Techniques to compensate mutual coupling effects in a Multiple Switched Beam Smart Antenna with Beam Shaping Capability

Freeborn Bobor-Oyibo, Stephen J. Foti, David Smith

Abstract— A smart antenna for mobile applications incorporating an array of ± 45^0 polarised stacked patch elements 4 columns wide excited by a multi-beamforming and beam shaping network is described. Four narrow overlapping beams, one wide "broadcast channel" beam and right and left shaped beams can be provided. The later shaped beams are to provide high capacity coverage in a specific narrow angular sector while low capacity coverage is maintained over the remainder of a 120^0 sector. Results are presented for the simulation of this smart antenna using CST EM simulation software. In addition, a demonstrator array has been constructed and tested which has yielded a positive conformation of the simulation results. It will be shown that the effects of mutual coupling degrade the beam shapes, particularly for the broadcast beam producing a significant reduction in gain over the centre of the pattern. Results are included to show the effects of applying modified complex excitation weights for compensation of mutual coupling. Whilst this technique can be shown to restore beam patterns it is also shown to introduce unacceptably high return loss at the antenna input ports. An alternative technique for producing Wide Angle Impedance Matching (WAIM) is described which is shown to improve return loss but degrade beam shapes. This work describes how both techniques can be combined to maintain good beam shapes and preserve good impedance matching, with consequent good return loss, over wide scan angles and also for shaped beams.

Index Terms— Mobile antennas, antenna arrays, beam shaping, mutual coupling..

1 Introduction

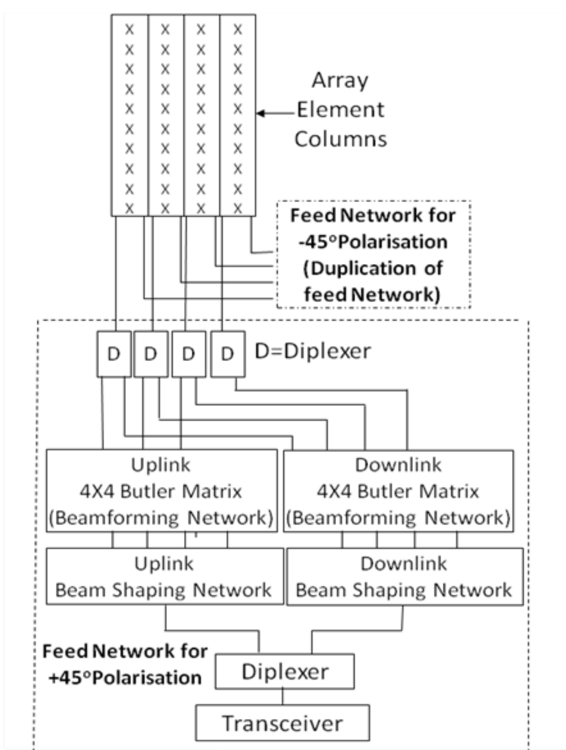
The Smart Antenna is one of the promising technologies that is currently accepted in mobile telecommunication systems to provide interference reduction and is also being proposed to dynamically optimize mobile telecommunication networks to enhance user capacity [1], [2]. It employs a set of radiating elements arranged in the form of an array. The signals from these elements are combined to form multiple fixed beams, a switchable beam pattern or one single beam that follows the desired user [3]. The total radiation pattern of an array antenna with identical elements and without mutual coupling is normally taken as the product of the antenna element pattern and the array factor [4]. The latter is the radiation pattern of an array of isotropic radiators. However when these antenna elements are arranged in an array, it is possible that some radiation from each of the elements could couple to one another [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 to fully realise the benefits of the smart antenna. Mutual coupling (MC) can alter the scan angle which in turn results in gain and pattern degradation [3]-[6].While the effects of MC on smart antennas is well known to smart antennas researchers, the majority of effort in current studies of MC on smart antennas has been directed towards adaptive smart antennas, direction of arrival estimation and beam forming algorithms [7]-[13]. It is clear that MC effects are more significant in adaptive smart antennas than in other types of smart antennas because of its ability to automatically place null to unknown interference and direct its signal to desired users. In [7] the authors show that mutual coupling distorts the adaptive matrices and the array pattern beam formed. The effects of mutual coupling on adaptive smart antennas were also investigated in [10]. Using an array of half wavelength dipole antennas it concluded that mutual coupling between array elements of an adaptive smart antenna distorts the radiation pattern of the antenna. References [9], [11]-[13] used an array of half wavelength dipoles to investigate the performance of adaptive smart antenna in the presence of mutual coupling. In [12] it is shown that MC affects the antenna gain and does not affect the adaptive processing of the antenna. The effects of MC on a multiple switched beam smart antenna excited with a beam shaping network [1] has not been investigated to the best of our knowledge.

A number of different techniques can be used to mitigate or compensate mutual coupling effects in smart antenna arrays. One technique is to place dummy columns between the array elements to prevent coupling between elements. This is at the expense of increased size and a major factor in not accepting smart antennas for base stations. Also, this would increase the spacing between elements causing grating lobes. A second technique is the use of decoupling networks [15] placed between the feed network and array elements. The technique shows that it can give some improvement in the array characteristics, but it would greatly increase the complexity of the network. Furthermore, unless the decoupling networks are adjustable, then mutual coupling can only be cancelled for a specific scan angle condition. It has been reported in [16] the best way to compensate in a shaped beam antenna is by modifying the excitation input from the beam forming network.

