Base Station Antenna Mutual Coupling Reduction by Means of Element Orientation

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Abstract

Typical base station antenna is actually an array arrangement of a number of basic antenna elements. The array nature of the base station antenna cannot avoid any consequence of the mutual coupling phenomenon, a phenomenon inherent in any type of array. A possible approach to counter the detrimental effects of mutual coupling is to align all elements in a manner that mutual coupling would cause the least of any possible detrimental effects. This approach is herein termed as element orientation. For obtaining the orientation of each element that leads to minimisation of mutual coupling effects GA optimization is employed. Simulation and simulator results show that mutual coupling is reducible by properly orientating the elements. This element orientation technique is thus a promising approach for mutual coupling reduction.

Keywords: element orientation, mutual coupling, base station antenna, dual polarisation antenna.

1. Introduction

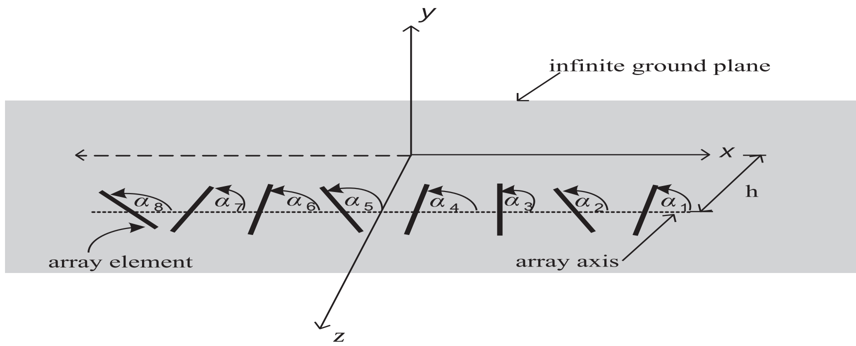
Mutual coupling is a phenomenon that affects an array type base station antenna's performance. In practice it is often found that the effects of mutual coupling are significant because mutual coupling causes undesirable antenna radiation characteristics, such as increased main beamwidth, null filling and increased sidelobe levels [1]. These effects inevitably boost capability of interference reception and hence lead to performance degradation of the base station antenna. Most literatures [2,3,4] use algorithmic or software approach for mitigating the mutual coupling effects. This article demonstrates a technique for reducing the effects of mutual coupling or decreasing capability of interference reception by using element orientation. This technique aligns different elements with different orientations, inter-element coupling is thus reduced as a result of polarisation mismatch between both adjacent and further away elements. This multi-element orientation appears disadvantageous in terms of cross polarisation performance under the circumstance of successfully purely single polarisation transmission. This ideality is never achievable in practice. However this multi-polarisation array is capable of receiving depolarised incoming signal of interest, an advantage impossible in an array of single-element-orientation, with lesser effects due to mutual coupling as compared with the dual polarisation array. The technique is based on field synthesis by adjusting the element orientation until obtaining the desired radiation pattern with low sidelobe levels, deep nulls, and narrow main beamwidth for example. The proper aligning of the element orientation is obtained by GA optimization. The Howells Applebaum algorithm and the Music algorithm are used for beamforming and estimating the direction of signal arrival. The investigation on the worthiness of the proposed technique is carried out by both computer simulation and experimentation with the base station antenna simulator.

Detail description of mutual coupling reduction by element orientation is in Section 2. The optimized radiation pattern from GA optimization and the simulation results are presented in Section 3. Results from experimentation with the simulator are presented in Section 4. Some concluding remarks are noted in Section 5.

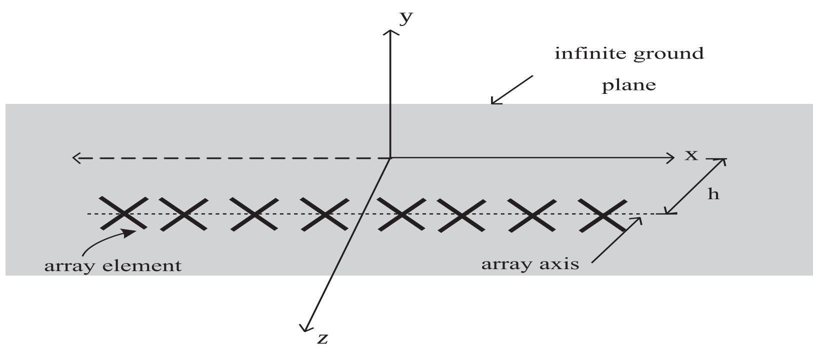
2. Mutual Coupling Reduction by Element Orientation

Typical base station antennas employ a uniform element orientation array antenna. This article suggests the use of elements with different orientations, or the so called multi-element-orientation as shown in Fig. 1 (a). This is due to its possibility in reducing mutual coupling effects by adjusting the element orientation until obtaining the low sidelobe levels, deep nulls, and narrow main beamwidth of the radiation pattern. Reduction of inter-element mutual coupling is obviously a result of inter-element polarisation mismatch.

