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Designing & implementation of multi beam smart antenna for aerospace communication using FPGA

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***Abstract*—Requirements for high bandwidth UAV communications are often necessary in order to move large amounts of mission information to/from Users in real-time. The focus of this paper is antenna beam forming for point-to-point, high bandwidth UAV communications in order to optimize transmit and receive power and support high data throughput communications. Specifically, this paper looks at the design and implementation of multi-beam smart antennas to implement antenna beam forming in an aerospace communications environment. The smart antenna is contrasted against fast fourier transform (FFT) based beam forming in order to quantify the increase in both computational load and FPGA resources required for multi-beam adaptive signal processing in the Smart Antenna. The paper begins with an overall discussion of Smart Antenna design and general beam forming issues in high bandwidth communications. Important design considerations such as processing complexity in a constrained Size, Weight and Power (SWaP) environment are discussed. The focus of the paper is with respect to design and implementation of digital beam forming wideband communications waveforms using FPGAs. A multi beam time delay element is introduced based on lagrange interpolation. Design data for multi beam smart antennas in FPGAs is provided in the paper as well as reference circuits for implementation. The multi beam smart antenna example design illustrates the concepts discussed in the paper and provides design insight into multibeam Smart Antenna implementation from the point of view of implementation complexity, required hardware, and overall system performance gain.**

***Index Terms*—Component, formatting, style, styling, insert.** *(key words)*

I. INTRODUCTION

In various UAV missions there is a consistent need for high throughput communications in order to move large amounts of mission data to/from Users in real-time. Often this requires wideband communications architectures such as OFDM (multicarrier system) or several single carrier channels, and optimizing several communication system parameters, including the antenna beam pattern, to achieve required performance. This paper considers the scenario of UAV or similar aerospace communications platform, which must perform wideband digital beam forming to achieve high throughput communications. In the context of this scenario Spatial filtering using antenna beam forming can provide communication system performance gains in terms of Space Division Multiple Access (SDMA) as well as Spatial Filtering for Interference Reduction (SFIR). The context of antenna beam forming to perform spatial filtering for wideband communications requires some clarification. Generally, antenna apertures can be grouped in capability based on (a) the type and number of antenna elements, (b) the method used to switch or steer antenna beams, which implies the level of complexity in the architecture as well as a switching speed, (c) the instantaneous bandwidth of the antenna aperture and (d) the signal processing used for the antenna aperture. This also implies an architecture complexity based on the number of steered antenna beams as well as the number of antenna nulls to reduce the effect of interferers. The latter capability reflects whether or not the antenna aperture is adaptive to the environment in which it is operating.

II. FRACTIONAL BANDWIDTH IN SMART ANTENNA

Fractional bandwidth is an important performance parameter in Smart Antennas and provides some insight into array capabilities. We can defme the fractional bandwidth of the antenna aperture:

$$BWfrac = \frac{BW_{RX}}{Fcarrier} \qquad (1)$$

where BWfrac is the fractional bandwidth, BW_{RX} is the received signal bandwidth and fcarrier is the carrier frequency. Fractional bandwidth impacts array design. Classic narrowband array design often uses phase shifters to implement corresponding delays such that the elements are added in correct phase for a given beam steer. As fractional bandwidth increases, narrowband design assumptions based on single frequency phase shifters are no longer valid. A wideband signal from a given direction of arrival, appears to arrive from an angular region in the narrowband array. The phenomenon is known as dispersion.

III. BEAM FORMER WEIGHTS IN SMART ANTENNA

Smart antennas adapt the weights based on the environment (interference, etc). An equation for obtaining an estimate of bema former weights for an adaptive array can be described by the optimum Weiner solution:

$$\hat{W}=kR^{(-1)}\ s \qquad (2)$$

Where $\hat{W}$, is the estimate of the beam former weights, $R^{(-1)}$ represents the inverse of the sample covariance matrix, s represents the spatial steering vector and k is a scale factor. The sample covariance matrix is estimated from the received data and contains information about the environment. A dynamic aerospace environment requires that the process of beam former weights be continually updated to adapt to changing Angle-Of-Arrival (AOA) of signals and interferers.