ISSN 2229-5518

This is discussed below in the scattering matrix compensation technique. However, for wide angle scanning, one of the easiest methods is to use a high dielectric thin sheet in front of the array elements called wide angle impedance matching (WAIM) sheet [17], [18]. The following sections investigate the use of these techniques. It will examine how the use of each technique in isolation affects both the antenna beam shapes and the input impedance match. The limitations of each technique will be described together with a proposed solution which produces a final design with desired beam shapes and has good impedance match. This paper investigates such an arrangement and considers the mutual coupling effects on a multiple switched beam smart antenna with an array of dual-polarised slant ± 45^0 stacked microstrip patch antenna elements 4 columns wide and excited by a Butler matrix and beam shaping network. This smart antenna can provide four narrow overlapping beams; one wide broadcast channel beam and right and left shaped beams [1]. This paper presents full EM simulation results for the simulation of a 4 column smart antenna array using CST EM simulation software. The remainder of the paper is organized as follows: Section II presents a brief description of the smart antenna under investigation; Section III discusses the antenna array with mutual coupling and compensating techniques. Section IV describes results achieved with compensated excitation weights and the introduction of an impedance matching sheet. The effects of combining both techniques and the overall improvement performance achieved by using the combined techniques are also discussed in this section. Section V describes experimental verification of the combined techniques effects on the smart antenna system performance.

2. MULTIPLE SWITCHED BEAM SMART ANTENNA WITH BEAM SHAPING NETWORK



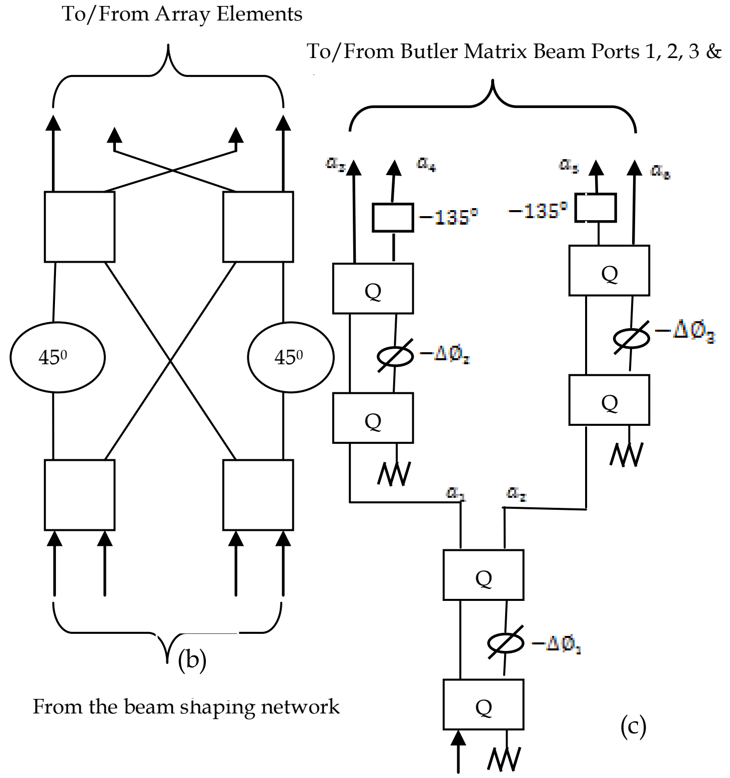


Fig.1 Multiple switched beam smart antenna with beam shaping capability

An outline of the antenna system under investigation is shown in Fig.1. The major components of this system include:

(1) An array of dual-band dual-polarized stacked microstrip patch antenna elements of 4 columns wide and 10 elements high.
(2) A beam forming network.
(3) A beam shaping network.

The azimuthal beam shapes produced by the antenna array are dependent upon the complex weights applied to each of the array element columns. The design of this antenna, aims to offer good coverage throughout a cell sector and to be able to dynamically reconfigure the beams to provide enhanced coverage in certain areas at reduced, but acceptable coverage throughout the rest of the cell sector. 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. Simulation results for this antenna design have been produced assuming ideal components (without mutual coupling consideration) within the array feed network. The results have been compared with those of a conventional design to show the performance improvement over uplink and downlink 3G sub-bands of Orange UK [1]. Hence as both sub-bands are very narrow frequency change is not an issue. The next subsection will explain the beam forming network and the beam shaping network. Then section III considers the effects of mutual coupling and investigates techniques for maintaining good beam shapes together with good impedance matching.

2.1 *Beam Forming Network*

Array antennas for multi-beam transmit/reception requires a beam-forming network (BFN) to separate signals according to the signal arrival or transmit directions. Several types of BFN exist like digital beam-forming (DBF), Maxon-Blass matrix multiple beam-forming, Nolen matrix beam forming network [19-20], Rotman lens multiple beam-forming [21] and Butler matrix multiple beam-forming network [22]. A multi-Beam forming network consists of interconnected components that introduce multiple phase shift distributions and weighting on the signals received by antenna array in parallel, thereby producing simultaneous beams. Therefore, it is used to provide the array element weights to form multiple overlapping fixed beams for 120 degree sector coverage.

The Butler matrix has been chosen for this design because it is simple to realize compared to other beam-forming networks. Butler matrix multiple beam forming network is anticipated to be the best overall performance for the specific application of a small number of smart antenna switched beams in 3G WCDMA mobile Networks. Another reason is its reliability in microstrip PCB (low cost), design simulation and optimisation can be done on in-house Microwave Office software or Genesis software and the PCB can be produced for experimental testing and verification of performance. It is a beam forming network that uses a combination of 90° hybrids and fixed transmission line phase shifters to form N simultaneous independent beams from an N element antenna array, where 'N' is a power of 2 (see fig.1c) [23]. It performs a spatial discrete Fourier transform and provides overlapping orthogonal beams. When used with a linear array the Butler matrix produces beams that overlap at 3.9 dB below the beam maximum. A Butler matrix-fed array can provide beams that can be used by a dedicated transmitter and/or receiver, or a single transmitter and/or receiver can be used and the appropriate beam can be selected using an RF switch. Any signal input into one of the Butler matrix input ports will be divided equally among the output ports with a progressive linear phase delay. However, in the subject application, shaped beams are required. These could be produced using the Blass matrix or Nolen matrix, for example; but the former is too lossy and the latter has the limitation that the number of beams must be less than or equal to the number of array elements. Hence, it was decided to employ the Butler matrix which produces focused beams augmented by a variable beam shaping network which essentially excites the appropriate combination of focused beams with specific complex weights to produce seven different beam shapes from only four array elements.

