

UPLINK BEAM STEERING USING THE INTELLIGENT QUADRIFILAR HELIX ANTENNA

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ABSTRACT

This paper investigates the uplink beam steering potential of the Intelligent Quadrifilar Helix Antenna (IQHA) [1]. The approach relies on producing a variable radiation pattern by adjusting the phase relationships between its elements. This paper presents results obtained from an investigation of the effects of applying different weights to the individual elements of a Meander Line Printed QHA (MPQHA) [2] structure using a real time demonstrator. Appropriate sets of weights were identified with the aid of a numerical far-field simulation to maximise radiation in the direction of the base station and reduce losses in the head. The real time demonstrator uses a micro-controller to feed the identified weights through the digital phase shifters on the individual elements of the MPQHA structure. The measured radiation patterns were compared to the radiation pattern measured from a MPQHA with conventional phase quadrature feed. Measurements were made both in free space and in the presence of a phantom head so as to demonstrate the impact of near-field coupling. The Specific Absorption Rate (SAR) was also monitored.

INTRODUCTION

It was found in previous measurements [3] that, with a single monopole antenna mounted on a small ground plane and situated close to a head, that the radiation in the direction blocked by the head had reduced signal strengths of the order of 30 dB. A two-element antenna array was used to form nulls towards the head and increase directivity in the useful direction, demonstrating the potential of using an array on the mobile terminal. The use of directional antennas for the mobile terminal was also demonstrated in [4] using an array of 4 dipoles. The overall radiation patterns of omni-directional antennas located close to the user's head were compared with those of directional ones, and the results shows that the shadow behind the head for the omni-directional antennas is almost as dark for the directional antennas.

The intelligent quadrifilar helix antenna (IQHA) [5] is a new intelligent antenna concept for mobile terminals. It has been invented at the University of Surrey under the auspices of the Mobile VCE as a means of maximizing

link quality for mobile systems, and a demonstrator is currently under development to verify the IQHA potential for GSM and UMTS applications [5]. Initial research has indicated that in excess of 10dB of diversity gain was obtainable in the downlink, and that substantial reductions in required transmit power were available in the uplink. The elements of the IQHA are treated as four independent elements of an array. Depending on the physical layout and feed configuration, the array can have increased directivity over a single element in some directions at the cost of directivity in others. The potential of the IQHA to operate in both terrestrial and satellite mobile communications was presented in [5]. By applying the conventional phase quadrature configuration, the QHA produces a hemispherical pattern suitable for mobile satellite communications; while the equal phase configuration produces an omni directional pattern suitable for terrestrial mobile communication. In this paper the MPQHA is used as a directional antenna by having different sets of phase configurations. The intention is to achieve a more directional antenna for the mobile terminal such that:

- (1) A greater proportion of mobile transmit power is directed into a direction which will eventually enhance signal energy at the base station.
- (2) Power absorbed in the user's head is reduced, increasing efficiency. This can be monitored via the SAR in a suitable head phantom.

BEAM STEERING MEASUREMENTS

TABLE 1 - Physical and Operating Characteristics of MPQHA

	MPQHA
L-axial (mm)	38.9
L-element (mm)	124
Radius (mm)	7
Track width (mm)	2
Number of turns (N)	0.75
ΔA (mm)	6
ΔL (mm)	4
Resonant Frequency (GHz)	2
Impedance Bandwidth for $S_{11} < -10$ dB (GHz)	1.9 to 2.09

The Antenna

The antenna used for all the measurements conducted in this paper is a MPQHA operating at 2 GHz. The physical and operating characteristics of the MPQHA is given in Table 1. In Table 1, ΔA and ΔL refers to the vertical and horizontal components of the meander line respectively. A meander line configuration was used to minimise the size of the antenna without significantly degrading efficiency.

Measurement Set-up

The measurements were carried out by using digitally controlled analog phase shifters to generate the weights for each individual element of the MPQHA structure. The micro-controller generates the phase in digital outputs to the digital phase shifters. The measurement set up in the chamber is shown in Figure 1. The responses to vertical and horizontal polarisations were measured, and the total power from the sum of the two polarisations is presented.

