Minimising the Sideband Patterns of Time-Modulated Arrays

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1. Introduction

In 1959 H E Shanks and R W Bickmore published a paper entitled 'Four-dimensional electromagnetic radiators' [1] in which they considered time as an extra variable to control the radiation pattern from array antennas. This paper and subsequent publications [2,3] demonstrated how 'time-modulated' (or 'time-switched') arrays could be used to provide a simple and low-cost system for electronic beam steering in antenna arrays. In addition these early papers also demonstrated how time-modulated arrays could be used to synthesize low sidelobe radiation patterns using simple binary switching of the array elements [2,3]. The concept of a time-modulated array may be explained with reference to Figure 1, which shows a conventional linear array topology to which switches have been added in the feed network connecting the outputs of the array elements to the summer. If all the element switches are closed the array behaves as a normal linear array with uniform element amplitude weighting. To synthesize an effective time-average weighting function across the face of the array, the elements of the array may be switched on for a period corresponding to a conventional element amplitude weight. For example, if a particular array element has a relative amplitude weight of a_i, then in the time-modulated array implementation the element would be switched on for a period corresponding to $a_i T_0$, where T_0 is the overall switching period. Hence, the technique can be used to synthesize any conventional array weighting function. Furthermore, as the switches can be controlled electronically the modulating sequence can be easily reprogrammed to provide arbitrary weighting functions in real time and hence provides an adaptive array system. A fundamental problem associated with time-modulated arrays is that they generate harmonics, or sidebands, at multiples of the switching frequency. So, for example if the array operates at a CW frequency of ω_0 and the array elements are time switched by a sequence with a period T_0 then harmonics will be generated at frequencies given by ω_0+/- n T_0, where n represents the number of the harmonic. These harmonics are generally unwanted as they waste energy and may cause interference in other parts of the radio spectrum. Consequently, much of the recent work on time-modulated arrays has investigated methods for minimising sideband levels using various adaptive optimisation techniques to modify the switching period of individual elements [4-6]. Almost all the schemes reported in the literature use a similar approach in which each element of the array is time-switched using a common switch-on time. However if the element switch-on time is arbitrary then this introduces an extra degree of freedom in the design process. This type of approach was recently investigated by Yang et al [7] in which the elements of a 16 element array could be assigned multiple 'ON-OFF' states during a switching period. The concept of a variable element switch on time combined with sub-array switching strategies was has also been investigated by the author [8]. In this paper we extend the approach presented in [8], by investigating a method for minimising the sidebands generated by time-switched arrays by controlling the time-domain output from the array.

2. Numerical simulations

To explore the effect of various switching strategies on the properties of time-modulated arrays we have employed an approach similar to that presented in [8]. The simulations are based on a 16 element linear array of half-wavelength spaced, isotropic elements weighted with a Chebyshev amplitude taper designed to produce -30dB sidelobe levels at the fundamental frequency, ω_0 . Figure 2 shows the element switching sequence for a conventional modulation scheme in which all the elements have a common switch on time. The corresponding array factor is presented in Figure 3 and shows the desired -30dB sidelobes at the fundamental frequency. Inspection of the array factor patterns at the harmonic frequencies however shows that they have significant levels in the main beam direction. In communications applications it is desirable to minimise the level of the harmonic components in the direction of the main beam and we now consider switching strategies which address this issue. All previously published work on minimising sideband levels in time switched arrays has considered direct minimisation of the array factors generated at the sideband frequencies, often by employing an adaptive optimisation technique [4-6]. However as the harmonics are generated as a consequence of time domain variations in the array output, one can also reduce sideband levels by minimising variations in the time domain. Consider first the conventional element switching scheme in Figure 2; the corresponding time domain out from the array (in the boresight direction) is shown graphically in Figure 3. The time domain output is plotted over two cycles of the switching sequence and shows that the magnitude of the signal peaks at a normalised level of 16, which corresponds to every element of the array being simultaneous energised. As the switching cycle continues the time domain output signal progressively reduces by increments of 2 normalised units until at the end of the cycle only the central two elements of the array are energised. The resulting staircase form of the output signal produces strong harmonic content as observed in the array factor patterns presented in Figure 2. Clearly if the variations in the time domain output of the array can be minimised then the magnitude of the array sidebands will also be reduced. Consider now a switching scheme based on the conventional scheme but in which half the array is switched with a common switch-on time and the other half with a common switch-off time as shown in Figure 4. The time domain output signal at boresight to the array is presented in Figure 5 and shows that the maximum variation in output level has been reduced from 14 units to 1 units when compared with the conventional switching scheme. The corresponding array factor produced by this switching strategy is shown in Figure 6 where it is observed that the magnitude of the sidebands in the boresight direction has been significantly reduced.

Conclusions

Conventional time-modulated arrays employ switching schemes in which each element of the array has a common start time and an switch-off time which varies according to a prescribed amplitude taper. In this paper we have examined switching strategies in which the element 'switch-on' time can be arbitrary. In particular we have shown that by minimising variations in the time domain output from the array, relatively simple switching schemes can be used to generate a prescribed angular nulls at harmonic frequencies.

