics algorithms offer further new approaches to both DF and ADBF.

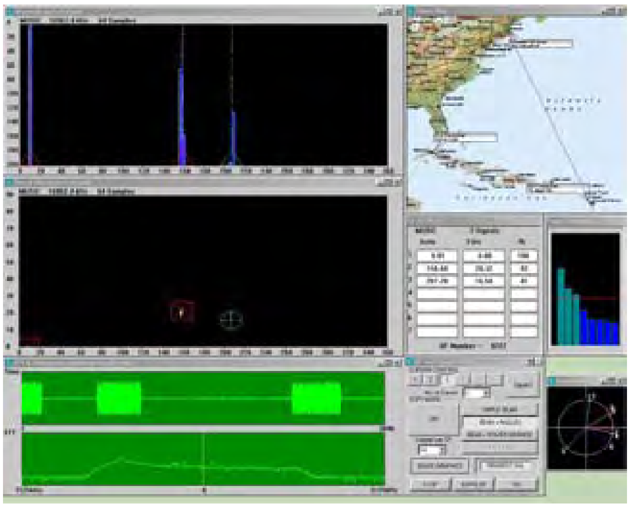

Figure 1: Roke SRDF Graphical User Interface

Roke SRDF systems are in operational use at a number of locations around the world. These have been primarily new installations but some have been to provide mid-life upgrades. For example, to the AX- 19 'Pusher' HFDF Circularly Disposed Antenna Array (CDAA) system.

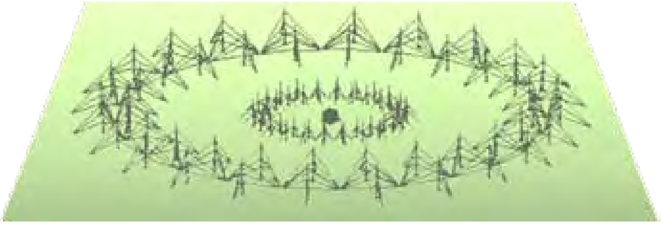

Figure 2: AX-19 'Pusher' HFDF CDAA

This Roke technology demonstrates excellent performance and is regarded by International End-Users as providing the highest standard of Direction Finding, Digital Beamforming and Geolocation capability.

Figure 3: Baldock Radio 'Pusher' site with Roke SRDF

The software algorithms and applications support a range of COTS 'N' Channel, Phase-Coherent HF Receiver systems, including the Roke MCDWR16 for HF and higher bands using downconverters.

Figure 4: Baldock Radio Operations Centre with Roke SRDF (image courtesy of Baldock Radio Station)

Why Superresolution?

The term Superresolution implies the ability to resolve two or more signals whose angular separation is less than the natural beamwidth of the array. Superresolution algorithms offer the following advantages:

- ability to handle multiple signals
- operation with very few samples
- not fixed to particular array geometries

Figure 5: High-Band Section of 'Pusher' HFDF CDAA

Superresolution processing correlates the I/Q data from each element with that in every other element, to form the data covariance matrix. This contains a complete description of the incident signal environment. The algorithms then determine the numbers of signals present, and using a knowledge of the array geometry, estimate the azimuth and elevation bearings of each signal, see Figure 5.

Software Architecture

To accommodate different multichannel receiver types, the SRDF / E-Copy software is split into a Data Server and a DF Processor. Different Data Servers are produced for each receiver, whilst the DF processor is receiver independent, see Figure 6. DF and E-Copy results from the DF Processor are displayed on the associated GUI, but are also made available over a network connection to a third party application. The format of all the commands and results returned are recorded in an Interface Control Document (ICD), to help with development of control clients. These interfaces have been successfully used by a number of companies.

