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Low Cost Em Signal Spectral Analysis with Two Element Time Modulated Array System by Multiple Signal Classification Algorithms

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ABSTRACT
Today homeland security is a big matter of concern. The present day wireless technology is available to anti-social elements, who are using this in several undesirable manners. By knowing the direction of the source of electromagnetic waves it becomes possible to locate such anti-social groups and take offensive action. In military applications also finding the direction of the signal source becomes very valuable information. The direction finding systems can achieve this goal.
Conventional radio direction finding (RDF) systems often use an array of two or more antennas and use either phase-comparison or amplitude-comparison of the received signals to determine direction of arrival information. In both of these techniques directional information is derived by processing array data at the receive signal frequency.
In this project an alternative approach to direction finding using the concept of a time-switched array is proposed. The time-switched array system uses simple signal processing techniques to provide a directional main beam and pattern nulls at harmonic frequencies. To determine two dimensional angles is three elements, the system cost has been mostly minimised. we now consider the problem of using our low cost system to detect and estimate the direction of arrival of a desired signal in the presence of array antenna.
The proposed scheme is cost effective technique in comparison with the existing schemes.
MATLAB/GNU OCTAVE simulation tool will be used for simulation. The simulation results, applications, merits and demerits of proposed approach will be analyzed and will be documented.
Index Terms-antenna, array, direction finding.

I. INTRODUCTION

Conventional Radio Direction Finding (RDF) systems often use an array of two or more antennas and also by using the concept of a time-switched array. The time-switched array systems uses simple signal processing techniques to provide a directional main beam and pattern nulls at harmonic frequencies use either phase-comparison of amplitude-comparison of the received signal to determine direction of arrival information. In both of these techniques directional information is derived by processing array data at the receive signal frequency.
It has been exploited in numerous applications (e.g., radar, sonar, wireless communications, seismic exploration, speech processing, medical imaging, radio astronomy).

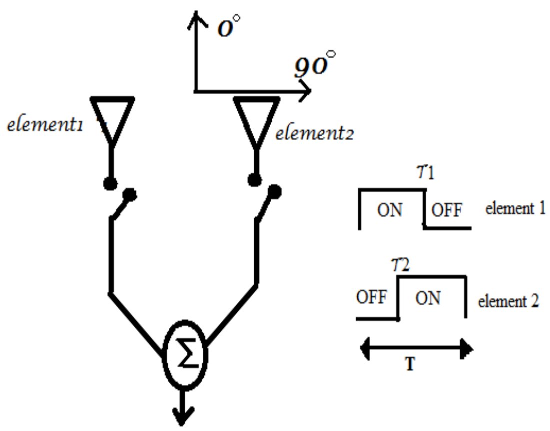

Fig 1: Two Element Time-Switched Array and definition of switching wave forms.

Time-modulated arrays we first proposed as a means of producing low side lobe antenna patterns by using simple on-off switching of the array element. The technique allows conventional array amplitude weighting patterns to be synthesized in a time-average sense by switching the array element on for a period that corresponds to the relative amplitude weight of the array element.

An inherent problem normally associated with time-modulated arrays is that they generate unwanted harmonics, or sidebands, at multiples of the switching frequency and most research into time-modulated arrays has concentrated on minimizing or controlling these harmonics [4]-[9]. More recently work has been carried out to investigate the use of phase centre motion to control side lobe levels [10] and the application of time-modulated arrays in Doppler radar.

In this contribution we describe a prototype two element time-switched array system and present measured data to illustrate the performance of the array.

Direction of arrival

We have seen that there is a one-to-one relationship between the direction of a signal and the associated received steering vector. It should therefore be possible to invert the relationship and estimate the direction of a signal from the received signals. An antenna array therefore should be able to provide for direction of arrival estimation. We have also seen that there is a Fourier relationship between the beam pattern and the excitation at the array. This allows the direction of arrival (DOA) estimation problem to be treated as equivalent to spectral estimation.

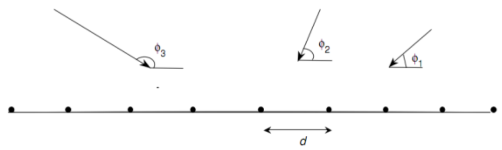

Fig 2: The DOA estimation problem

The problem set up is shown in Fig. 2. Several (M) signals impinge on a linear, equispaced, array with N elements, each with direction φi. The goal of DOA estimation is to use the data received at the array to estimate φi, i = 1, . . .M. It is generally assumed that M < N, though there exist approaches (such as maximum likelihood estimation) that do not place this constraint.