Comparing this multi-element-orientation antenna with a typical dual polarisation antenna, Fig 1(b), it is found that (i) the number of antenna elements in the dual polarisation antenna is usually greater than that of the multi-element-orientation antenna, occasionally twice as many. (ii) Dual polarisation antenna cannot avoid any effects of mutual coupling, because in this type of antenna there are two sets of orthogonal orientation arrays. Thus same set mutual coupling is inevitable.



(a)



(b)

Fig. 1. Geometry of an array antenna using 8-element dipole on an infinite ground plane.

A. Mutual Coupling Modeling

The induced EMF method is adopted in computing mutual coupling. The computational geometry is as shown in Fig. 2. The inter-element mutual coupling is as follows [5]

$$z_{ij} = z_{ACij} + z_{IMij} \qquad (1)$$

where

z_{ij} = mutual impedance between element i th and j th

z_{ACij} = mutual impedance between element i th and j th of the actual current (element above an infinite ground plane)

z_{IMij} = mutual impedance between element i th and j th of the image current (element below an infinite ground plane)

Both z_{ACij} and z_{IMij} can be expressed as follow [6]

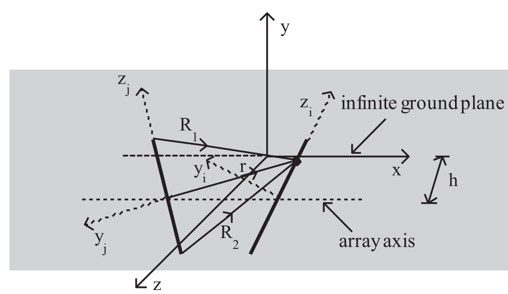


Fig. 2. Geometry for mutual coupling computation.

$$z_{ACij} = \frac{j\eta I_{im} I_{jm}}{4\pi I_{i1} I_{2i}} \int_{-l_i/2}^{l_i/2} \sin\left[k\left(\frac{l_i}{2} - |z_i|\right)\right] \left[\frac{e^{-jkR_1}}{R_1} + \frac{e^{-jkR_2}}{R_2} - 2\cos\left(k\frac{l_j}{2}\right)\frac{e^{-jkr}}{r}\right] dz_i \qquad (2)$$

$$z_{IMij} = -z_{ACij} \qquad (3)$$

The difference between (2) and (3) is that the current in (3) is phase reversed by 180 degrees with respect to the actual current.

The weighting schemes employed for array beam forming is the Howells- Applebaum algorithm; as follows [7]

$$w = \mu C_U^{-1} U_d \tag{4}$$

the covariance matrix C_U is

$$C_U = E\left(X \bullet X^T\right) = E\begin{pmatrix} x_1^* x_1(t) & . & . & x_1^* x_N(t) \\ . & & . & . \\ . & & . & . \\ x_N^* x_1(t) & . & . & x_N^* x_N(t) \end{pmatrix} \tag{5}$$

Where x_N is the N^{th} element signal vector, U_d is the desired signal vector, μ is constant, T denotes the transposition and $*$ denotes the conjugation.

The weighting scheme in (4) does not take into account mutual coupling effects. To incorporate mutual coupling, the signal vector is modified as follows [8].

$$X_m = Z^{-1} X \tag{6}$$

where Z is the normalized impedance matrix.

B. GA Optimisation

The GA optimisation is employed for the search of the global minimum of the objective function [9] in this article.

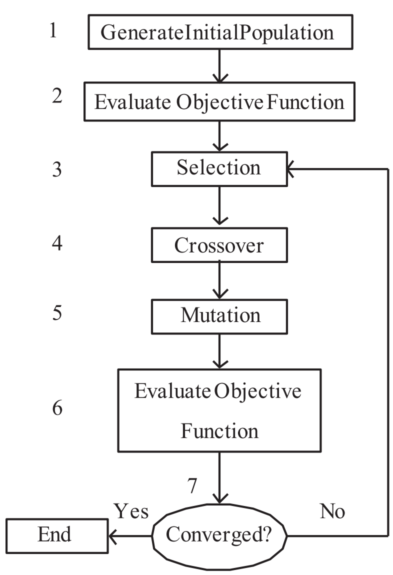


Fig. 3. A flowchart illustrating the GA process.

The orientation of each element of the antenna (α_n) is obtained by GA optimisation as to the flowchart in Fig. 3 [10].

