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Techniques to Improve the Wide Angle Scanning Performance of Multiple Beam Smart Antennas

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ABSTRACT

This work describes the development of techniques to overcome problems associated with the design and operation of smart antenna systems for mobile systems. In particular the use of closely spaced elements leads to mutual coupling effects which can seriously degrade the beam patterns and can produce very poor impedance matching due to high active reflection coefficients. This work describes how a combination of two techniques, excitation weight compensation and Wide Angle Impedance Matching, can be employed to improve antenna performance. It demonstrates that the simple combination of these two techniques does not provide a satisfactory solution. It describes how the combination of techniques can be refined to produce a final design which demonstrates good beam patterns and impedance match. The validity of this approach has been demonstrated by conducting experimental results on a demonstrator array. Simulation results using the refined approach have been shown to provide good agreement with experimental results.

Keywords : Mobile antennas, antenna arrays, beam shaping, mutual coupling

1 Introduction

The use of Smart Antennas offers a method of increasing capacity for mobile systems[1], [2]. This can be achieved by offering a selection of beam patterns which can be changed on a dynamic basis Smart antennas employ sets of radiating elements arranged in the form of an array with the signals from these elements combined to form the required beams [3]. When these antenna elements are arranged in a closely spaced array radiation from one elements can couple to adjacent elements. [3]. Accurate determination of this mutual coupling between the array elements is an important factor which needs to be considered when designing smart antenna systems. Mutual coupling (MC) can alter the scan angle which in turn results in gain and pattern degradation [3]-[4]. In [5] and [6] the authors show that mutual coupling distorts the array pattern beam formed. In [7] it is shown that MC affects the antenna gain. A number of different techniques can be used to mitigate or compensate mutual coupling effects in smart antenna arrays. These include the use of dummy columns and the use of decoupling networks. [8] These technique can give some improvement in the array characteristics, but it will increase the complexity of the network. It has been reported in [9] the best way to compensate in a shaped beam antenna is by modifying the excitation input from the beam forming network. The modified excitation weights can result in unacceptably high active reflection coefficients being generated for the outer elements. For wide angle scanning one method of reducing this effect is to use a high dielectric thin sheet in front of the array elements called wide angle impedance matching (WAIM) [10], [11]. It can be shown that whilst this can reduce the reflection coefficient it can also result in degradation of the original beam patterns. This work examines how the use of each technique in isolation affects both the antenna beam shapes and the input impedance match through the active reflection coefficient. The limitations of each technique will be described together with a proposed solution to produce a final design with desired beam shapes and good impedance match. The remainder of the paper is organized as follows: Section II presents a brief description of the smart antenna under investigation and discusses excitation weight compensation and WAIM sheet matching. Section III describes full EM simulation results for the array using CST EM simulation software achieved with compensated excitation weights and the introduction of an impedance matching sheet. It is then shown that a simple combination of both techniques does not produce acceptable results and further refinement of the excitation coefficients to account for the revised mutual coupling in the presence of the dielectric sheet provides good performance for both beam patterns and reflection coefficients. Section IV gives details of a small demonstrator array which has been developed to provide experimental verification of radiation patterns and active reflection coefficients. Results are included to show good agreement with ideal radiation patterns whilst maintaining good impedance matching. Section V provides concluding remarks.

2 ANTENNA DESIGN

Detailed The major components of the antenna system under investigation include an array of dual-band dual-polarised stacked microstrip patch antenna elements of 4 columns wide and 10 elements high, a Beam Forming Network (BFN) and a beam shaping network (BSN) . **The azimuthal beam shapes produced by the antenna array are dependent upon the complex weights applied to each of the array element columns. The proposed smart antenna has three shaped beams in addition to the four narrow overlapping beams. They are**

the right-hand shaped beam (RS Beam), left-hand shaped beam (LS Beam) and a broadcast channel shaped (BC Beam) beam for the broadcast channel to avoid the use of a separate integrated sector antenna for the broadcast channel

2.1 *Beam Forming Network and Beam Shaping Network*

A Butler Matrix Beam Forming Network was chosen for this design in preference to a Maxon-Blass, higher loss, or Nolen, insufficient output beams, networks. The Butler Matrix, augmented by a variable beam shaping network, as detailed below, is able to produce seven different beam shapes from only four array elements. The beam shaping network is was constructed using a variable four-way power divider utilizing a two-way variable power divider driving two two-way variable power dividers. Each two-way variable power divider is realised by connecting two 90^0 hybrids and a variable phase shifter. The seven required beams can be obtained by a simple variation of the phase shifters, $\Delta\phi_1$, $\Delta\phi_2$, $\Delta\phi_3$. Three two-way power dividers are connected together with two 45^0 phase shift networks to form the beam shaping network. Depending upon the communications traffic demand, a control algorithm based on the output of the beam shaping network can adjust the relative power divider ratio to blend all the beams, do beam switching or beam broadening to provide the required complex weights for the seven output beams. .