.

2.2 *Beam Shaping Network*

The beam shaping network is essentially a variable 4-way power divider/combiner that utilizes a 2-way variable power divider/combiner which drives two 2-way variable power dividers/combiners as shown in Fig.1c. Each 2-way variable power divider/combiner is realised by connecting two 90^0 hybrids and a variable phase shifter. When two 3dB hybrids are arranged the output signals a_1 and a_2 are given by the equation

$$a_1 = \frac{1}{2} + \frac{1}{2} e^{-j\left(180^0 + \Delta\emptyset_1\right)}$$
$$a_2 = \frac{1}{2} e^{-j\left(90^0\right)} + \frac{1}{2} e^{-j\left(90^0 + \Delta\emptyset_1\right)}$$

Also outputs of, a_3, a_4, a_5 and a_6 are given by the equations

$$a_3 = a_1\left[\frac{1}{2} + \frac{1}{2} e^{-j\left(180^0 + \Delta\emptyset_2\right)}\right]$$
$$a_4 = a_1\left[\frac{1}{2} e^{-j\left(90^0\right)} + \frac{1}{2} e^{-j\left(225^0 + \Delta\emptyset_2\right)}\right]$$
$$a_5 = a_2\left[\frac{1}{2} + \frac{1}{2} e^{-j\left(315^0 + \Delta\emptyset_3\right)}\right]$$
$$a_6 = a_2\left[\frac{1}{2} e^{-j\left(90^0\right)} + \frac{1}{2} e^{-j\left(90^0 + \Delta\emptyset_3\right)}\right]$$

For equal amplitude and phase outputs from the 2-way power divider/combiner,

$|a_1| = |a_2| \quad \Delta\emptyset = 270^0$

For routing the entire signal to port 1, i.e. zero at port 2, $\Delta\phi_1$

$\Delta\emptyset = 180^0$

Three two-way power dividers/combiners are connected to form the beam shaping network of figure 1c. Depending upon the communications traffic demand, a control algorithm based on the output of the beam shaping network can adjust the relative power divider/combiner ratio to blend all the beams, or do beam switching or beam broadening for optimum service i.e. control of the three phase shifters within the beam shaping network dynamically provides the required complex weights for the desired beam shapes. A good beam shapes together with good impedance matching.

3 ANALYSIS OF MUTUAL COUPLING EFFECTS

For a multiple switched beam smart antenna system fed by a feeder network as shown in Fig.2 below, the element output complex voltage $[v_i]$ is defined by [14]:

$[v_i] = [a_i]+[b_i]$ (1)

Where $[a_i]$ is the complex incident voltage wave at array element i (These are the outputs of the array feed network.) and $[b_i]$ is the complex reflected voltage wave at array element i

For the case of an ideal antenna with no mutual coupling

$[v_i] = [a_i]$ when $[b_i] = 0$ (2)

However for a practical antenna where mutual coupling is present $[b_i] = [S_{ij}][a_i]$, where $[S_{ij}]$ are the S-parameters. S_{ij}, $i \neq j$ are the mutual coupling coefficients which will depend upon the specific radiating elements used and the array geometry. tables and figures will be processed as images. You need to embed the images in the paper itself. Please don't send the images as separate files.

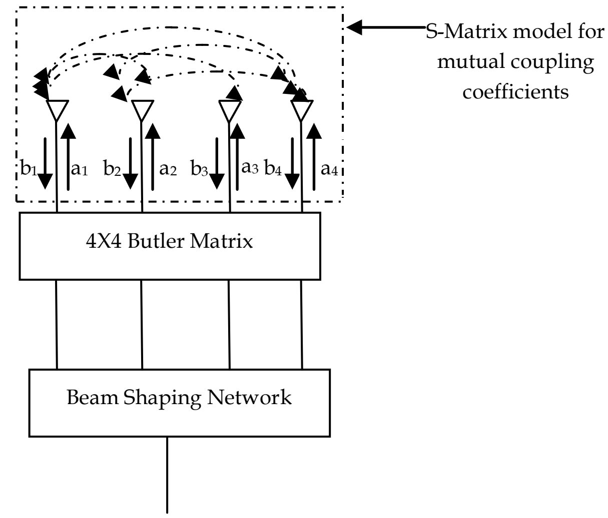
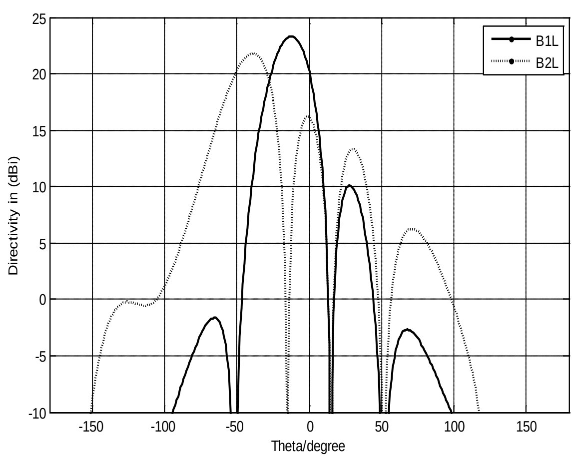
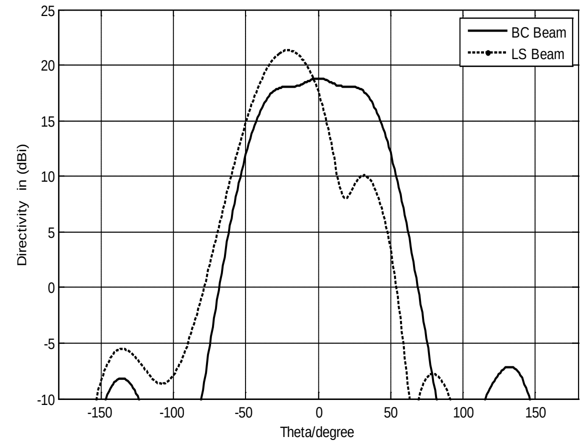


