Novel Design and Implementation of Base Line Interferometry Direction Finding Bli Df Algorithm

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ABSTRACT: *The electronic warfare receiver aims to intercept the radar signal and analyze its characteristics like frequency, pulse width, pulse repetition interval, amplitude and also its direction of arrival. Today's modern radars are employing pulse compression to achieve low probability of intercept features. To analyze such radar signal, signal processing algorithm needs to be implemented in hardware. The digital receiver hardware is based on Fast Fourier Transform which provides processing gain over analog receiver. The Intermediate Frequency form RF front end in the range of 750 to 1250 MHZ forming the input to the digital receiver The IF is digitalized using Analog to Digital Converter and processed using FPGA in the digital receiver by implementing FFT to extract the parameters like Frequency Amplitude, pulse width, PRI. The DOA is computed based on base Line Interferometry technique. In this four channels are to extract the DOA. The BLI technique implemented in FPGA provides very fine DF accuracy in order of 10 RMS. The algorithm will be tested in real time for signals like pulse CW, Chirp, FM CW, phase Coded Rader signals. The Project involves literature survey, simulation of BLI, development of VHDL code for the Digital receiver, Implementation of BLI algorithm in FPGA. The system consists of base line interferometry configuration for high accuracy direction finding measurement with sector selection based on amplitude direction finding technique. Advanced signal processing algorithms with time frequency analysis are implemented in real time in field programmable gate array to extract all the basic as well as advanced parameters of frequency and phase modulations such as chirp, barker, and poly-phase (Frank, P1-P4) codes in addition to the pulse and continuous wave signals. The intercepted intrapulse modulated signal parameters have been extracted with very high accuracy and sensitivity.*

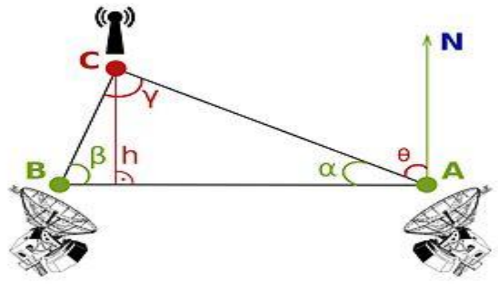
Keywords *EW-Electronic Warfare, ESM-Electronic Support Measure, DSP-Digital Signal Processing, FFT-Fast Fourier Transform, FPGA-Field Programmable Gate Array, MATLAB-Matrix Laboratory, VHDL- Very High Speed Integrated Circuit Hardware Description Language Intra pulse Modulation*

1. INTRODUCTION

The accurate measurement of radar's intra pulse parameters in real time is very essential to determine the characteristic of radar signals, which makes it possible to take counter action against the intended radar1. First, it is important to determine the primary parameters like frequency, pulse width, amplitude, direction and time of arrival of the radar signals. The analog receiver is capable of measurement of primary parameters but has a limitation of sensitivity, fine accuracy and also resolving time coincidence signals. These limitation being overcome by using the digital receiver, where the parameter extraction happens in frequency domain after fast Fourier transform (FFT) processing. The high sensitivity of the receiver is achieved results of FFT processing gain, accuracy of parameters achieved due to signal processing at higher point FFT and providing solution for simultaneous intercepted signals because of frequency domain analysis. Subsequently, the advanced parameters like pulse modulation, frequency modulation and phase modulation are to be determined using digital receiver. Measurement of these parameters accurately is also important, because it will help to identify two similar radars operating at very close frequency. The digital receiver is a single board solution for the modern day electronic warfare (EW) receivers instead of multiple boards. Modern electronic intercept systems must perform the tasks of detection, classification, identification and exploitation in a complex environment of high noise, interference and multiple signals. Some waveforms are intentionally designed to make the detection process nearly impossible. Such signals are referred to as Low Probability of Intercept (LPI) waveforms [1]. Parameters such as carrier frequency, modulation type, data rate and time or angle-of-arrival are just a few of the fundamental features that distinguish one signal from another. The sorting and cataloging of signals leads to the process of identification. The task of classification requires sorting into groups having similar characteristics. Each of these initial processes: detection, Classification, identification and exploitation require advanced signal processing techniques. A combination of FPGA (pre processing) and DSP processor (post processing) is being used to extract all the parameters of LPI radar. The complete information of a pulse is embedded in the form of a Pulse Descriptor Word which is further processed to display the parameters of an emitter on ESM display.