3 Analysis of Mutual Coupling Effects

As The performance of this antenna for ideal multiple input beams at the uplink centre frequency, (uplink f_c = 1.9747GHz), of UK Orange network band has been determined as shown in Figure 2. Results shown are for individual beams and shaped beams for the left side only. The performance of the proposed smart antenna [1] in the presence of mutual coupling was also simulated, these results shows that the mutual coupling has significant effect upon the beam direction as shown in Figure 1. Additionally examination of the active reflection coefficients for the antenna elements indicates a high degree of impedance mismatch with return loss higher than -3dB. This will result in an unacceptable reduction in antenna gain and hence compensation is desired.

It has been established that the effects of mutual coupling on the antenna excitation weights $[a_i']$ can be compensated by modifying the original excitation weights, $[a_i]$, according to

$$[a_i'] = [[u] + [s]]^{-1} [a_i] \quad [16] \qquad (1)$$

Where $[a_i']$ are the compensated excitation weights, *u* is the unit matrix, *s* are the S-parameters (mutual coupling coefficients) and $[a_i]$ is the excitation that would have been required if there was no mutual coupling. The s-matrix can be determined from CST [24] by inputting known $[a_i]$ in the array antenna and then determining $[a_i']$. The complex weights are provided by the array feed network. The total feed network is realised by cascading a 4x4 Butler matrix beam forming network and a beam shaping network as shown in Fig.1. The former produces multiple narrow beams each corresponding to a signal at one of the four beam ports and latter provides a combination of excitations (i.e. ''beam blending'') to each of the beam ports. This results in the required complex weights at the array elements to achieve the desired shaped beams

The use of compensated excitation weights results in improved beam patterns for both shaped beams and the broadcast beam but an examination of the antenna active element reflection coefficients, given by the upper set of results in Table 1, indicates a high degree of impedance mismatch with corresponding loss of gain. This problem can be addressed by the use of the Wide Angle Impedance Matching, WAIM, sheet technique. The Wide Angle Impedance Matching technique as reported in [10] is realized with a thin high-k dielectric sheet located λ./8 above the radiating elements. Magill and Wheeler describe how the reflection due to the antenna aperture in an array can be cancelled over wide angles by the introduction of an additional susceptance provided by the dielectric sheet located at an appropriate distance from the antenna aperture. This is possible because the sheet susceptance varies differently in the E and H planes [10, 11]. The reflection of the antenna element at the aperture plane can be determined by measurement or in our case by simulation. This can be translated to provide the reflection coefficients in the E and H planes at the position of the thin dielectric sheet. These can be cancelled by the addition of the reflection provided by the dielectric sheet. For the geometry used in this work the optimum distance has been determined as 0.125λ. Full EM simulations have been carried out, using CST [12], for the case of a WAIM sheet with εr = 10, thickness, t = 1.5mm, located at a height, h = 18.12mm, above the antenna.

4 COMBINED TECHNIQUE

If **It has been shown that mutual coupling effects can be compensated for by using modified complex excitation weights to excite the array elements. The resultant beam patterns are close to the ideal case, however this results in unacceptable impedance mismatch at the antenna input ports. By incorporating a WAIM sheet it has been possible to improve the impedance matching but at the expense of degrading the antenna beam patterns. The simple combination of the WAIM sheet with the modified excitation weights results in an improvement in the impedance matching but at the expense of a degradation of beam patterns. Further work has been carried out to investigate methods for achieving good radiation patterns and low active reflection coefficient performance. It has been found that the introduction of the WAIM sheet has significantly altered the mutual coupling between antenna elements. By conducting simulation results for the antenna array in the presence of the sheet a further set of modified excitation weights can be obtained. These in turn will result in a change in the reflection from the dielectric sheet. In general an iterative approach will be required to determine the final excitation coefficients and position of the WAIM sheet. In practice it has been found that a single iteration provides satisfactory results. Using the final excitation coefficients obtained as detailed below CST simulation results for antenna beam patterns of this antenna are given in Fig.2. This approach produces significantly improved pattern for the broadcast beam together with improved shaped beams, closely matching the patterns for the ideal**

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case. Table 1 indicates that this arrangement also results in active reflection coefficient values for all beam excitations of less than 10 dB.