From Fig. 3 the *elitism* operator is used after step 6, before convergence checking at step 7, to ensure that there is a monotonic increase of the best fitness in the population as a function of time [11]. The objective function of this article is derived from the *field synthesis* concept [12] as follows

$$MINIMIZE \rightarrow$$

$$error_{chr} = \frac{1}{N}\left(\begin{array}{l} \sum c_1 \left| \dfrac{E_{coidmain} - E_{comutmain}}{E_{coidmain}} \right|^2 \\ + \sum c_2 \left| E_{comutside} \right| \\ + \sum c_3 \left| E_{comutnull} \right| \\ + \sum c_4 \left| E_{crmut} \right| \end{array} \right) \tag{7}$$

where

$E_{coidmain}$ = main lobe co-polarization (linearly polarized in y - direction) electric field of the ideal case where mutual coupling effects are not accounted for

$E_{comutmain}$ = main lobe co-polarization (linearly polarized in y - direction) electric field where mutual coupling effects are accounted for (orientation of element obtained by GA)

$E_{comutside}$ = sidelobe co-polarization (linearly polarized in y - direction) electric field where mutual coupling effects are accounted for (orientation of element obtained by GA)

$E_{comutnull}$ = null direction co-polarization (linearly polarized in y - direction) electric field where mutual coupling effects are accounted for (orientation of element obtained by GA)

E_{crmut} = all sampled angles cross-polarization (linearly polarized in x - direction) electric field where mutual coupling effects are accounted for (orientation of element obtained by GA)

$c_1 = 0$ when $|E_{comutmain}| \geq |E_{coidmain}|$

$c_1 = 1$ when $|E_{comutmain}| < |E_{coidmain}|$

$c_2 = 0$ when $E_{comutside} \leq -20dB$

$c_2 = 1$ when $E_{comutside} > -20dB$

$c_3 = 0$ when $E_{comutnull} \leq -50dB$

$c_3 = 1$ when $E_{comutnull} > -50dB$

$c_4 = 0$ when $E_{crmut} \leq -30dB$

$c_4 = 1$ when $E_{crmut} > -30dB$

The values of c_1, c_2, c_3 and c_4 are chosen so that the convergence rate of (7) is satisfactory.

c_1 : It is expected that the main beam of the multi-element-orientation antenna should be as closest as possible to the ideal main beam of the single-element -orientation antenna that there is no presence of mutual coupling.It is usually unlikely that $|E_{comutmain}| \geq |E_{coidmain}|$ Hence this extraordinary case is regarded satisfactory rather than problematic.

c_2, c_3 and c_4 are set to make sure that the sidelobe, the null and the cross polarisation levels respectively are within or below certain level as stated above.

N = number of sampled angles

The use of the objective function (7) is to ensure that the GA optimised pattern of the multi-element-orientation antenna closely matches that of the ideal single- element-orientation antenna that has no presence of mutual coupling at all. The binary setting of all parameters from $c_1 - c_4$ is aimed at accelerating the convergence of the optimisation procedure.

The fitness of each chromosome is obtained by the transformation of the objective function in (7) as follows:

$$F_{chr} = \frac{1}{1+\sqrt{error_{chr}(\theta)}} \tag{8}$$

The value of fitness in (8) is the normalized objective function, its best value is 1, which means that $error_{chr}$ equals 0. Actually, it is difficult to get $error_{chr}$ equal to 0 so if the value in (8) is closer to 1, it means that the optimized radiation pattern is closer to the desired radiation pattern.

3. Simulation Results

A base station antenna with an 8-element dipole array on an assumed infinite ground plane is simulated at 1000 MHz. The GA optimization is employed for the search of the set of optimum orientation of all array elements. The Howells-Applebaum algorithm is adopted as a weighting scheme. Music is employed for DOA estimation [13]. Parameters of the GA optimizer are summarised in Table 1.

The set of the optimized orientation of all array elements is as in Table 2. The orientation according to Table 2 should produce minimum mutual coupling effects. The convergence of the objective function as in (8) with parameters as in Table 1 is shown in Fig. 4. It is found from Fig. 4 that after about 300 generations the desired orientation is obtained. The GA optimized radiation pattern with parameters as in Table 1 is shown in Fig. 5. Additional calculation shows that the multi-element-orientation antenna has gain of 14.9 dB in the presence of mutual coupling. A gain drop of 1.5 dB from that of the single-element-orientation antenna in the same situation. This is a result of the arisen cross palarisation produced by the various orientation of the antenna's elements.