2. DIRECTION FINDING

Direction finding (DF), or radio direction finding (RDF), refers to the measurement of the direction from which a received signal was transmitted. This can refer to radio or other forms of wireless communication. By combining the direction information from two or more suitably spaced receivers (or a single mobile receiver), the source of a transmission may be located in space via triangulation. Radio direction finding is used in the navigation of ships and aircraft, to locate emergency transmitters forsearch and rescue, for tracking wildlife, and to locate illegal or interfering transmitters.



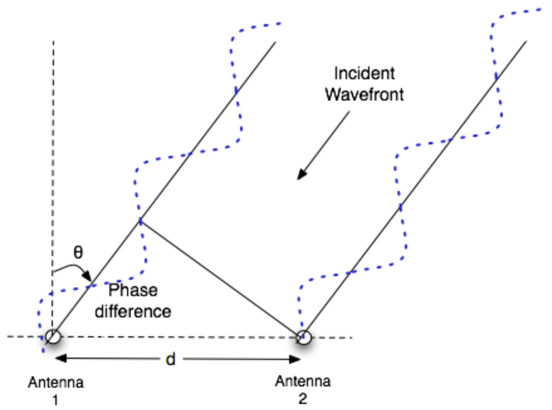
RDF systems can be used with any radio source, although the size of the receiver antennas are a function of the wavelength of the signal - very long wavelengths (low frequencies) require very large antennas, and are generally used only on ground-based systems. These wavelengths are nevertheless very useful for marine radio navigation as they can travel very long distances "over the horizon", which is valuable for ships when the line-of-sight may be only a few tens of kilometres. For aerial use, where the horizon may extend to hundreds of kilometres, higher frequencies can be used, allowing the use of much smaller antennas. An automatic direction finder, which could be tuned to radio beacons called non-directional beacons or commercial AM radiobroadcasters, was until recently, a feature of most aircraft, but is now being phased out

For the military, RDF is a key component of signals intelligence systems and methodologies. The ability to locate the position of an enemy broadcaster has been invaluable since World War I, and played a key role in World War II's Battle of the Atlantic. It is estimated that the UK's advanced "huff-duff" systems were directly or indirectly responsible for 24% of all U-Boats sunk during the war. Modern systems often used phased array antennas to allow rapid beamforming for highly accurate results, and are part of a larger electronic warfare suite.

Several distinct generations of RDF systems have been used over time, following the development of new electronics. Early systems used mechanically rotated antennas that compared signal strengths, and several electronic versions of the same concept followed. Modern systems use the comparison of phase or doppler techniques which are generally simpler to automate. Early British radar sets were referred to as RDF, which is often stated was a deception. In fact, the Chain Home systems used large RDF receivers to determine directions. Later radar systems generally used a single antenna for broadcast and reception, and determined direction from the direction the antenna was facing.

3. BASE LINE INTERFEROMETRY

An interferometer is an antenna system composed Of two or more elements which is used to determine the direction-of-arrival of a received signal utilizing the measured relative phase between the various elements. Phase-comparison mono pulse (also called phase-interferometry) describes a technique that can be used in radar and direction finding applications to accurately estimate the direction of arrival of a signal from the phase difference of the signal measured on two (or more) separated antennas. Assume two antenna separated by a distance d, with a wavefront incident at an angle θ, then the extra path the signal must travel between Antenna 1 and Antenna 2 (see figure) results in a phase difference, ΔΦ, between the two antennas. This can be used to calculate the direction of arrival using.



$$\theta = \sin^{-1}\left(\frac{\lambda\ \Delta\Phi}{2\pi d}\right)$$

Where λ is the signal's wavelength.

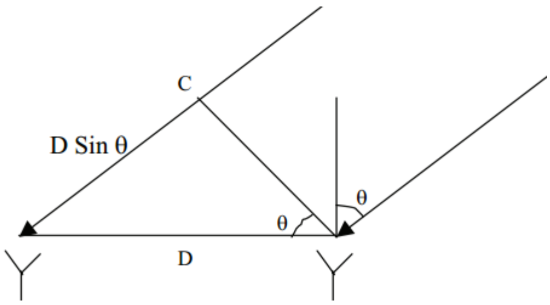
For unambiguous results, the antennas should be spaced half a wavelength apart, or less. However, this can result in significant mutual coupling between elements, which means that each antenna's phase measurement will be corrupted by the others. The approach assumes that the phase centres of the antennas are exactly known. With more complex antenna structures (such as the log-periodic antenna) the effects of mutual coupling can make the phase centre locations unknown. In this case, calibration or electromagnetic modeling may be required.