5 EXPERIMENTAL VERIFICATION

A representative 4 element horizontal array has been developed to verify the results of Section IV. This consists of a beam forming network and a beam shaping network manufactured on 1.575mm RT/duriod substrate material, with relative permittivity of 2.33 and a loss tangent of 0.0012. This array has been designed to operate halfway between the uplink and downlink frequency of orange UK 3G band. Fig.1a shows the antenna system demonstrator arranged in the anechoic chamber prior to far field testing with Fig.1b showing a detailed view of the PCB microstrip beam shaping network. Control of the three phase shifters within the beam shaping network dynamically provides the required complex weights for the desired beam shapes. This can be done using passive sliding microstrip sections with a thin dielectric insulator to avoid nonlinear metal-to-metal contact. The use of active (nonlinear) phase shifting devices is precluded due to the very onerous passive intermodulation specification which must be met, -153 dBc with 2 x 20 watt carriers, for mobile operators.

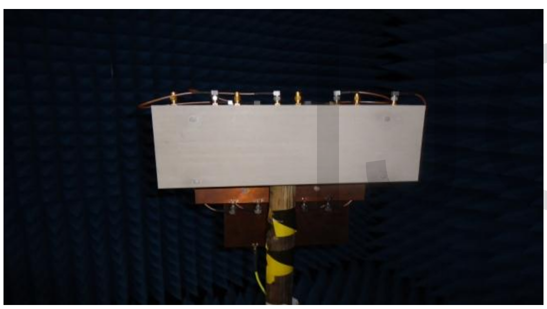


Fig.1a: Multiple switched beams smart with beam shaping and WAIM sheet covering top of the array antenna capability in ane-

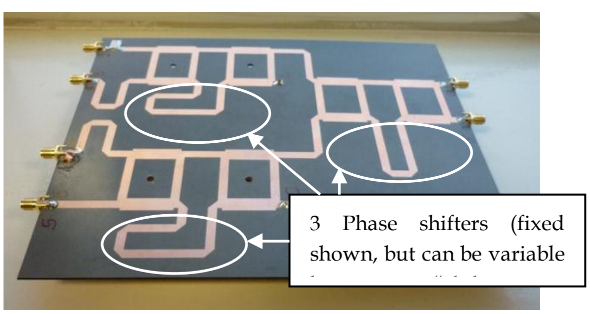
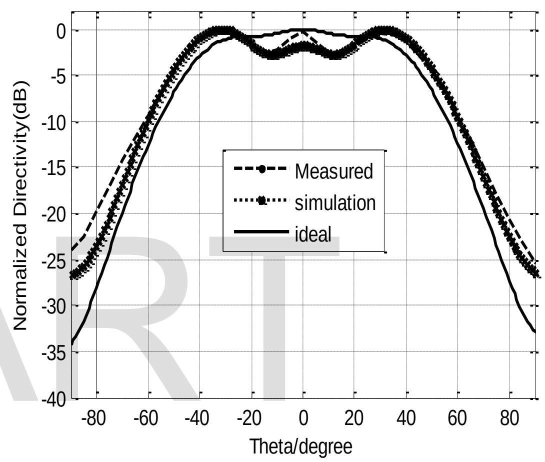


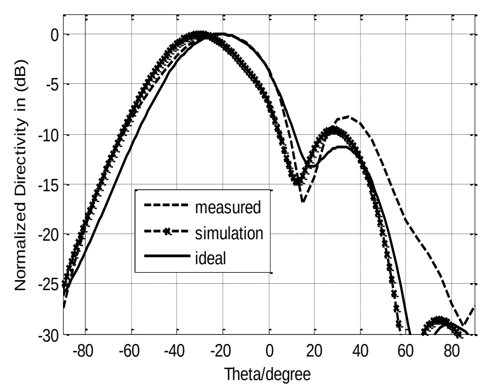
Fig.1b: PCB microstrip beam shaping network @uplink frequency band