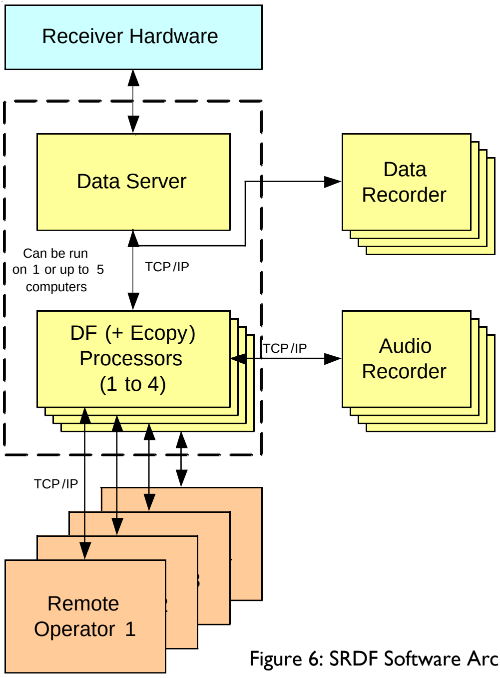

Figure 6: SRDF Software Architecture

DF Algorithms

The MUSIC (MUltiple SIgnal Cancellation) algorithm is a widely recognised Superresolution algorithm capable of finding the directions of multiple signals. The technique is resilient to jamming and de-correlated multipath since they just look like additional, independent signals. The performance tends to degrade in the presence of strong, correlated multipath. DF results and subsequent beam steering are of both azimuth and elevation. Angles defined.

ADBF Options

The software has several Adaptive Digital Beamforming options to enhance the output audio of the chosen signal (E-Copy). These listings are enscribed below:-

Figure 7: 1x element of Roke 8-Element HFDF Array incorporating Roke Compact Crossed-Loop (Central Europe)

(1) Simple beam – a conventional unweighted beam is formed in the direction of the wanted signal. For an N element array this will provide a signal to noise improvement of up to 10log(N). The beamwidth for typical HF arrays is some 10° to 40° and so beams are easily directed accurately enough to achieve full gain. However, the sidelobes of these beams are relatively poor and thus offer little protection to interference signals.

(2) Beam plus nulls – a beam is formed in the wanted signal direction, whilst introducing nulls in the pattern in the direction of interference signals. Again the accuracy of the direction estimate for the wanted signal is not that critical, however, the accuracy needed to provide deep nulls requires great precision. To provide 40dB nulls requires the phase and amplitude weights to be correct to around 1 degree of phase and 0.2 dB of amplitude. Even on a good antenna site it is not possible to characterise the array manifold to these accuracies and thus only modest nulling of say 15 to 20 dB is possible in practice. This level of interference rejection can still be very valuable when the interference is of a similar level to the wanted signal.

(3) Beam plus power minimise – this method works well when the interference is considerably stronger than the wanted signal. A gain constraint is imposed upon the ADBF algorithm to maintain gain in the wanted signal direction, whilst minimising power in all other signals. If the constraint direction is accurate then the wanted signal will be maintained whilst very deep adaptive nulls are directed towards the interference. With this algorithm it is possible to recover wanted signals buried some 40dB in interference. If there are errors in the wanted signal constraint, the wanted signal may also be minimised, and thus for this case the previous 'beam plus nulls' algorithm is more appropriate.

(4) Higher Order Stastics (HOS) based ADBF Algorithm – this is a method of signal separation based upon the statistics of the signal rather than being driven from the DF results. The Roke implementation is based on the Public Domain algorithm JADE. The general principal of the algorithm is to analyse the 2nd order and 4th order statistics of the multi-channel data, to provide sufficient unique measures to extract the individual source signals. DF results are extracted from the steer vectors used by the HOS algorithm. The main restriction of this algorithm is that it only works well with non-Gaussian signals.