The ability to accurately measure a signal's phase depends on the signal-to-noise ratio (SNR), and hence the accuracy of this technique is dependent on the SNR. The Direction of Arrival (DOA) of a radar signal is the most important parameter that has to be measured for locating the Radar using an EW system this is because the DOA is the only parameter that cannot be camouflaged by the enemy radar, other parameters like frequency, pulse width, PRF (Pulse Repetition Frequency) etc can be varied when incorporated, for acquiring valid DF.

Consider a two element interferometry array as shown in fig 1. Consider a plane wave signal incident on the array at an angle θ with respect to boresight of the array. Consider a plane wave signal incident on the array at an angle θ with respect to boresight of the array. The phase delay ψ is given by

$\Psi = (2\pi d \sin\theta) = \psi + 2\pi m$

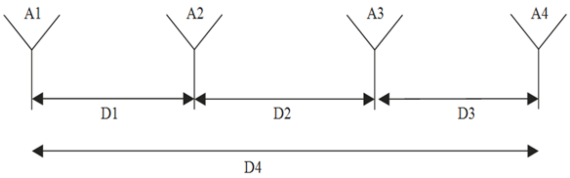
where φ is the λ true phase delay between



Basic Interferometry

From the above equations it is obvious that to get a higher DFaccuracy one has to

go for a higher spacing between the antennas.



An interferometer system consisting of two antennas in space causes an ambiguity in determination of AOA. The system has coverage of 180 degrees in azimuth; however it is not clear from which half of the hemisphere the signal originated. Practical interferometer systems solve this problem by using another system such as DF system to select proper estimate of DOA or use quadrant arrays of antennas shielded from each other,. Another method to resolve ambiguities is to use a multiple antenna elements, called multiple baseline interferometers. In a typical design of multiple baseline interferometers, there exists a reference antenna and a series of companion antennas, spaced in line and located at different distances from the reference antenna in order to operate together. In multiple baseline interferometer systems, there are two types of choice of antenna element location. A harmonic binary related interferometer system divides each aperture baseline by a factor of 2 is given in Figure

The number of ambiguities is increased as the spacing to the reference antenna is increased. In the selected quadrant, first antenna pair, forming a $\lambda/2$ baseline, solves the ambiguity problem coverage.

4. PARAMETER OF BLI

4.1 Phase Error Margin :

We have already seen that in case an error occurs in phase measurement we may get non-integer results for certain computations in the algorithm which ideally should have been integers. Rounding off the results to the nearest integer does not affect the algorithm provided the errors are below a specific value. Phase Error Margin is defined as the maximum permissible error in phase measurement below which the algorithm described will not break down. The breakdown of the algorithm is said to take place if rounding off gives a wrong result due to excess phase errors while estimating the modulo integer. This will result in gross errors in DOA computation. There will be no breakdown in the algorithm if

$(2\delta\emptyset 1-\delta\emptyset 2) / 2\pi < 0.5$

Where Ø1 is the error in Ø1 andØ2 is the error in Ø2 $(2\delta\emptyset 1-\delta\emptyset 2) < \pi$

The RF front end following all the antennas in the array is identical and so are the phase measurement and digitization units. Hence we can assume that the error statistics for phase measurements are independent of the spacing. We can also assume that the error statistics for all the phase measurements.Let the peak error in phase measurement in any channel be δØ.Hence we get from equation

$3\ \delta\emptyset < \pi$

Hence the available phase error margin in the algorithm is ± 60° for the first step in the algorithm. It can be similarly shown that the available phase error margin for the second and final steps in the algorithm are ± 51° and ±

55° respectively. Therefore the system phase error margin is the minimum of all the above three i.e. ± 51°. In case higher phase error margins are required the array spacing has to be suitablysynthesized.

4.2 SENSITIVITY:

The sensitivity of the DF system is defined as the minimum processed signal for which the measured DF data satisfies the RMS accuracy specification. The processed sensitivity of a broadband receiver is given by

$$Smin = -114 + 10 \log (BW) + NF \qquad (4.4)$$

Where Smin the minimum processed signal in dBm -114 is the noise power per MHz bandwidth in dBm BW is the total bandwidth in MHz and NF is the noise figure in dB (A noise figure of 10 dB is a practically achievable in the 8-18 GHz band).

The above equation assumes a theoretical processing capability at 0dB SNR at the output of the RF front end. However in practical systems there will be a degradation of up to 3dB in the processed sensitivity. For the 8-18 GHz band the practically achievable processed sensitivity is better than -60 dBm.