5.1 Measured Radiation Pattern

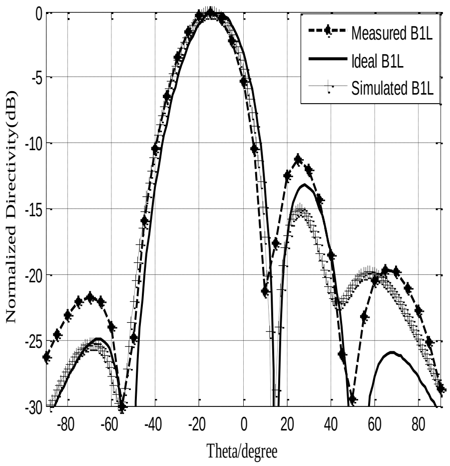
Far field radiation patterns for the demonstrator antenna have been determined using an in house anechoic chamber, 3m x 3m x 5m, together with a standard gain horn antenna, Agilent E8247C 250kHz-20GHz signal source and Agilent E4419B EPM series power meter. A full range of far field patterns have been recorded. Representative patterns for the broadcast beam, BC, left shaped beam, LS and left narrow beams, B1L, B2L, are shown in Fig.2. Similar results have been obtained for beams covering the right hand side of the cell. Examination of Fig. 2c and 2d indicates that the use of multiple switched beams results in significant nulls appearing within the sector coverage area, results shown in Fig. 2b for the shaped beam show improved coverage over the left part of the sector, with a maximum directed at 37^0 , with coverage maintained over the remainder of the cell. All experimental results show good agreement with simulation.



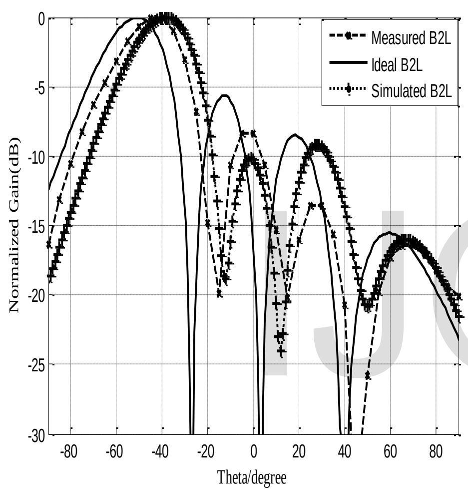
(a)



(b)



(c)



(d)

Fig.2: (a) Measured and simulated and ideal Broadcast channel beam @uplink f_c (b) Measured, simulated and ideal Left hand shaped beam @uplink f_c (c) Measured, simulated and

5.2 Active Reflection Coefficient

The active reflection coefficient was determined by inserting a directional coupler into each input line in turn with phase matched cables inserted into the remaining three lines. The input port of the feeder network was connected to port *A* of a network analyzer and the coupled port of the coupler was connected to port *B* of the network analyzer while the other port of the coupler was matched to 50ohm load. Table 5 presents the measured active reflection coefficient with and without WAIM sheet. The results presented in Table 5 show the smart antenna demonstrator with active reflection coefficient better than -10dB.

TABLE 5
MEASURED ACTIVE REFLECTION COEFFICIENTS WITHOUT WAIM (WITH WAIM)

	Γ_{A1}dB	Γ_{A2}dB	Γ_{A3}dB	Γ_{A4}dB
B1L	-13.02 (-10.6)	-9.45 (-10.4)	-5.30 (-10.3)	-15.73 (-19.1)
B1R	-15.73 (-19.2)	-5.30 (-10.3)	-9.45 (-10.4)	-13.02 (-10.6)
B2L	-9.70 (-10.5)	-18.50 (-15.0)	-10.4 (-13.4)	-14.80 (-10.2)
B2R	-14.80 (-10.2)	-10.39 (-13.4)	-18.5 (-15.0)	-9.70 (-10.5)
BCBeam	-17.10 (-19.0)	-12.03 (-10.0)	-9.53 (-11.2)	-13.10 (-10.1)
LSBeam .	-14.21 (-12.7)	-12.80 (-11.4)	-11.0 (-10.0)	-2.46 (-10.1)
RSBeam	-2.46 (-10.1)	-11.00 (-10.0)	-12.8 (-11.4)	-14.21 (-12.69)

6 CONCLUSION

. An investigation has been carried out into methods of providing a variety of dynamically variable beams from a smart antenna in a manner which ensures low active reflection coefficient. This method has been shown to be able to offer a range of beams, including multiple high gain beams, shaped beams and a sector wide broadcast beam. It has been shown that the effects of mutual coupling lead to changes in beam patterns and an increase in active reflection coefficients between elements. Whilst the use of excitation weight compensation can restore the required beam patterns unacceptably high reflection coefficients remain, particularly for wide scan angles. Wide Angle Impedance Matching techniques have been examined to improve these values. It has been found that the simple combination of both techniques is not able to provide the desired beam patterns together with low reflection coefficients. By adopting an iterative approach it has been shown that good beam patterns and low reflection coefficients can be obtained. These techniques have been validated by the construction of a small demonstrator array whose results agree well with predicted simulation results

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