Fig. 2 S-matrix model of mutual coupling with feed network

Fig.3 below shows the radiation pattern of the ideal (i.e. no mutual coupling) multiple switched beam smart antenna at the uplink centre frequency, (uplink f_c = 1.9747GHz), of UK Orange network band. Results shown are for individual beams and shaped beams for the left side only. From symmetry, similar results have been achieved for beams to the right hand side. The performance of the proposed smart antenna [1] in the presence of mutual coupling was also simulated over the uplink frequency band as shown in Fig.4 below. An examination of these results shows that the mutual coupling has little effect upon the shape or side lobe levels of the four individual beams but leads to a substantial dip, ~10dB, in the shaped beam patterns and a poorly shaped central section of the broadcast beam. Additionally examination of the active reflection coefficients for the antenna elements, as given in Table 1, indicates a high degree of impedance mismatch with return loss higher than -4dB. This will result in an unacceptable reduction in antenna gain and hence, compensation is desired.

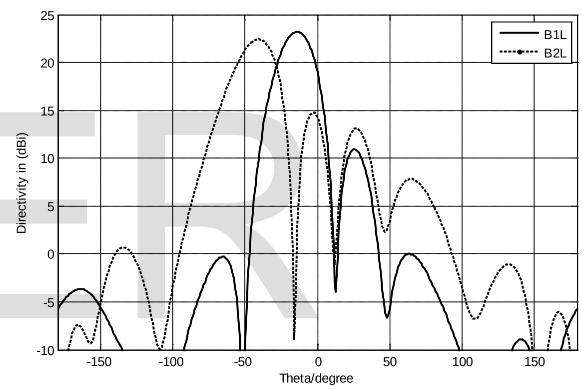


(a)

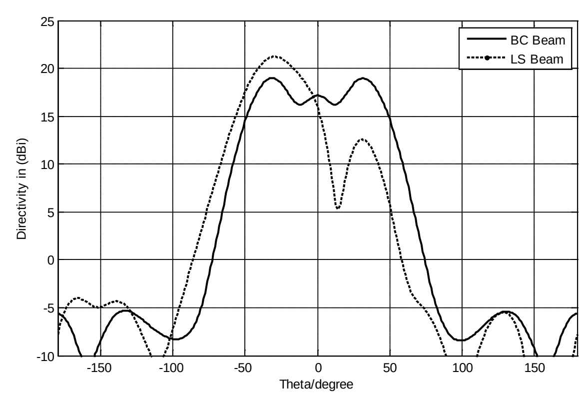


(b)

Fig. 3(a) Ideal azimuth plots of multiple beam patterns and (b) Ideal azimuth plots of shaped beam patterns



(a)



(b)

Fig. 4 (a) Azimuth plots of multiple beam patterns with mutual coupling included and (b) Azimuth plots of shaped beam patterns with mutual coupling included

ISSN 2229-5518

Table 1 Element Reflection Coefficients with MC

	Γ_{A1} dB	Γ_{A2} dB	Γ_{A3} dB	Γ_{A4} dB
B1L	-14.25	-9.90	-11.99	-16.76
B1R	-16.99	-12.01	-9.95	-14.20
B2L	-7.61	-5.96	-7.96	-11.37
B2R	-11.15	-7.914	-6.04	-7.84
BC-Beam	-8.644	-18.77	-18.66	-8.85
LS-Beam	-7.73	-29.04	-11.14	-3.836
RS-Beam	-3.58	-11.04	-29.35	-7.95

.

3.1 Compensation of Complex Weights based upon the Scattering Matrix

The complex weights compensation technique as defined in [16], is:

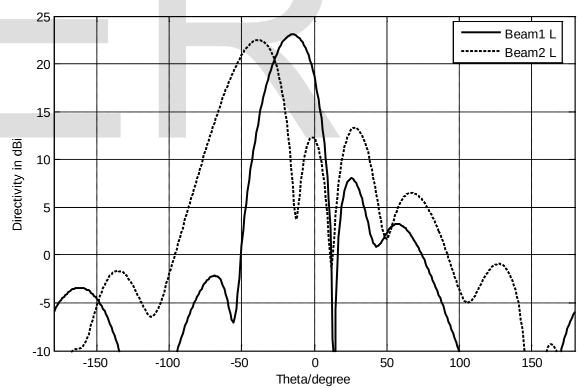
$$[V_i] = [U_{ij}+S_{ij}]^{-1}[a_i] \quad (3)$$

Where 'V_i' are the compensated excitation weights, 'U_{ij}' is the unit matrix, 'S_{ij}' are the S-parameters (mutual coupling coefficients) which depends upon the specific radiating elements used and the array geometry and 'a_i' is the excitation that would have been required if there was no mutual coupling. Applying the technique directly does not compensate for pattern distortion caused by the scattering between array elements, however, modification of the excitation weights gives a closer pattern to the ideal one. 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 figure 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. The 4x4 Butler Matrix produces equal amplitudes and linear phase progressions to the array elements and the beam shaping network provides simultaneous excitation of the beam ports with relative amplitudes and phases. The relative amplitudes are dynamically changed by adjusting the three phase shifters within the beam shaping network. This results in the required complex weights at the array elements to achieve the desired shaped beams. The ideal and compensated excitation weights for the broadcast beam and the shaped beams are shown in Table 2