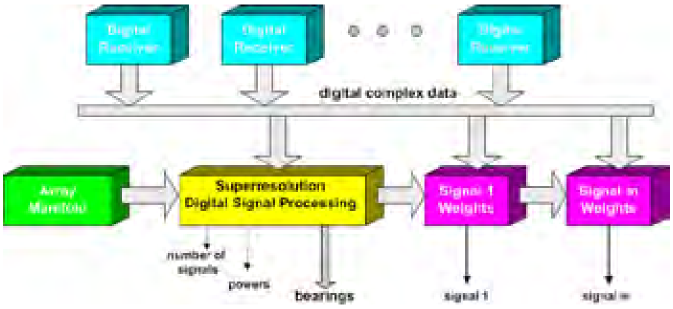

Figure 8: SRDF flow diagram showing receiver input through to bearing and audio outputs

DF Processor GUI

The DF Processor Graphical User Interface (GUI) has a main control panel, diagnostic plots and number of display views including a map. The basic controls allow the user to connect to and control the receiver and select the signal counting technique and E-Copy modes. The software can automatically estimate the number of signals present, or the user can apply thresholds or adopt a fixed count.

DF azimuth and elevation direction results can be viewed in 2D as a scatter plot with tracking cursors, or as an azimuth scan waterfall showing result history.

The 3D surfaces produced by the MUSIC algorithm may also be viewed in order to assess the quality of the results.

Detailed receiver data FFT displays and oscilloscope-like plots of the extracted audio help identify signals. Plots include a scrolling spectrum (waterfall)

The resulting lines of bearing can be overlaid on a map to help identify the location of signals. By coordinating DFs at multiple sites, emitters may be localised. Roke has enabled OFCOM (formerly the UK Radiocommunications Agency) to link its HF Direction Finding site at Baldock (central UK) into the European CEPT network for this purpose.

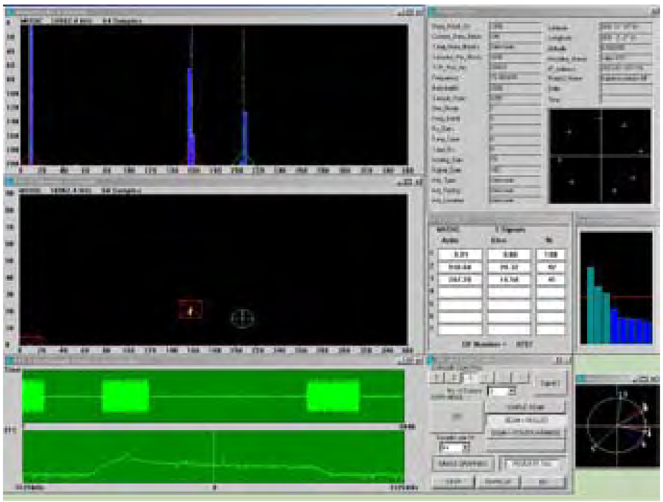

Figure 9: SRDF Processor GUI showing bearing waterfalls, scope plots, maps and control panel

Figure 9 above shows a typical display with a number of the display options visible. The data was collected in New Hampshire USA, and comprises a strong local jammer and two distant signals all within the receiver bandwidth. When listening on a single antenna, the jammer is all that can be heard.

Top left is a "DF Result Histogram" plot showing the three dominant signal directions (the blue bars grow taller as more results fall consistently in that direction).

The display centre left is an "Azimuth Elevation Graph" showing a scatter plot of results. The local jammer is at 0° elevation around 10° azimuth, an FSK signal just above 20° elevation at 160° azimuth, and a Morse code signal just below 20° elevation at 205° azimuth.

The display at the bottom on the left shows a "Scope Plot" of the Morse code signal. The signal is very clean and was able to be interpreted by machine and human readers. The same signal could not be heard when switching back to a single antenna.

As there are currently 3 "cursors" (using a threshold counting method) active, the 3 signals are correctly being tracked and the three signals were cleanly heard using the "beam plus nulls" or "beams plus power minimise" E-Copy algorithm.

The map in Fig. 1 shows the Lines of Bearing plotted. Each respective LoB successfully intersects the known locations of each transmitter prosecuted in this scenario.