IV. MULTI BEAM SMART ANTENNA BASED ON SMI & FFT

The multi-beam smart antenna can be considered as an extension of the smart antenna. A multi-beam smart antenna architecture can modelled using sample matrix inversion method. For the smart antenna implementation using SMI, the interval when the sampled data is collected is an important initial metric for the update rate of the beam forming weights as well as applying FPGA resources sharing[9].Obtaining a good sample covariance matrix estimate and then inverting the sample covariance matrix, referred to as Sample Matrix Inversion (SMI) or Direct Matrix Inversion (DMI) [3], can require substantial FPGA resources. The number of complex multiplies and memory depends on the array size, method used to obtain the weights including any algorithm computational load reduction techniques, and the FPGA implementation. Fast Fourier Transform (FFT) based methods, or frequency domain beam forming, [4][5][6] refers to the use of the FFT as the implementation method to accomplish digital beam forming. FFT based methods are often used as an approach to accomplish AOA. FFT based methods are non-adaptive systems that use the FFT to either perform digital beam steering or provide AOA information to accomplish the beam steering function, respectively. As simple FFT based beam forming is not adaptive and does not require an estimate and correction for the received signal environment, the signal processing load and the implementation complexity is not as high as it is for the Smart Antenna. However, when there is a system requirement to operate in an environment that contains interference (i.e. we want to null out co-channel interference, etc.). Smart Antennas represent a capable solution. Smart Antennas may use various algorithms to optimize the estimate of the beam-forming weights. In this paper we will focus on the SMI approach, also called a block adaptive implementation since it uses a block of sampled data to obtain the covariance matrix. The accuracy of this sampled matrix is sensitive to the length of the data block (the size of K or the number of samples) and the instantaneous environment during the interval when the sampled data is collected. Furthermore the length of the data block also impacts the side lobe level which can be achieved.

V. PROPOSED METHODOLOGY

In the proposed methodology, the array sensor output is split into multiple data streams each delayed as required based on the respective direction of a given receive beam. The time delay elements for the receiver would take the individual sensor output and implement time delays, one delay for each receive beam, on the data producing a single data output stream for each delay which would be combined with its respective output from the other sensors to implement the SMI architecture. On the other hand, a simple algorithm to implement the smart antenna using SMI would consist of complex multiply and accumulate (CMACC) operations over the matrix followed by the matrix inversion operation to estimate the sample covariance matrix. Complex multiplications are then used to multiply the inverse sample covariance matrix with the spatial steering vector to obtain an estimate of the beam former weights. Finally complex multiply operations are used at each element in the smart antenna to multiply the beam forming weights with the individual channels in the delay and sum beam former. The resulting output in each channel is summed together to obtain the beam former output y[n].

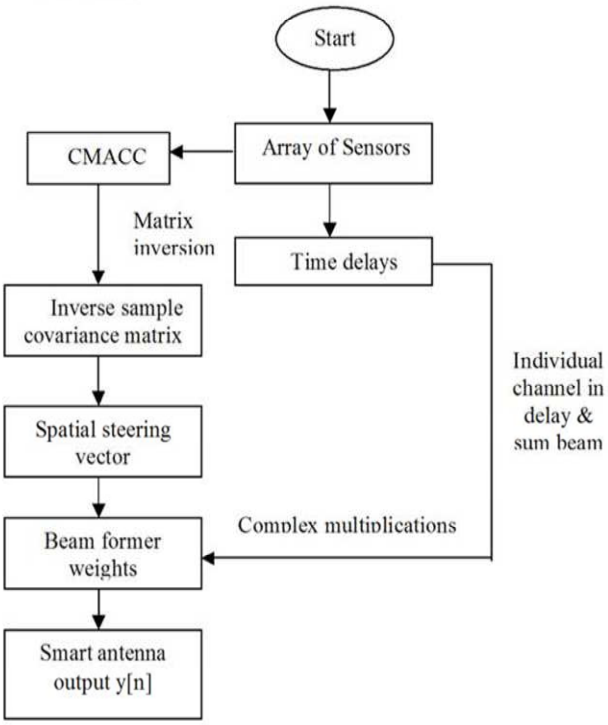

Fig 1. Flow diagram of proposed system

A. Time delays:

The time delay element is based on Lagrange interpolation, which supports a four beam receive operation at the output of a single sensor at full clock rate for the smart antenna. The time delay elements for the receiver would take the individual sensor output and implement time delays, one delay for each receive beam, on the data producing a single data output stream for each delay which would combined with its respective output from the other sensors to implement the SMI architecture.