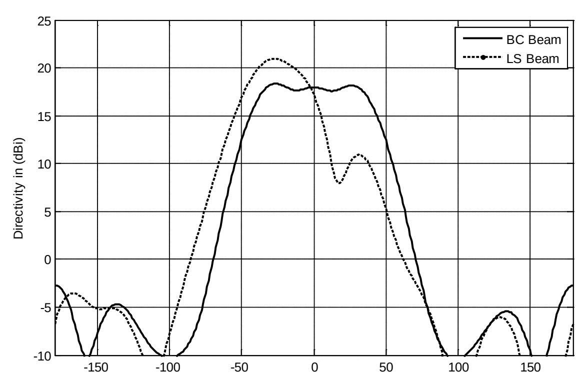
TABLE 2
IDEAL AND COMPENSATED EXCITATION WEIGHTS FOR SHAPED BEAMS

Beams	Ideal Excitation Weights		Modified Excitation Weights	
	Mag.(dB)	Phase(dg)	Mag.(dB)	Phase(dg)
BC Beam	-9.099	-131	-9.0	-132
	-4.292	-5.635	-3.0	-20
	-4.292	-5.635	-3.0	-20
	-9.010	-131	-9.0	-132
Left Shaped Beam	-6.347	-162	-5.0	-160
	-3.161	-62	0.0	-62
	-5.757	-1.349	-4.0	-8
	-18.32	-163.4	-18.0	-160
Right Shaped Beam	-18.43	-98.53	-18.0	-78
	-5.83	60.44	-4.0	52
	-3.158	0.025	0.0	0.78
	-6.264	-100.1	-5.0	-88

Fig.5 below shows the simulation for shaped beam patterns using modified complex excitation weights. The use of compensated excitation weights has resulted in improved beam patterns for both shaped beams and the broadcast beam but an examination of the antenna active element reflection coefficients, as shown in Table 3, indicate a high degree of impedance mismatch with corresponding loss of gain.



(a) Azimuth plots of multiple beam patterns



(b) Azimuth plots of shaped beam patterns

Fig. 5 Azimuth patterns using compensated complex weights based upon the scattering matrix

TABLE 3 ACTIVE REFLECTION COEFFICIENTS AFTER

ISSN 2229-5518

EXCITATION COMPENSATION

Beam Excitation	Γ_{A1} dB	Γ_{A2} dB	Γ_{A3} dB	Γ_{A4} dB
B1L	-12.58	-10.96	-13.02	-14.97
B1R	-15.14	-13.89	-11.65	-12.05
B2L	-6.544	-7.37	-9.63	-10.47
B2R	-10.28	-9.61	-7.46	-6.75
BC-Beam	-7.69	-17.06	-16.99	-7.87
LS-Beam	-5.36	-35.15	-9.52	-3.70
RS-Beam	-3.36	-9.47	-40.82	-5.68

3.2 WAIM Sheet Technique

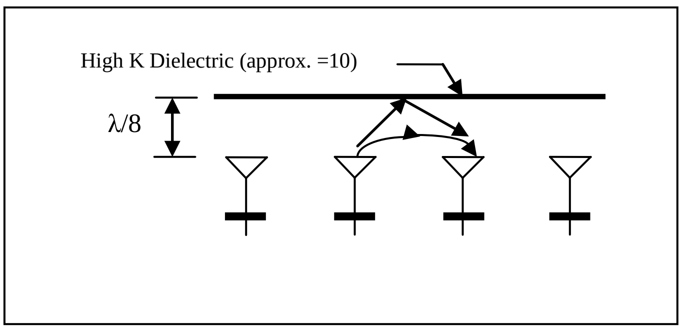


Fig.6 Wide angle impedance matching (WAIM) structure Geometry

The Wide Angle Impedance Matching technique as reported in [18] is realized with a thin high-k dielectric sheet as shown in Fig.6 above where 'λ' is the mean wavelength between up and downlink wavelengths. The thin sheet is as large as the array, placed in front, parallel to the array face. The sheet wave-reflection properties depend on polarization and scan angle. From Fig.2 the active reflection coefficient Γ_{active} is given by:

$\Gamma_{i\text{-active}} = b_i/a_i$ where $i = 1, 2......4$ (3)

$\Gamma_{1\text{-active}} = b_1/a_1 = S_{11} + S_{21}\, a_2/\, a_1 + S_{31}\, a_3/\, a_1 + S_{41}\, a_4/\, a_1$ (4)

The WAIM sheet, attempts to cancel the second, third and fourth term in equation (4) thereby reducing the effects of mutual coupling. Full EM simulations have been carried out, using CST, for the case of a WAIM sheet with εr = 10, thickness, t = 1.5mm, located at a height, h = 18.12mm, above the antenna.

Results shown in Table 4 and Figure 7 indicate, as expected, an improvement in the impedance matching but at the expense of a degradation of beam patterns, in particular this has resulted in a pronounced reduction dip in the central section of the control beam and the return of a pronounced local minimum for the shaped beams.

