Use of a Single Snapshot Based Adaptive Processing Using a Direct data Approach

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Abstract

The objective of this presentation is to describe a general methodology for adaptive processing using conformal arrays for a single snap shot of data and without any statistical assumption on the noise and the interferences. The antenna elements in a conformal array can be unequally spaced and they need not be situated over a planar surface. In addition the antenna elements can have a directive gain. The goal is to present a signal processing methodology coupled with electromagnetic physics that can deal with non-uniformly spaced directive antenna elements over a conformal surface.

1. Description of the Methodology

The phased arrays are used to sort out signals in space specifically when there are coherent multipaths of the signal, as the information about the multipaths does not exist in the temporal domain. A more sophisticated form of phased arrays is an adaptive array which spatially filters out the signal of interest in the midst of clutter, jammer and interference. The science of adaptive phased arrays, which started over fifty years ago, was primarily implemented through analog processing, as during that period of time the analog correlation processing was the only way. However, with the advent of digital signal processing we are currently using the same algorithms in the digital scenario without taking a critical look whether such a methodology is really meaningful. For example, when using an analog adaptive algorithm, it is imperative that the adaptive weights can never be greater than unity as that would be tantamount to using an amplifier for the weights. Hence, the antenna array pattern for analog systems has a great physical significance. Therefore, with analog processing the array resolution is essentially limited by the size of the aperture and how closely one can resolve spatially spaced signals are dictated by the Rayleigh resolution criteria. So with the advent of digital signal processing one can go beyond the Rayleigh resolution and resolve signals within the width of the main beam of the array. Secondly, the adaptive weights can take any complex value numerically as we are now processing the signals digitally and the purpose of the weights is equivalent to multiplying the voltages at the antenna feed points by some numbers. In such scenarios, the antenna array pattern looses to have any special significance at all.

The second shortcoming of the current phased array methodology is that the mathematical description of the adaptive problem is set up as a detection problem rather than as an estimation problem. To illustrate this point when we are dealing with radars we are sending out a waveform and the assumption is that we are trying to detect the same transmitted waveform delayed in time and attenuated, since the radar signal is not getting dispersed as it is propagating through free space. Hence, in such a situation we only want to know if the transmitted radar signal reflected from the target exists or not. If the radar return exists then we know how far is the target from the time delay and from the Doppler shift, the velocity of the target. The optimum way to detect the existence of a particular wave shape we transmitted is to use a matched filter whose transfer function is the complex conjugate of the Fourier transform of the transmitted radar waveform. However, in a multi-path rich mobile communication, detection is not the problem that we want to address, because we know the signal is there, what we want to do is to estimate its correct amplitude, as that will correct for fading. The current mathematical approach of adaptive filtering is to use a Wiener filter based model where a pilot signal is transmitted before every transmission and the channel along with the array is calibrated before the actual signal is sent. This leads to serious problems for real time transmission as the assumption that the environments are identical when the pilot signal was sent and when the actual transmission is arriving may not be the same in a mobile environment. That is why a direct data domain least squares approach based on a single snapshot of the voltages measured at the feed point of the antenna elements at a particular instance of time has been used to solve the estimation problem directly [1,2].

In this presentation we are going to extend the single snapshot based direct data domain approach to deal with conformal adaptive phased arrays. In the current way of thinking one wants to use essentially an antenna element that has as close to an omni directional pattern as possible and then derive the gain by using hundreds and even thousands of

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them to get any significant gain from the array. Now one has to put a receiver channel at each of these antenna elements and that exponentially increases the cost. So in order to minimize the cost one then defines a sub aperture and then sums up all the voltages in an analog fashion at the feed point of these antennas. Then either a sum and a difference beam pattern is formed to resolve the target or digital beam forming using these summed up voltages This is not a sound procedure as it defeats the entire purpose of digital beam forming. This can easily be seen that it negates the basic fundamental model of any adaptive signal processing algorithm! Most authors in the Electromagnetics related conferences erroneously use the term *Digital Beam Forming* to imply that the signal is being processed by a digital computer rather than doing it in an analog fashion. In scientific terms, *Digital Beam Forming* has a completely different connotation. It implies that we can do super-resolution, i.e., resolve targets in the main beam, thereby go beyond the Rayleigh resolution criteria determined by the size of the antenna aperture. What is proposed here is to use directive elements on a conformal surface to perform adaptive processing. Use of directive elements will significantly reduce the number of antenna elements and then if one places these directive elements on a conformal surface to do adaptive processing it will require significantly less number of antenna elements without sacrificing the gain. This requires characterization of near field effects. Such a methodology is illustrated here.