B.Spatial steering vector

Spatial steering vector provides the time delay, while designing the frame. It is used to correct the errors on channels. When the data sends on each channel, due to some errors some data will be loss, which can be concluded from the acknowledgement which gets received from the receiver. If there is an error the angle of arrival and the time delays are provided to them in order to remove the errors. AOA decides on how much error is there on channel when input data sends on that channel.

C.Beam former weights:

Arrays multiply the incident signal by beam former weights, for each array element. Smart antennas adapt the weights based on the environment (interference, etc.). An equation for obtaining an estimate of beam forming weights for an adaptive array can be described by the optimum Weiner solution:

$$\hat{W}=kR^{(-1)}\ s \qquad (2)$$

Where $\hat{W}$**,** is an estimate of the beam former weights, R^(-1**)**represents the inverse of the sample covariance matrix, s represents the spatial steering vector and k is a scale factor. The sample covariance matrix is estimated from the received data and contains information about the environment.

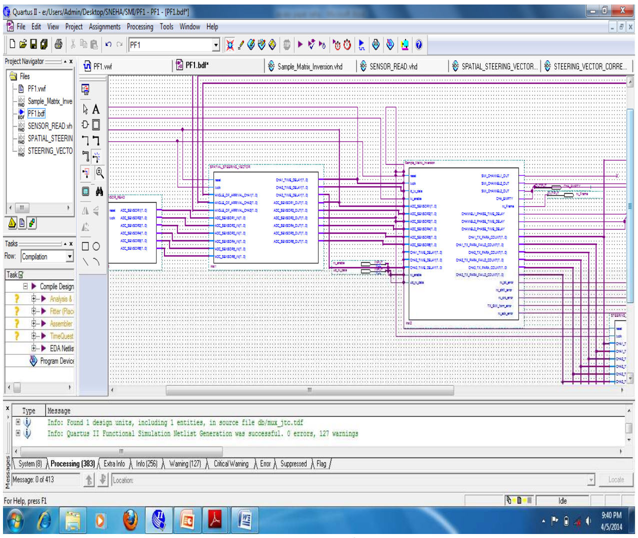

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Fig 2. Top level view of SMI algorithm

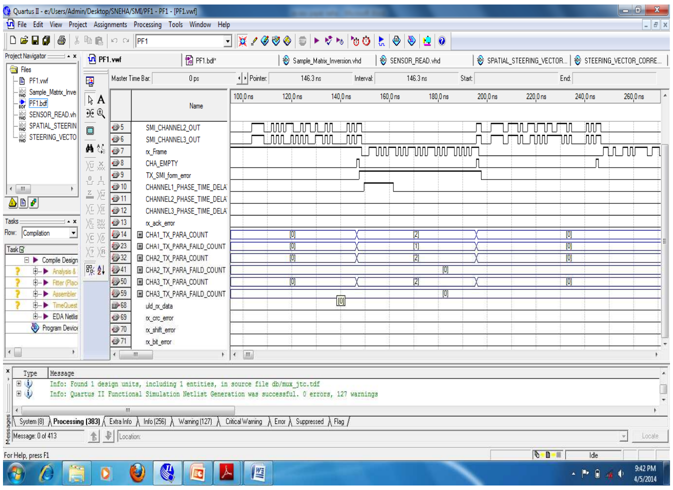

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Fig 3. Output simulation graph of SMI algorithm

VI. CONCLUSION

In this paper, we have examined the design and FPGA implementation of both Smart Antennas and FFT beam formers for high bandwidth UAV communications. Specifically, both architectures were examined for single beam and multibeam cases and used the delay-and-sum beam former as a basis for a wideband communications array. The Smart Antenna architecture in this paper implemented the SMI algorithm. Both architectures were contrasted to quantify the design complexity and implementation cost associated with this type of adaptive signal processing versus simple beam steering using the FFT beam former. In multi-beam smart antenna the significance and value of the increase performance and mission capability to aerospace platforms often justifies. Hence, computational load, signal to noise ratio, throughput and system complexity has been achieved by the SMI algorithm.

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