TABLE 4 ACTIVE REFLECTION COEFFICIENTS WITH WAIM SHEET

Beam Excitation	Γ_{A1} dB	Γ_{A2} dB	Γ_{A3} dB	Γ_{A4} dB
B1L	-12.25	-7.66	-9.00	-10.95
B1R	-11.12	-8.94	-7.72	-11.976
B2L	-13.79	-15.58	-14.46	-10.72
B2R	-10.62	-14.33	-15.82	-14.13
BC-Beam	-15.9	-10.977	-10.95	-15.33
LS-Beam	-11.26	-15.43	-8.69	-11.466
RS-Beam	-10.78	-8.65	-15.39	-11.23

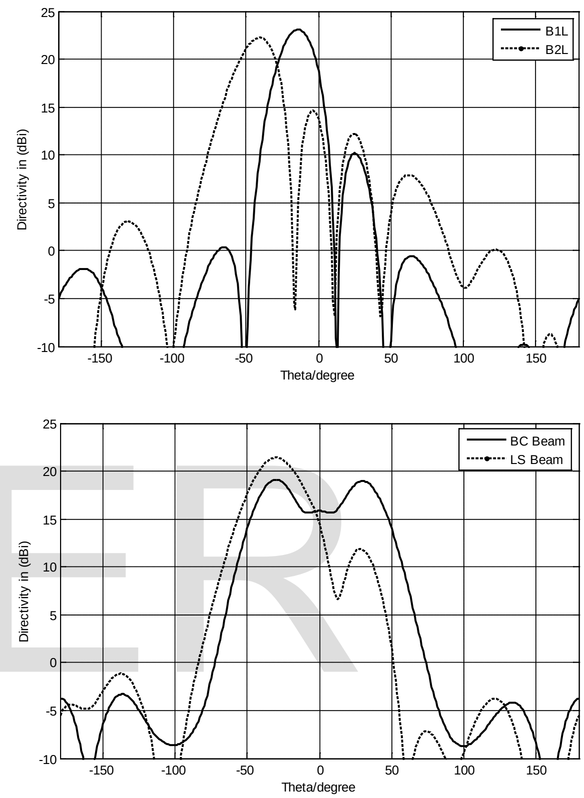


Fig. 7(a) Azimuth Plots of Multiple Beam Patterns compensated with WAIM and (b) Azimuth Plots of Shaped Beam Patterns compensated with WAIM

4 COMBINED TECHNIQUE

We have shown that mutual coupling effects in multiple switched beam smart antennas with beam shaping capability 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 Wide Angle Impedance Matching Technique (WAIM sheet) we have been able to improve the impedance matching but at the expense of degrading the antenna beam patterns. An investigation has been carried out into the effects of combining both techniques to provide good antenna patterns and good impedance matching. This has been achieved by adding the compensated excitation weights for the antenna together with a WAIM sheet. CST simulation results for antenna beam patterns of this antenna are given in Figure 8. This approach produces a significantly improved pattern for

ISSN 2229-5518

the broadcast beam together with improved shaped beams, closely matching the patterns for the ideal case. Table 5 indicates that this arrangement also results in active reflection coefficient values for all beam excitations of less than 10 dB.

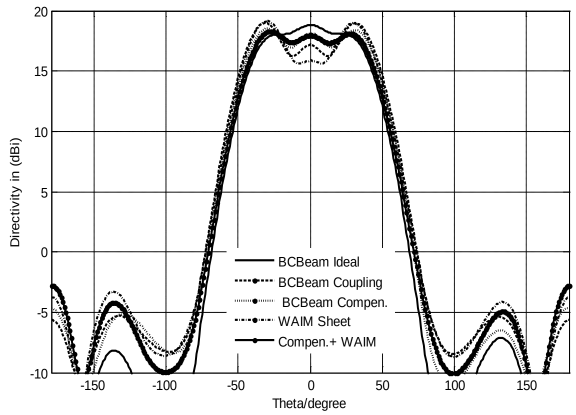


Fig.8a Azimuth Plot of Broadcast Beam Patterns compensated weight. +WAIM sheet

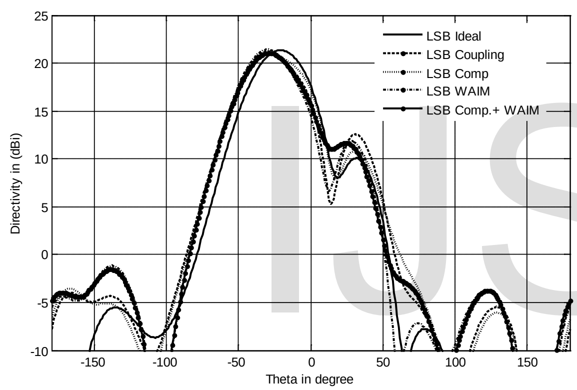


Fig.8b LS beam pattern using different compensation techniques

TABLE 5 ACTIVE REFLECTION COEFFICIENTS AFTER COMPENSATION AND WAIM SHEET

Beam Excitation	Γ_{A1} dB	Γ_{A2} dB	Γ_{A3} dB	Γ_{A4} dB
B1L	-12.25	-10.02	-11.22	-11.23
B1R	-11.23	-11.22	-10.02	-12.25
B2L	-11.67	-11.11	-11.35	-10.47
B2R	-10.48	-11.35	-11.11	-11.67
BC-Beam	-13.37	-12.34	-12.32	-13.30
LS-Beam	-13.819	-17.43	-10.43	-10.27
RS-Beam	-10.27	-10.43	-17.43	-13.819

5 EXPERIMENTAL VERIFICATION

The smart antenna system which comprises of four columns of dual-polarized slant $\pm 45^0$ stacked microstrip patch elements, a beam forming network and a beam shaping network is manufactured on 1.575mm RT/duriod substrate material, which has permittivity of 2.33 and a loss tangent of 0.0012 to operate (uplink frequency of 1.9697GHz to 1.9797GHz and downlink frequency of 2.1597GHz to 2.1697GHz) halfway between the uplink and downlink frequency of orange UK 3G band. Fig9a shows the antenna system demonstrator in anechoic chamber under test.and Fig9b is the PCB microstrip you are using beam shaping network. Depending upon the required beam, control of the three phase shifters within the beam shaping network dynamically provides the required complex weights for the desired beam shapes.