Operational example:

Discrimination between groundwave and skywave transmissions

Specific User communities may, as an example, wish to rapidly discriminate between local, low power groundwave transmissions and higher power, long-haul skywave transmissions on the same frequency. In this example, the groundwave of a nearby low power tactical HF transmission, on a Line of Bearing of 180 degrees from the HFDF array, is being received on a frequency of 17807 kHz, but the skywave components of other transmissions on the same frequency are interfering with the User's monitoring of the groundwave tactical HF transmission.

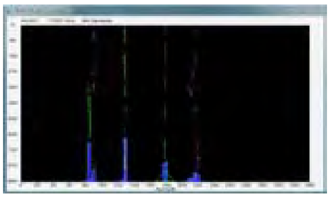

Figure 10: SRDF algorithms applied to 17807kHz showing 4 diverse signals on same frequency (azimuth vs time plot)

Without Super-Resolution Direction Finding (SRDF) and Adaptive Digital Beam-Forming (ADBF), it is difficult for the User to monitor and DF the Signal of Interest. However, once SRDF and ADBF algorithms are applied, the User can then rapidly determine that, in this example, his local Signal of Interest (i.e. groundwave) is on a Line of Bearing of 180 degrees, whilst the interfering skywave transmissions are on other Lines of Bearing from the HFDF array. Application of Roke ADBF algorithms to Signal 4 (see figure 11 below) then allows the groundwave Signal of Interest to be isolated for further processing. Note that Signal 4, on a low elevation, is visually discriminated as groundwave.

Conversely, similar techniques and procedures can be employed to reject local HF groundwave transmissions, whilst simultaneously enhancing distant skywave transmissions as required.

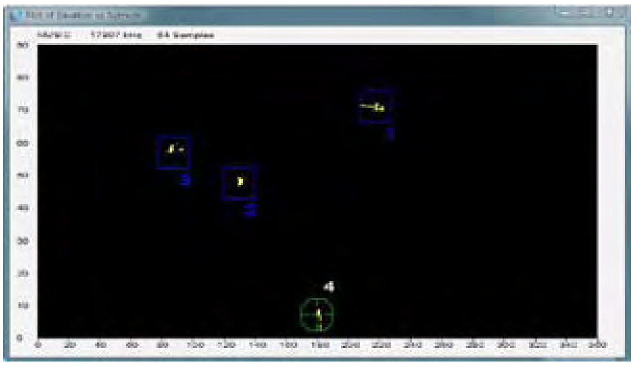

Figure 11: ADBF algorithms applied to 17807kHz – Enhanced Copy applied to Signal 4 (azimuth vs elevation plot)

Specifications

Parameter	Specification
Frequency Range	5kHz to 30MHz
Maximum Bandwidth	50kHz
Demodulation Modes	CW, FM, USB, LSB, ISB, AM
Number of Receivers supported (N)	3 to 16
DF Algorithm	MUSIC
DF Rate	100 DFs/s
DF Accuracy (Hardware dependant)	<1°
Number of Simultaneous signals in band	N-1, maximum 7
Azimuth Coverage	Full 360°
Elevation Coverage	0° to 90°
Samples per DF	64
ADBF Algorithms	4
Number of Beams/Nulls	6
Simple Beam Interference suppression	<9dB SINR
Simple Beam plus Nulls Interference suppression	<20dB SINR
Beam plus power minimise Interference suppression	40dB SINR
HOS Algorithm Interference suppression	40dB SINR
FFT Size (Spectrum)	1024 point
FFT Rate (Spectrum)	10 per second
PC Platforms Supported	Intel Pentium 4 or better
Operating Systems Supported	Microsoft Windows®

Ordering Information

Part: SRDF Number: X72/TB/2502/50
Part: SRDF E-Copy Number: X72/TB/2502/60
Part: SRDF HOS E-Copy Number: X72/TB/2502/70
Part: MCDWR_Server Number: X72/TB/2502/40

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