II. SYSTEM DESCRIPTION

The time-switched array system is shown schematically in Fig.1 and consists of two antenna elements separated by a distance d. Each element is assumed to exhibit an Omni directional radiation pattern in the plane of the diagram. The output from each element is connected to the array output via a switch in the feed line; the element switching period are also defined in Fg.1. A complete analysis of the system may be found in [2] but for the purpose of this contribution we will assume that the elements are alternately switched on and off with an equal mark-space ratio square wave switching function such that $t_1 = t_2 = \frac{T}{2}$

If we assume that the spacing between the elements is a half wavelength, the output from the array may be described [2] by

A (θ,t) = $\Psi \cos \omega t$,where

$$\Psi = \begin{cases} 1; & nT \le t < nT + \frac{T}{2} \\ e^{j\pi \sin\theta}; & nT + \frac{T}{2} \le t < (n+1)T \end{cases}$$

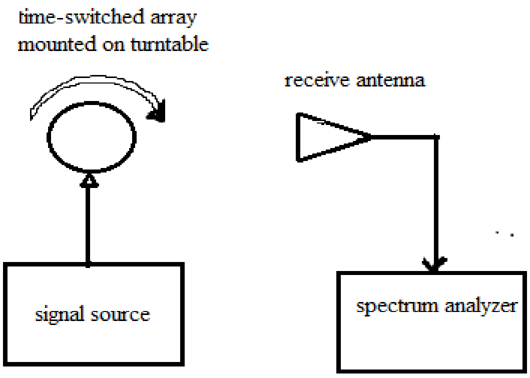

Fig 3: Details of the measurement set-up.

Hence the output of the array is phase modulated and the depth of modulation is dependent on the angle of arrival of the incident signal. For illumination broadside to the array, the array output is not modulated. However, as the illumination angle increases the depth of modulation increases until at end fire illumination (θ = 90deg and the array output exhibits 270 deg phase shift modulation. A plot of the array receive pattern at the illumination frequency, ω , is given in Fig.2 and shows a directional response with a peak on broadside and a null response at $\pm 90^0$. The directional pattern occurs because as the depth of phase modulation increases energy is redistributed from the carrier into sidebands, and at end fire there is zero energy at the carrier frequency. If we now examine the output of the time-switched array at the first harmonic.

Multiple Signal Classification Algorithms:

Of all techniques shown in Fig. 2, MUSIC is probably the most popular technique. MUSIC, as are many adaptive techniques, is dependent on the correlation matrix of the data. Using the data model ,

$$\mathbf{x} = \mathbf{S}\boldsymbol{\alpha} + \mathbf{n}.$$

$$\mathbf{S} = [\mathbf{s}(\phi_1)\ \mathbf{s}(\phi_2)\ \ldots,\ \mathbf{s}(\phi_M)],$$

$$\boldsymbol{\alpha} = [\alpha_1,\ \alpha_2\ \ldots\ \alpha_M]^T.$$

The matrix S is a N ×M matrix of the M steering vectors. Assuming that the different signals to be uncorrelated, the correlation matrix of x can be written as

$$\begin{aligned} \mathbf{R} &= \mathrm{E}\left[\mathbf{x}\mathbf{x}^H\right], \\ &= \mathrm{E}\left[\mathbf{S}\alpha\alpha^H\mathbf{S}^H\right] + \mathrm{E}\left[\mathbf{n}\mathbf{n}^H\right], \\ &= \mathbf{S}\mathbf{A}\mathbf{S}^H + \sigma^2\mathbf{I}, \\ &= \mathbf{R}_s + \sigma^2\mathbf{I}, \end{aligned}$$

Where

$$\mathbf{R}_s = \mathbf{S}\mathbf{A}\mathbf{S}^H \tag{45}$$

$$\mathbf{A} = \begin{bmatrix} \mathrm{E}\left[|\alpha_1|^2\right] & 0 & \cdots & 0 \\ 0 & \mathrm{E}\left[|\alpha_2|^2\right] & \cdots & 0 \\ 0 & 0 & \cdots & \mathrm{E}\left[|\alpha_M|^2\right] \end{bmatrix}. \tag{46}$$

The signal covariance matrix, Rs, is clearly a N × N matrix with rank M. It therefore has N−M eigenvectors corresponding to the zero eigenvalue. Let qm be such an eigenvector. Therefore,

$$\mathbf{R}_s\mathbf{q}_m = \mathbf{S}\mathbf{A}\mathbf{S}^H\mathbf{q}_m = 0, \tag{47}$$

$$\Rightarrow \mathbf{q}_m^H\mathbf{S}\mathbf{A}\mathbf{S}^H\mathbf{q}_m = 0, \tag{48}$$

$$\Rightarrow \mathbf{S}^H\mathbf{q}_m = 0 \tag{49}$$

where this final equation is valid since the matrix A is clearly positive definite. Equation (49) implies that all N −M eigenvectors (qm) of Rs corresponding to the zero eigenvalue are orthogonal. to all M signal steering vectors. This is the basis for MUSIC. Call Qn the N ×(N −M) matrix of these eigenvectors.

Note that since the eigenvectors making up Qn are orthogonal to the signal steering vectors, the denominator becomes zero when φ is a signal direction.