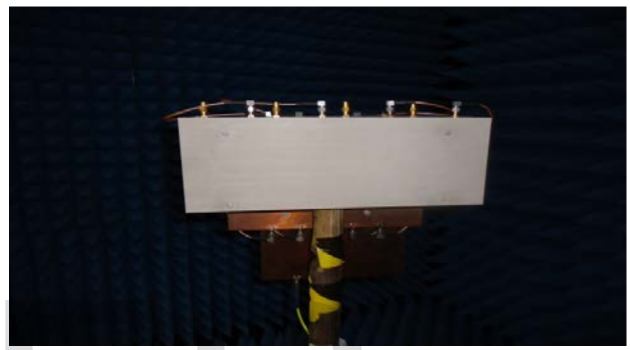


Fig.9a: Multiple switched beams smart with beam shaping and WAIM sheet covering top of the array antenna capability in anechoic chamber under test

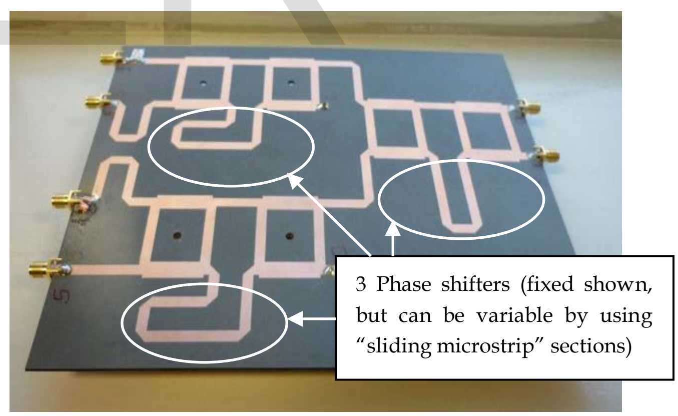


Fig.9b: PCB microstrip beam shaping network @uplink frequency band

5.1 Insertion Loss of the Network with matched load

Insertion loss is the net unrecoverable power loss in dB dissipated within the beam forming network and the beam shaping network within the specified frequency range. The input to output *couplings are S1 (dB), S2 (dB), S3 (dB) and S4 (dB). If* $a_i = 10^{S_i(\mathrm{dB})/20}$ where $i = 1, 2, 3$, and 4.
The total insertion loss in dB = $10Log_{10} \sum (a_i)^2$. The insertion loss calculated for this feeding network of this antenna system is 0.424dB.

5.2Measured radiation pattern and active reflection coefficient

The basic properties used to describe the performance of an antenna include: active reflection coefficients and 3dB radiation pattern. Fig10 and Table 6 show the measured radiation patterns and active reflection coefficient of the smart antenna system using the combine mutual coupling compensation techniques.

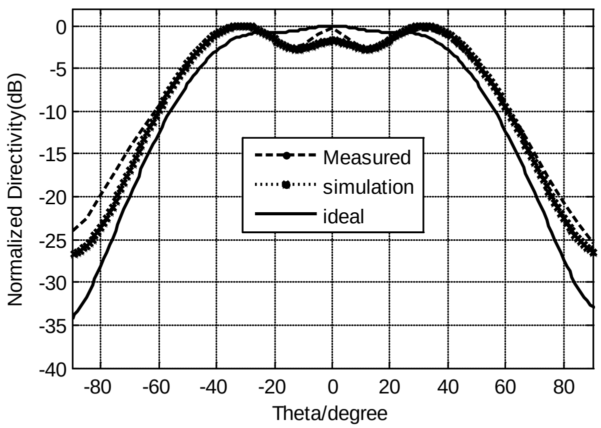


Fig.10a: Measured and simulated and ideal Broadcast channel beam @uplink f_c

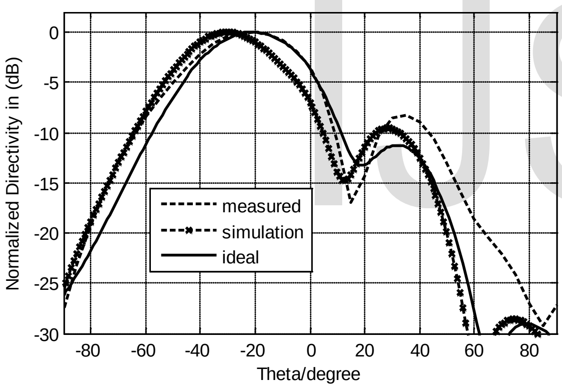


Fig.10b: Measured, simulated and ideal Left hand shaped beam @uplink f_c

TABLE 6 MEASUREDACTIVE REFLECTION COEFFICIENTS WITHOUT WAIM

Number	**Measured reflection coefficient without WAIM sheet**			
Beam Number	Γ_{A1}dB	Γ_{A2}dB	Γ_{A3}dB	Γ_{A4}dB
B1R	-15.73	-5.30	-9.45	-13.02
B2R	-14.80	-10.39	-18.50	-9.70
BC-Beam	-17.10	-12.03	-9.53	-13.10
LS-Beam	-14.21	-12.80	-11.00	-2.46

TABLE 7 MEASURED ACTIVE REFLECTION COEFFICIENTS WITH WAIM

Number	**Measured reflection coefficient with WAIM sheet**			
Beam Number	Γ_{A1}dB	Γ_{A2}dB	Γ_{A3}dB	Γ_{A4}dB
B1R	-19.19	-10.33	-10.43	-10.64
B2R	-10.20	-13.4	-15.07	-10.50
BC-Beam	-19.03	-10.03	-11.22	-10.16
LS-Beam	-12.69	-11.40	-10.05	-10.11

6 CONCLUSIONS

An investigation has been carried out into a 4 column smart antenna array suitable for mobile base station use. Full electromagnetic simulation has shown that the performance of a practical antenna departs significantly from the ideal case due to mutual coupling. The use of compensated excitation coefficients has been shown to restore acceptable beam patterns but introduces significant impedance mismatch at the input ports of the antenna elements. The inclusion of a high dielectric constant WAIM sheet has been shown to improve the impedance match but degrades the beam patterns. By suitable combining of both techniques it has been shown that it is possible to achieve good beam patterns and good impedance matching resulting in improved antenna efficiency. Note that all simulation results presented were for the uplink band. Very similar results have also been obtained for the downlink band. In addition, a demonstrator array has been constructed and tested which has yielded a positive conformation of the simulation results

References

[1] F. Bobor-Oyibo, S. J. Foti, and D. Smith, "A multiple switched beam Smart antenna with beam shaping for dynamic optimisation of capacity & coverage in mobile telecommunication networks," in *Antennas, Propagation and EM Theory, 2008. ISAPE 2008. 8th International Symposium on*, 2008, pp. 356-359.