Table 1. Parameters of GA optimizer

Parameter	Value
Probability of crossover (one-point crossover)	0.75
Probability of mutation	0.005
No. of bit/gene	10
No. of gene/chromosome	8
No. of chromosome	50
No. of generation	1200

Table 2. The set of element orientation of all array elements

α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8
146.39°	30.79°	136.36°	56.83°	124.22°	53.48°	152.72°	48.38°

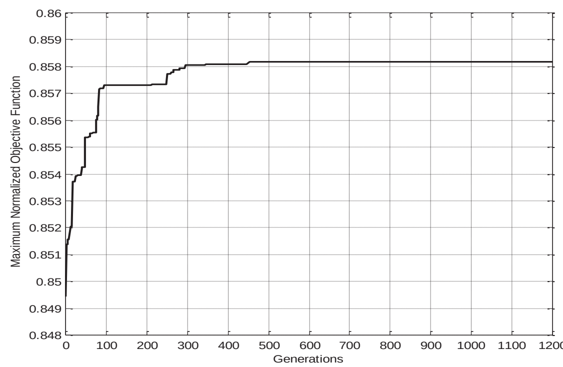


Fig. 4. The convergence of the maximum normalized objective function.

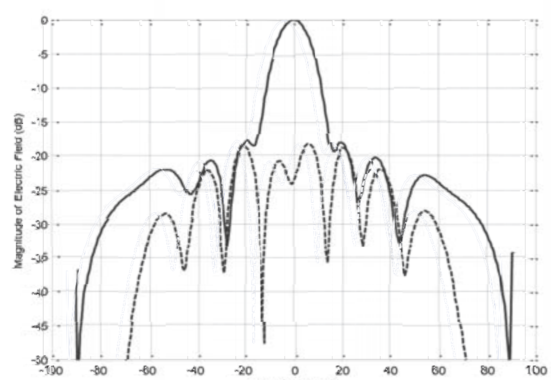


Fig. 5.The optimized radiation pattern by GA optimization at generation 1200^{th} . (-)co-polarization, (--)cross-polarization..

SINGLE ELEMENT ORIENTATION							
85.656 + 71.53i	12.109 - 30.711i	-9.2705 + 8.0886i	5.3173 - 2.9146i	-3.2926 + 1.3265i	2.2062 - 0.70451i	-1.5714 + 0.41608i	1.1725 - 0.26529i
12.109 - 30.711i	85.656 + 71.53i	12.109 - 30.711i	-9.2705 + 8.0886i	5.3173 - 2.9146i	-3.2926 + 1.3265i	2.2062 - 0.70451i	-1.5714 + 0.41608i
-9.2705 + 8.0886i	12.109 - 30.711i	85.656 + 71.53i	12.109 - 30.711i	-9.2705 + 8.0886i	5.3173 - 2.9146i	-3.2926 + 1.3265i	2.2062 - 0.70451i
5.3173 - 2.9146i	-9.2705 + 8.0886i	12.109 - 30.711i	85.656 + 71.53i	12.109 - 30.711i	-9.2705 + 8.0886i	5.3173 - 2.9146i	-3.2926 + 1.3265i
-3.2926 + 1.3265i	5.3173 - 2.9146i	-9.2705 + 8.0886i	12.109 - 30.711i	85.656 + 71.53i	12.109 - 30.711i	-9.2705 + 8.0886i	5.3173 - 2.9146i
2.2062 - 0.70451i	-3.2926 + 1.3265i	5.3173 - 2.9146i	-9.2705 + 8.0886i	12.109 - 30.711i	85.656 + 71.53i	12.109 - 30.711i	-9.2705 + 8.0886i
-1.5714 + 0.41608i	2.2062 - 0.70451i	-3.2926 + 1.3265i	5.3173 - 2.9146i	-9.2705 + 8.0886i	12.109 - 30.711i	85.656 + 71.53i	12.109 - 30.711i
1.1725 - 0.26529i	-1.5714 + 0.41608i	2.2062 - 0.70451i	-3.2926 + 1.3265i	5.3173 - 2.9146i	-9.2705 + 8.0886i	12.109 - 30.711i	85.656 + 71.53i