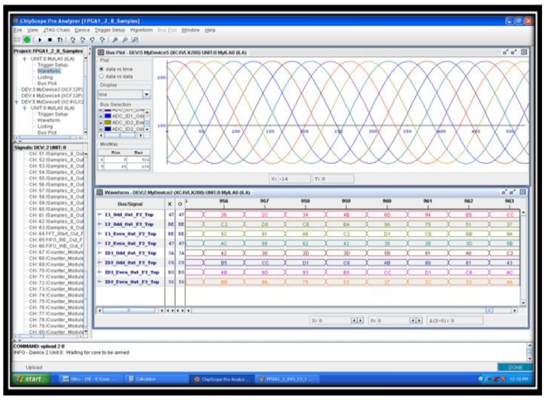
4.3 Dynamic Range:

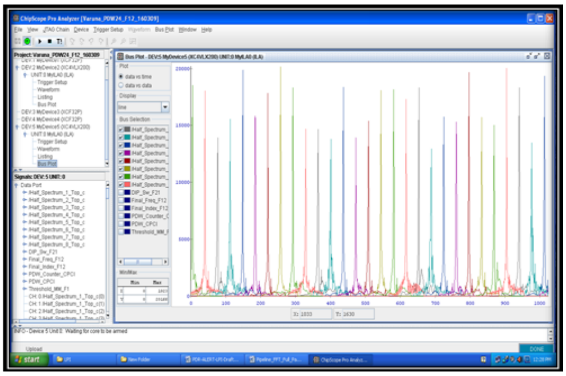
The dynamic range of the DF system is defined as the difference in dB between the lowest processed signal power and the highest processed signal power. The RF front end of a broad band interferometer DF system consists of a limiting amplifier with adequate gain such that the signals from -60 to 0dBm are compressed to an output range of +6 to +10 dBm. This is possible since the system has to measure only the phase of the signal which is preserved by the limiting amplifier.

5. DIGITAL RECEIVER

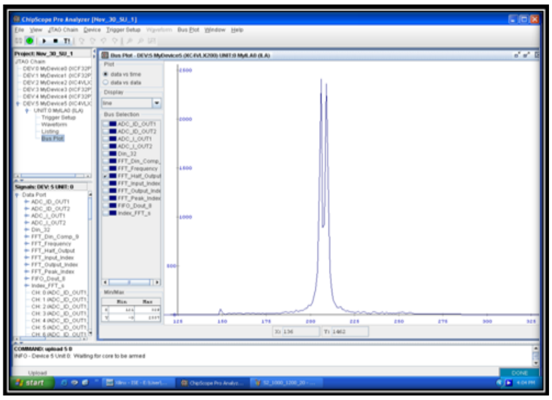
The ADCs present here are the dual channelled ADCs, there are three FPGAs. Each FPGA has its own specification in which the operation and functions are implemented. The FPGA 1 consists of the parameter extraction module in which the parameters are extracted. FPGA 2 consists of the FIFO which lets the data synchronised and sends it to the FFT. The FFT thus performed undergoes

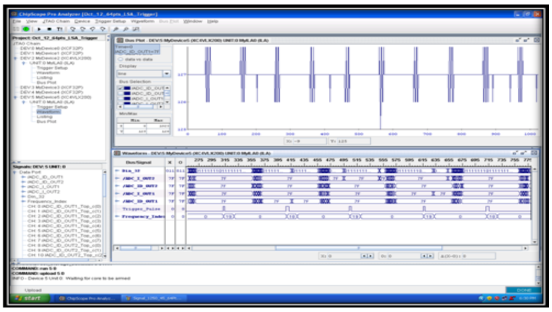
from CORDIC to the unwrapping and DF algorithm

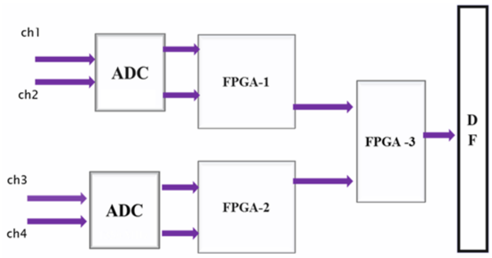




6.RESULT ANALYSIS







7. CONCLUSION

The paper outlined both the pre and post Digital Signal processing methodology for Detection, Identification & Classification of Intra Pulse Modulated LPI Radar Signal. The pre-processing and post processing is achieved with a combination of high end Virtex-6 FPGA, advanced Tiger SHARC DSP processor and Power PC. The proposed hardware along with algorithms discussed serves as a single board solution to detect the various frequencies and phase coded radar signals and identifies their characteristic parameters.

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