[2] B. Allen and M. Beach, "On the analysis of switched-beam antennas for the W-CDMA downlink," *Vehicular Technology, IEEE Transactions on,* vol. 53, pp. 569-578, 2004.

[3] C. A. Balanis, Antenna Theory. *Analysis and Design Third Edition*: John Wiley and Sons, pp.945-962, 2005.

[4] M. J. L. Alves and M. Sampaio de Alencar, "Effects of mutual coupling in smart antenna arrays," in *Microwave and Optoelectronics Conference, 2007. IMOC 2007. SBMO/IEEE MTT-S International*, 2007, pp. 418-421.

[5] E. Z. Ahmed, *Smart antenna engineering*. London: Artech House, 2005.

[6] K. R. Dandekar, L. Hao, and X. Guanghan, "Experimental study of mutual coupling compensation in smart antenna applications," *Wireless Communications, IEEE Transactions on,* vol. 1, pp. 480-487, 2002.

[7] I. Gupta and A. Ksienski, "Effect of mutual coupling on the performance of adaptive arrays," *Antennas and Propagation, IEEE Transactions on,* vol. 31, pp. 785-791, 1983.

[8] H. Hon Tat, "Reducing the mutual coupling effect in adaptive nulling using re-defined mutual impedance," *Microwave and Wireless Components Letters, IEEE,* vol. 12, pp. 178-180, 2002.

[9] R. M. Korany, I. E. Mohamed, B. Rajeev, H. Z.-D. Saber, and M. M. I. Sabry, "Analysis of uniform circular arrays for adaptive beamforming applications using particle swarm optimization algorithm," *International Journal of RF and Microwave Computer-Aided Engineering,* vol. 18, pp. 42-52, 2008.

[10] A. A. Maha and W. Parveen, "Effect of mutual coupling in adaptive arrays," *Microwave and Optical Technology Letters,* vol. 35, pp. 270-274, 2002.

[11] L. Min and Y. Luxi, "Blind Calibration and DOA Estimation With Uniform Circular Arrays in the Presence of Mutual Coupling," *Antennas and Wireless Propagation Letters, IEEE,* vol. 5, pp. 315-318, 2006.

[12] Y. Qiaowei, C. Qiang, and K. Sawaya, "Performance of adaptive array antenna with arbitrary geometry in the presence of mutual coupling," *Antennas and Propagation, IEEE Transactions on,* vol. 54, pp. 1991-1996, 2006.

[13] H. Zhiyong and C. A. Balanis, "The MMSE Algorithm and Mutual Coupling for Adaptive Arrays," *Antennas and Propagation, IEEE Transactions on,* vol. 56, pp. 1292-1296, 2008.

[14] H. Zhiyong, C. A. Balanis, and C. R. Birtcher, "Mutual Coupling Compensation in UCAs: Simulations and Experiment," *Antennas and Propagation, IEEE Transactions on,* vol. 54, pp. 3082-3086, 2006.

[15] L. G. Sodin, "Frequency-Independent Approximate Compensation of Mutual Coupling in a Linear Array Antenna," *Antennas and Propagation, IEEE Transactions on,* vol. 57, pp. 2293-2296, 2009.

[16] A. G. Demeryd, "Compensation of mutual coupling effects in array antennas," in *Antennas and Propagation Society International Symposium, 1996. AP-S. Digest*, 1996, pp. 1122-1125 vol.2.

[17] E. Magill and H. Wheeler, "Wide-angle impedance matching of a planar array antenna by a dielectric sheet," *Antennas and Propagation, IEEE Transactions on,* vol. 14, pp. 49-53, 1966.

[18] A. J. Kelly, "Comment on Wide-Angle Impedance Matching of a Planar array Antenna by Dialectric Sheet," *IEEE Trans. Antenna Propag.,* vol. 14, pp. 636-637, 1966.

[19] Y.T. Lo and S.W. Lee Antenna handbook CH.17, Ch.19, ITP, 1993.

[20] N. J. G. Fonseca, "Printed S-Band 4X4 Nolen Matrix for Multiple Beam Antenna Applications," *Antennas and Propagation, IEEE Transactions on,* vol. 57, pp. 1673-1678, 2009.

[21] L. Jangsoo, P. Sangbok, L. Dongkyu, S. Saengseub, L. Sanghyo, S. Joonho, K. Youngwoo, S. Kwangseok, and C. Changyul, "Development of a V-band rotman lens using thin-film dielectric," in *Antennas and Propagation Society International Symposium, 2007 IEEE*, 2007, pp. 2670-2673.

[22] Tayeb. A. Denidni and Tarob Eric Libar, Wide Band Four-Port Butler Matrix for switched Multibeam Atenna Arrays, the 14th IEEE international Symposium on Personal, Indoor and Mobile Radio Communication Proceedings, PP.2461-2464, 2003.

[23] El Zooghby, Ahmed 'Smart antenna engineering'- Boston, Mass.; London: Artech House, 2005.