MULTI-ELEMENT ORIENTATION							
85.656 + 71.53i	-13.498 - 0.12474i	-7.3008 + 0.31565i	0.027564 - 0.0063407i	-1.9261 + 0.22353i	-0.061281 + 0.0060842i	-0.29717 - 0.16706i	-0.073709 + 0.0016062i
-13.115 + 0.8018i	85.656 + 71.53i	-7.1021 + 2.715i	-7.5117 + 2.5493i	-0.20896 + 0.043273i	-1.8057 + 0.14647i	-0.23035 - 0.13122i	-0.69901 - 0.010411i
-6.5536 - 1.3326i	-8.2423 + 0.38839i	85.656 + 71.53i	3.7568 - 3.502i	-8.3167 + 2.9751i	0.42936 - 0.08596i	-0.82782 - 0.50995i	0.038465 - 0.0019131i
0.017097 + 0.0047272i	-5.9268 - 1.4234i	4.5544 - 2.3167i	85.656 + 71.53i	7.8197 - 7.653i	-8.4837 + 2.9875i	-0.18761 - 0.1i	-1.8785 + 0.082544i
-1.0951 - 0.35313i	-0.12147 - 0.046935i	-7.6009 + 0.87785i	7.6927 - 7.8198i	85.656 + 71.53i	7.0133 - 6.1299i	-5.4843 - 1.9256i	0.79383 - 0.10262i
-0.033313 - 0.0086939i	-0.96807 - 0.41842i	0.35739 - 0.0061789i	-8.6512 + 3.5627i	6.7714 - 6.4582i	85.656 + 71.53i	-5.0318 + 0.1754i	-8.0979 + 1.8274i
-0.40282 - 0.1284i	-0.27234 - 0.11244i	-1.4218 - 0.14007i	-0.36283 + 0.07802i	-7.2308 + 2.2307i	-3.6492 + 2.6873i	85.656 + 71.53i	-6.1229 + 3.3409i
-0.04292 - 0.0092767i	-0.37012 - 0.14388i	0.033659 + 0.0006968i	-2.2179 + 0.3404i	0.89699 - 0.22262i	-8.3942 + 2.7289i	-7.8354 - 0.011235i	85.656 + 71.53i

Fig. 6. Impedance matrices of both the single-element- orientation and multi-element-orientation antennas.

Table 3. 24 cases of simulation

Case	DOA_d	DOA_{I1}	DOA_{I2}	M
1	0	20	-40	0.5
2	0	20	-40	1
3	0	20	-40	10
4	0	30	-30	0.5
5	0	30	-30	1
6	0	30	-30	10
7	20	40	-60	0.5
8	20	40	-60	1
9	20	40	-60	10
10	20	30	-30	0.5
11	20	30	-30	1
12	20	30	-30	10
13	-20	0	60	0.5
14	-20	0	60	1
15	-20	0	60	10
16	-20	30	40	0.5
17	-20	30	40	1
18	-20	30	40	10
19	30	20	-35	0.5
20	30	20	-35	1
21	30	20	-35	10
22	30	60	-30	0.5
23	30	60	-30	1
24	30	60	-30	10

Note: DOA_d is the desired direction of arrival, DOA_I is the interference direction of arrival and M is the ratio between the magnitude of the interference signal and the desired signal.

Mutual coupling reduction as a result of adopting multi-element orientation is evidenced from the decrease of the mutual impedance as displayed in Fig. 6. Values of all off diagonal elements of the impedance matrix for the multi-element orientation case are reduced significantly. This demonstrates that polarisation mismatch due to different orientations of all elements help reduce mutual coupling.

It is seen that the radiation pattern obtained from GA optimisation has the sidelobe levels of the co-polarisation electric field below -20 dB in all directions of the sidelobes except both first sidelobes that appear shoulder-like and the cross-polarisation electric field levels are below -30 dB only in some directions but the nulls are not below -50 dB in all directions of the co-polarisation electric field. The 24 simulation cases of the base station antenna have the desired direction and interference direction that cover the main lobe, sidelobe and null directions as summarised in Table 3.

This article defines the set of orientation of all 8 elements at 90° ($\alpha_i = 90°$ as in Fig. 1) as the conventional single-element-orientation and the set of orientation which is obtained by GA (as in Table 2) as the multi-element-orientation. Both terms are to be used in further discussion.

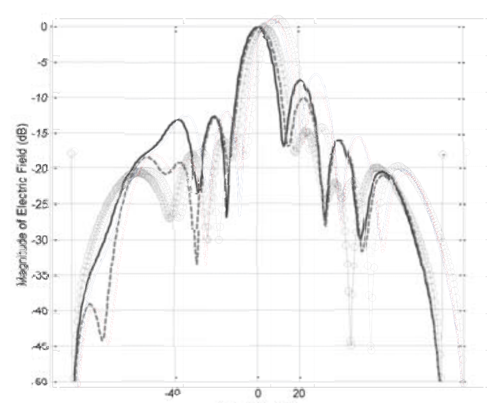


Fig. 7. Case 1: the radiation pattern in quiescent environment (-),of the single-element - orientation (--) and of the multi- element-orientation (-o).