References

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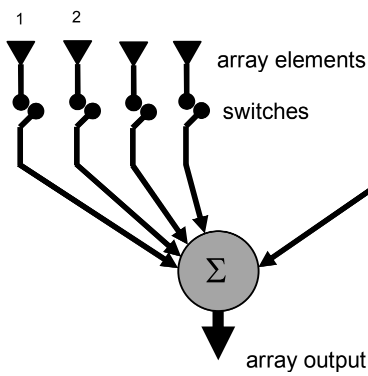

Figure 1. The concept of a time-switched array in receive mode

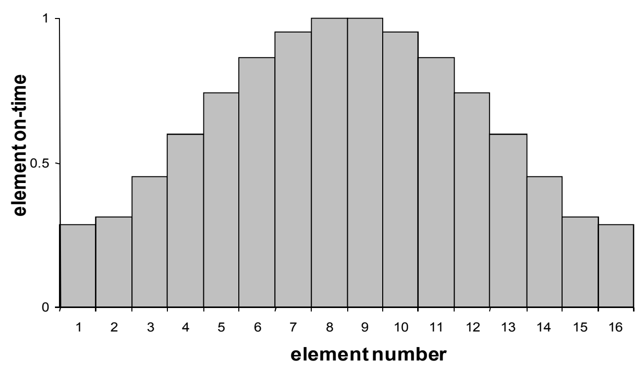

Figure 2. Conventional element switching for -30dB sidelobe Chebyshev weights

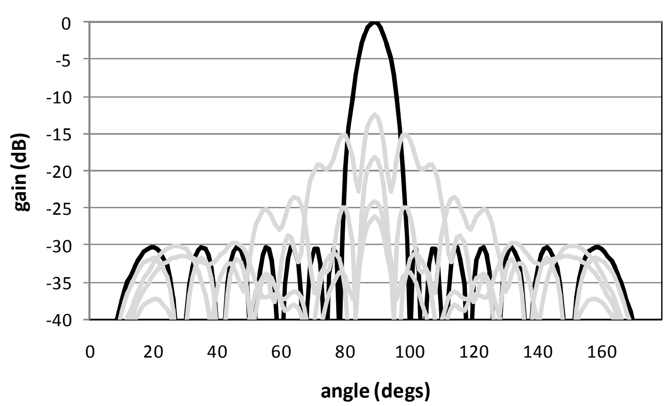

Figure 3. Array factor at the fundamental (black line) and first 5 harmonics (grey lines)

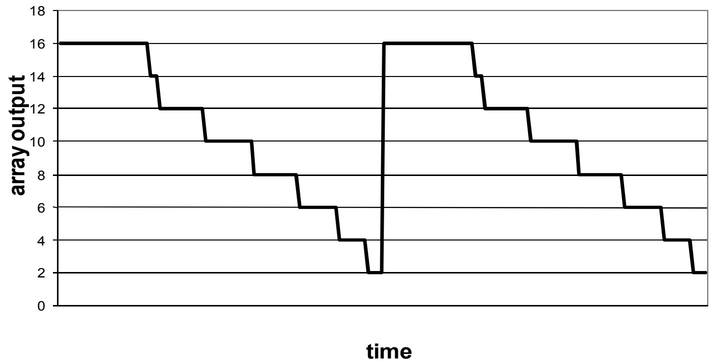

Figure 4. Array output signal at boresight over two cycles of the switching waveform (conventional switching).

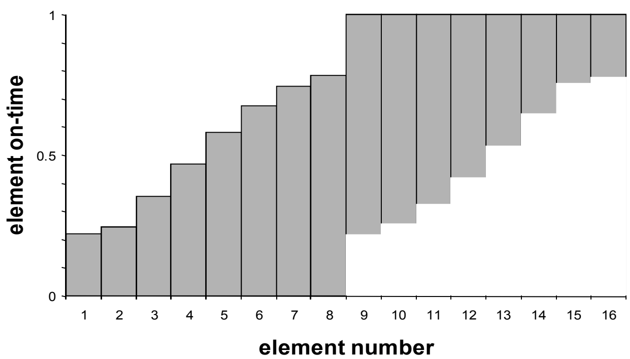

Figure 5. Offset element switching for -30dB sidelobe Chebyshev weights

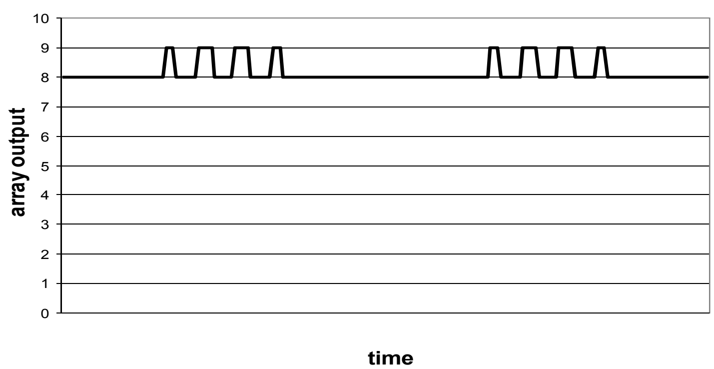

Figure 6. Array output signal at boresight over two cycles of the switching waveform

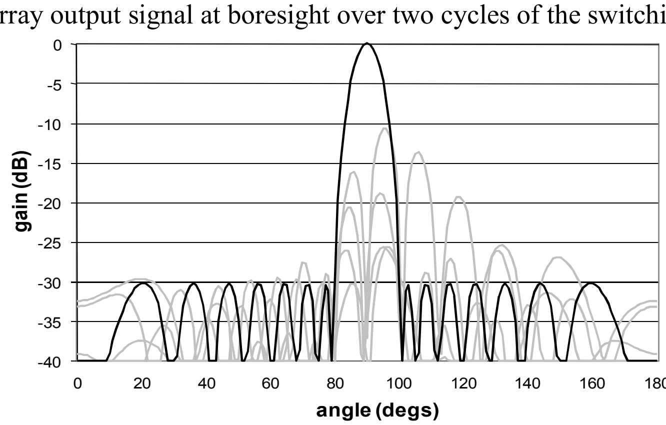

Figure 7. Array factor at the fundamental (black line) and first 5 harmonics (grey lines)