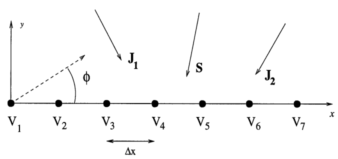

Fig. 1. A seven element array

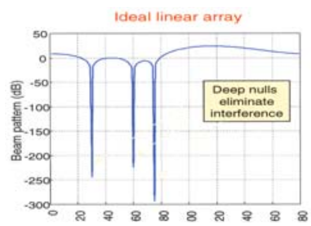

Fig. 2 The adapted pattern using an ideal array

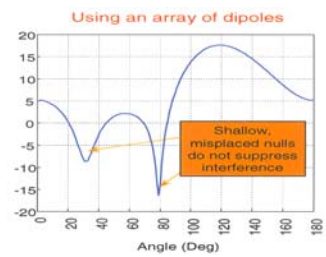

Fig. 3 Pattern in the presence of mutual coupling

2. The Relevance Of Electromagnetics In Adaptive Processing

An antenna is a spatial sampler of the electric/magnetic field propagating through space. The primary function of an antenna is to couple to the displacement current propagating through space and sample that dynamic information-carrying field. It is well known in antenna theory and available in any standard textbooks that the voltage generated at the terminals of the antenna is the result of the spatial integration of the field incident along the length/orientation of the antenna. Typically an antenna is half a wavelength long to have better efficiency, gain and good electrical properties. Therefore, the induced voltage is a result of integration of the incident field over half a wavelength. Common sense also tells us that from the integral of a waveform over half a wavelength it is not possible to say what is the value of the incident field at the feed point of the antenna. But it is this value at the feed point of the antenna that any signal-processing algorithm needs to carry out its calculations. Therefore unless the electromagnetic effects of the antenna or the transfer function/impulse response of the antenna is deconvolved out of the response, just carrying out mere signal processing is a complete wastage of natural resources! Let us illustrate this with a simple problem. Consider an array of seven point source antenna elements as shown on Fig 1. The desired signal of interest arrives from 45° and is of amplitude 1V. There are 3 coherent interferers coming from 30°, 60° and 75° of amplitudes 2, 1.5 and 1V respectively. Application of an adaptive algorithm to this scenario to extract the desired signal works fine as shown by the radiation pattern of Fig. 2. Now we replace the idealized sources by seven half wave dipoles of radius $\lambda/200$ and centrally loaded by 50 Ω. These voltages are then used to carry out the adaptive processing. The result is shown in Fig 3. It is clearly seen that the solution is wrong and an adaptive system just relegated to signal processing only, has failed miserably! However, if the mutual coupling between the antenna elements are carefully taken into account through the solution of Maxwell's equations then the nulls are restored to their proper positions and the signal is estimated accurately, as seen in Fig. 4. This simple problem thus clearly illustrates that unless the electromagnetic effects like mutual coupling and presence of near field scatters are accounted for carrying out signal processing is not going to be very fruitful!

3. Solving An Estimation Problem Rather Than A Detection Problem Is Essential

Most of the signal processing algorithms that are in vogue solve a detection problem rather than an estimation problem. The various algorithms had been developed when the world was analog in nature some 30-50 years ago. In addition, they were addressing the radar problem. In a radar problem, one knows exactly what pulse shape had been transmitted and that will be more or less the shape of the pulse that is going to come back. So in order to establish whether there exists a target of interest is to simply look for the radar return, or equivalently look for a particular shape of pulse that exists. In the current way thinking we are still using essentially the same concept but has relaxed the idea that the return pulse shape may be different. Yet, the fundamental philosophy is still the same when we are looking for a signal in clutter. A block diagram of the Wiener filter will illustrate this scenario. It is shown in Fig. 5. What is clear from this block that an error is being minimized between the desired signal and a filtered output signal. Hence the goal is to have the system adapt to the desired signal. So one sends a pilot signal and have the system adapt to it. And then transmit the message and pray that the environment is identical to when the pilot signal was transmitted. The result is that the system needs to be calibrated before every message record. The problem is with the philosophy. The goal here is again to detect whether the signal of interest is there or not. Now so far it is workable provided there are no interfering multipaths. In the presence of coherent/incoherent multipaths the problem that needs to be solved is not the detection problem but the estimation problem. In the detection problem one needs to know whether the signal of interest is there or not and the query ends there. In an estimation problem the goal is not only to detect whether the signal is there or not but also to simultaneously estimate its amplitude. When there are multipath effects present, we know there are signals but we do not know its actual amplitude as due to constructive or destructive interferences between the signal and its multipaths we have fading and we want to extract the true signal out of it! So the detection of the signal is not a meaningful methodology, as we need to get the correct amplitude. Hence we need to estimate the signal amplitude in real time [1].

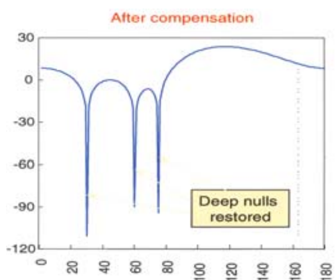

Fig 4. Adapted pattern after accounting for the various electromagnetic effects

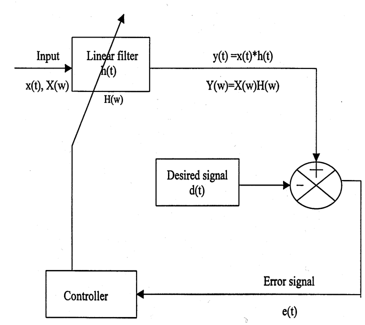

Fig. 5. Block Diagram of an adaptive Weiner Filter

4. Conclusion

The objective of this presentation is to illustrate that the solution of Maxwell's equation is quite important in addressing system issues in a smart antenna system. Neglect of this important principle will not deliver the promises of wireless.

5. Reference

[1] T. K. Sarkar, M. C. Wicks, M. Salazar-Palma and R. Bonneau, *Smart Antennas*, IEEE Press &John Wiley & Sons, 2003.
[2] T. K. Sarkar, M. Salazar-Palma and E. L. Mokole, Physics of Multiantenna Systems and Broadband Processing, IEEE Press &John Wiley & Sons, 2008.