The illustrative radiation patterns of case 1 and case 3 are shown in Fig. 7 and Fig. 8 respectively. Both figures compare the performance between the single-element-orientation antenna and the multi-element-orientation antenna in the presence of mutual coupling. In case 1, it is found from Fig. 7 that the multi-element-orientation antenna is better than the single-element-orientation antenna on capability of interference nullifying in both directions of interference, as shown in Table 3. In case 3, it is found from Fig. 8 that DOA error of the multi-element-orientation antenna is less than that of the single-element-orientation antenna and interference nullifying in the -40° direction of the multi-element-orientation antenna is better than that of the single-element-orientation antenna. In summary, 17 cases of all 24 cases of the multi-element-orientation antenna perform better than those of the single-element-orientation antenna. Thus, it can be concluded that the use of multi-element-orientation can enhance the base station antenna performance.

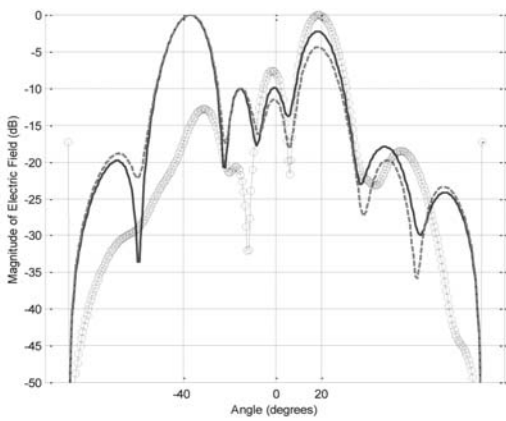


Fig. 8. Case 3: the radiation pattern in quiescent environment (-), of the single-element-orientation (--) and of the multi-element-orientation (-o).

4. Experimental Results

Two sets of the base station antenna have been constructed for experimental investigation. The first set is an 8-element dipole array on a small ground plane of $0.15m \times 1.2m$ (as in Fig. 9) and the second set is an 8-element dipole array on a large ground plane of $0.3m \times 1.575m$ (as in Fig. 10).

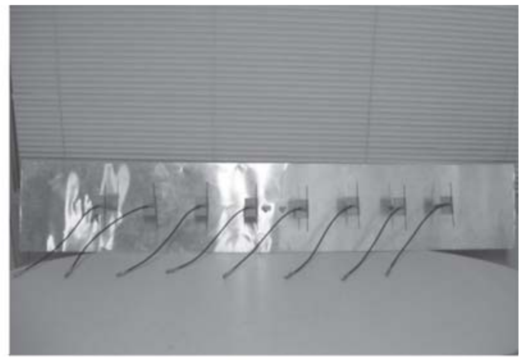


Fig. 9. The 8-element dipole array on a large ground plane.

Fig. 10. The 8-element dipole array on a small ground plane.

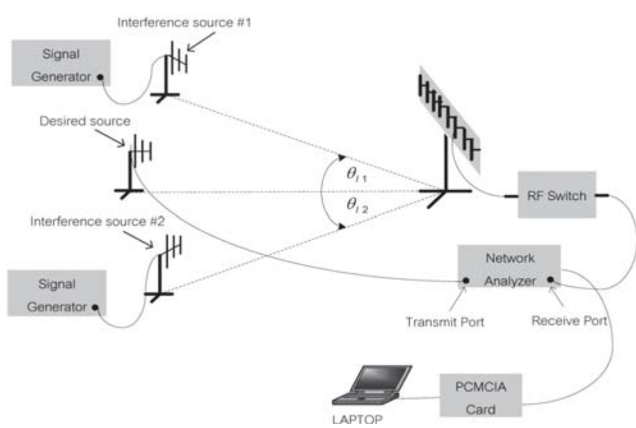


Fig. 11. Diagram of the experimental set-up.

The base station antenna simulator operates at 1000 MHz. The dipole elements are constructed from the wire of 0.2 cm radius and the length of half wavelength. The two ground planes are constructed from a rectangular patch of aluminum. Experiments have been carried out at the football pitch of the Faculty of Political Science, Chulalongkorn University. All signal processing tasks have been performed off line and the diagram of the experimental set-up is as shown in Fig. 11. The six cases of experiments are shown in Table 4.

Table 4. 6 cases for experimental investigation

Case	DOA_d	DOA_{I1}	DOA_{I2}	M
1	0	20	-40	1
2	0	20	-40	10
3	-20	30	40	1
4	-20	30	40	10
5	30	20	-35	1
6	30	20	-35	10

Note: DOA_d, DOA_I and M are the same as those of Table 3.

In case 1 of the small ground plane mounting, it is found from Fig. 12 that the capability of interference nullifying in both directions of interference as in Table 4, of the multi-element-orientation antenna is better than that of the single-element-orientation antenna. In case 6 of the small ground plane mounting, it is found from Fig. 13 that the capability of interference nullifying in both directions of interference as in Table 4, of the single-element-orientation antenna is better than that of the multi-element-orientation antenna.