Algorithm steps

Step1: Estimate the correlation matrix R using Eqn. (54). Find its eigendecomposition R = QΛQH.
Step 2: Partition Q to obtain Qn, corresponding to the (N − M) smallest eigenvalues of Q, which spans the noise subspace.
Step 3: Plot, as a function of φ, the MUSIC function PMUSIC (φ) in Eqn. (53).
Step 4: The M signal directions are the M largest peaks of PMUSIC (φ).

The time-switched array was designed and constructed to operate at 2400MHz using quarter-wave monopoles as the two array elements. The monopoles were constructed from 1.5 mm copper wire mounted on a 200 mm diameter ground plane using chassis mounting 3.5mm connectors. Because the array was only required to operate with equal mark-space ratio square-wave switching, a SPDT switch was constructed based on a design provided by Philips Semiconductors using BAP51-02 surface mount PIN diodes. The switch was using constructed using micro strip on standard FR4 circuit board. The switch was mounted on the underside of the array ground plane and connections were made to the monopoles using connected to the monopoles using short length of co-axial cable. However as the outputs of the SPDT switch were not phase matched, a co-axial line stretcher was inserted into one of the monopole connections to allow phase compensation. For ease of measurement the array was tested when operating in transmit mode. The measurements were made in an anechoic antenna test chamber using an HP 8350B as the RF source and an Agilent E4407B spectrum analyzer as a receiver.

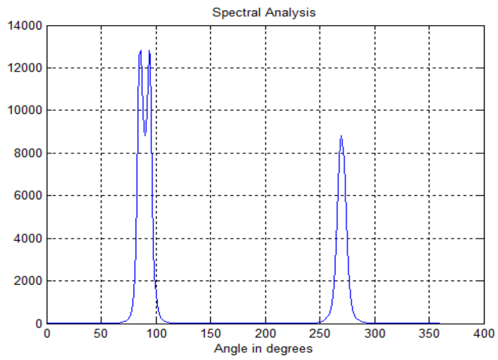

Fig 4: Spectral Analysis using MUSIC Algorithm

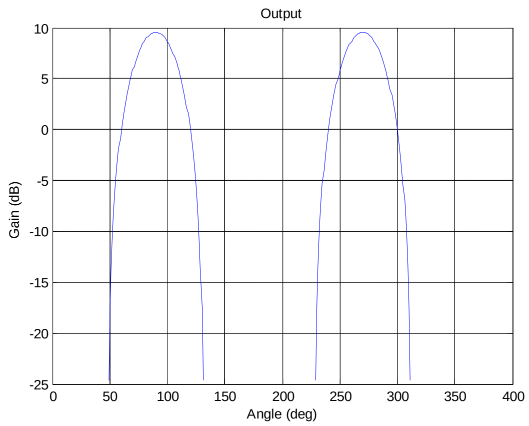

Fig 5: Measured Angle of Arrival: 90,270

Antenna Arrays

An antenna Array is a configuration of individual radiating elements that are arranged in space and can be used to produce a directional radiation pattern Single-element antennas have radiation patterns that are broad and hence have a low directivity that is not suitable for long distance communications.

A high directivity can be still be achieved by increasing the electrical dimensions (in terms of wavelength) and hence the physical size of the antenna.

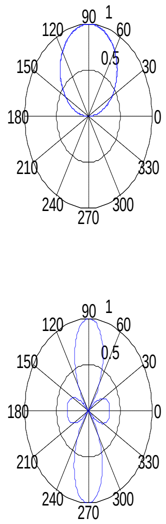

Fig 6: Array Factor and Array Element

The SPDT switch was modulated with a square wave derived from a standard laboratory signal generator at a frequency of 20 kHz. Fig. 3 shows the received spectrum measured broadside to the array prior to phase compensation.

The spectrum contains a components at the fundamental frequency (2400 MHz) and also harmonic components at 20 kHz intervals due to the fact that the outputs from the RF are not phase matched. It is also evident that although the array was modulated with an equal mark-space ratio switching waveform, even harmonics are present in the spectrum. However the even harmonics are at a low level (more that 25 dB below the unmodulated fundamental) and may be attributed to a combination of many factors including a non-ideal switching waveform and small differences in the amplitudes of the signals radiating from the two monopoles. With the array still orientated at broadside the line stretcher was adjusted until the harmonics of the received spectrum were minimized. With the array calibrated, measurements of the received power levels were recorded at the fundamental and the first harmonic frequency over an angular range of +/-90 deg and 270 deg. To obtained from a simple model based on array factor.

III. CONCLUSION

While in the presence of a two element time-switched array system have been proposed. The signals to each element of the array are time switched to provide a phase modulated output signal in which the depth of modulation is dependent on the angle of arrival of the received signal. The angular response to the array at the fundamental frequency of the received signal exhibits a directional response at broadside, while the response at the first harmonic of the switching frequency exhibits a deep null.

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