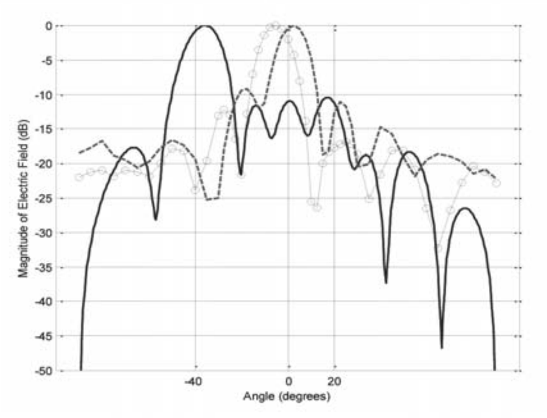


Fig.12. Case 1 of small ground plane: the Radiation pattern in quiescent environment (-), of the single-element-orientation (--) and of the multi- element-orientation (-o).

In case 1 of the large ground plane mounting, it is found from Fig. 14 that the capability of interference nullifying in the $20°$ direction of the multi-element-orientation antenna is better than that of the single-element-orientation antenna about 15 dB, but in the $-40°$ direction the single-element-orientation antenna can nullify interference better than the multi-element-orientation antenna by only about 5 dB. In case 6 of the large ground plane mounting, it is found from Fig. 15 that the capability of interference nullifying of the multi-element-orientation antenna is better than the single-element-orientation antenna in both directions of interference.

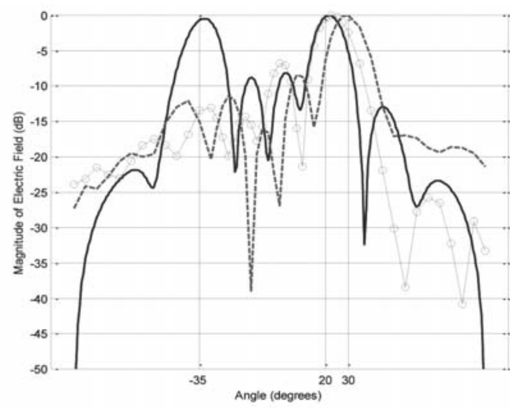


Fig. 13. Case 6 of small ground plane: the radiation pattern in quiescent environment (-), of the single-element-orientation (--) and of the multi-element- orientation (-o).

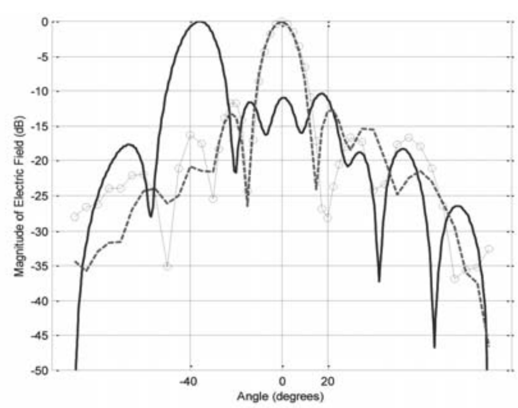


Fig. 14. Case 1 of large ground plane: the radiation pattern in quiescent environment(-), of the single-element-orientation (--) and of the multi-element-orientation (-o).

Comparison between simulation and experimental results is also worth noting. Both Figs. 16 and 17 show rather good agreement between the simulation and experimental results. Discrepancies are due to some nonideal characteristics typical of the out door test range.

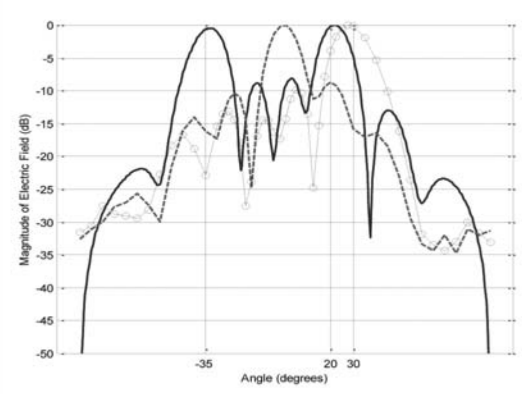


Fig. 15. Case 6 of large ground plane: the radiation pattern in quiescent environment (-), of the single-element-orientation (--) and of the multi-element-orientation (-o).

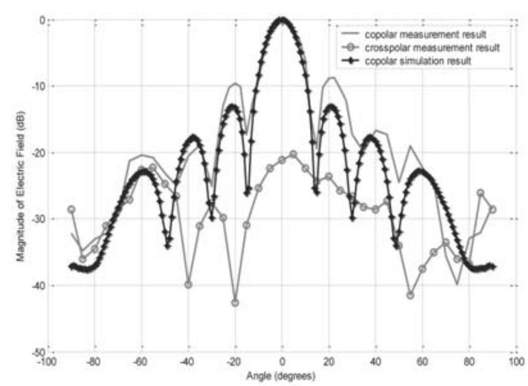


Fig. 16. Comparison of the measured and calculated radiation patterns of the single-element-orientation antenna mounting on a large ground plane.

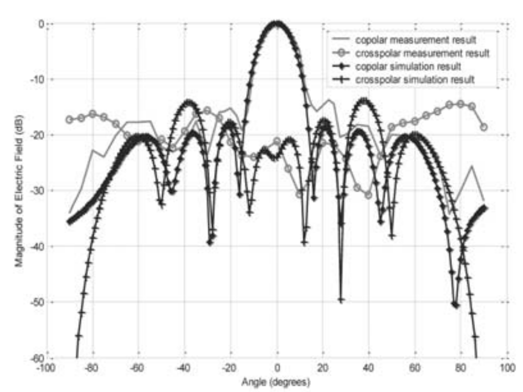


Fig. 17. Comparison of the measured and calculated radiation patterns of the multi-element-orientation antenna mounting on a large ground plane.

5. Conclusion

A technique for mutual coupling reduction by orientating all elements of the array differently has been investigated. Theoretically this use of multi-element orientation can reduce mutual coupling between the array elements through polarisation mismatch. It is confirmed by both simulation and experimental results. The impedance matrix obtained from simulation clearly displays significant reduction of the mutual impedance values for the multi-element orientation antenna compared with that of the single-element orientation antenna. Element orientation is thus a promising technique for mutual coupling reduction which ultimately leads to performance enhancement of the smart antenna.

Reference

[1] R. Borowiec, R. Hossa, P. Slobodzian, and Z. Langowski."Compensation of Mutual Coupling in Small Antenna Arrays." *Mikon-2002. 14th International Conference on Microwaves, Radar and Wireless Communication*,vol.3, 20-22 May. 2002, pp. 894-897.

[2] R.S. Adve and T.K. Sakar. "Compensation for the Effects of Mutual Coupling on Direct Data Domain Adaptive Algorithms." *IEEE Trans. Antennas Propagate*., vol. AP-48, no. 1, Jan. 2000, pp. 86-94.

[3] H. Steyskal and J.S. Herd. "Mutual Coupling Compensation in Small Array Antennas." *IEEE Trans. Antennas Propagate*., vol. AP-38, no. 12, Dec. 1990, pp. 1971-1975.

[4] P. Darwood, P.N. Fletcher, and G.S. Hilton. "Mutual Coupling Compensation in Small Planar Array Antennas." *IEEE Trans. Antennas Propagate*., vol.AP-145, no.1, Feb. 1998, pp.1-6.

[5] J.D. Kraus. " Chapters 11," in *Antennas*,New York: McGraw-Hill, 1998 , pp. 461-463.

[6] C.A. Balanis. " Chapters 8,"in *Antenna Theory and Analysis and Design Second Edition*, John Wiley & Sons, Inc., 1996 , pp. 416.

[7] R.T. Compton . *Adaptive Antennas : Concepts an Performance*, Prentice Hall, New Jersey, 1988.

[8] I.J. Gupta and A.A. Ksienski . "Effect of Mutual Coupling on the performance of Adaptive Arrays," *IEEE Trans. Antennas Propagate*., vol. AP-31, Sep. 1983, pp. 785-791.

[9] R.L. Haupt. "An Introduction to Genetic Algorithms for Electromagnetics," *IEEE Trans. Antennas Propagate*., vol. AP-37, no. 2, Apr. 1995, pp. 7.

[10] D.S. Weileand E. Michielssen. "Genetic Algo rithms Applied to Electromagnetics:A Review," *IEEE Trans. Antennas Propagate*., vol. AP-45, no. 3, Mar. 1997, pp. 347.

[11] Y. Rahmat-Samii and E. Michielssen."Chapters 1, "in *Electromagnetic Optimization By Genetic Algorithms*, John Wiley & Sons, Inc.,1999,pp.17

[12] Y. Rahmat-Samii and E. Michielssen. "Chapters 6, " in *Electro magnetic Optimization By Genetic Algorithms*, John Wiley & Sons, Inc., 1999, , pp. 157.
[13] L.C. Godara."Application of Antenna Arrays to Mobile Communications, Part II:Beam-Forming and Direction-of-Arrival Considerations," *IEEE Proceeding*, vol. 85, no.8, Aug. 1997, pp. 1223.

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