The measurements were also carried out with a phantom head to account for the near field coupling. Figure 2 shows the phantom head set up. The shell of the phantom head used in the measurements is made of glass fibre. The liquid used to fill the phantom is a mixture of water, sugar and cellulose to achieve dielectric properties at DCS 1800 as similar as possible to that of the human head. The MPQHA is placed in a touch cheek position so that the results are consistent when compared with the SAR measurements. For the elevation pattern measurements, the phantom head is tilted so that the MPQHA is parallel to the ground.

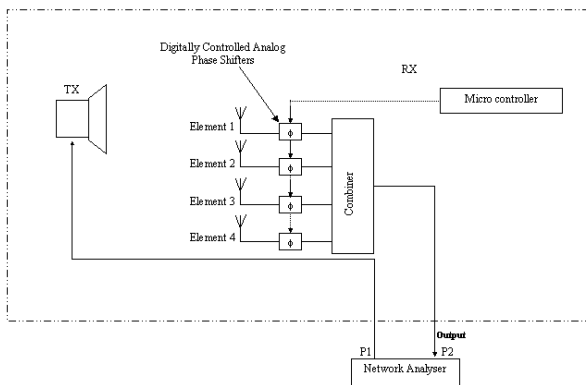


Figure 1. Anechoic Chamber Measurement Set-up

Four different weighting configurations were used in the measurements. Referring to Table 2, WT1 configuration will produce the conventional hemispherical shape radiation pattern and WT2, WT3 and WT4 are configurations that produce radiation patterns with increased power in the direction of the base station. Figure 3 illustrates that, for all measurements, the $+x$ direction refers to the direction

TABLE 2 – Feeding Configurations for Beam Steering MPQHA

Name	Weights W_n ($^\circ$)			
	W1	W2	W3	W4
WT1	0	270	180	90
WT2	0	220	230	220
WT3	0	170	220	230
WT4	0	170	230	240

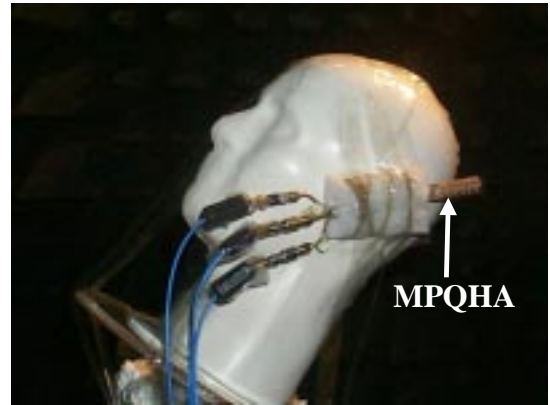


Figure 2. The Phantom Head Set-up in the Anechoic Chamber

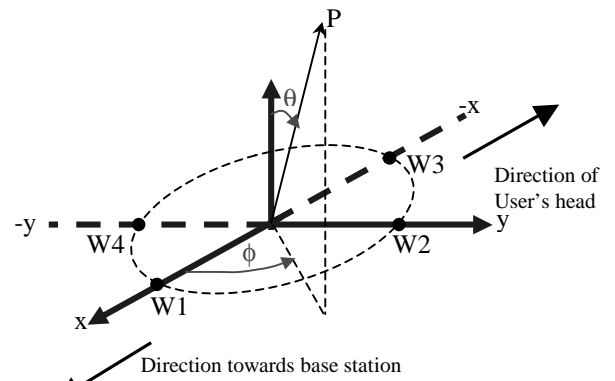


Figure 3. Representation of the Weighting Configuration in Cartesian Coordinates

towards the base station and W1 is located at the $+x$ direction.

Results and Analysis

Free space measurements were first carried out to compare the radiation patterns produced using WT2, WT3 and WT4 to the pattern produced from WT1.

In the polar diagrams of the radiation patterns, the angle 180° to 359° represents the direction towards the base station and 0° to 180° represents the direction towards the user's head. It is assumed that the incident wave is

uniformly distributed in the azimuth and the elevation angle distribution is assumed to be a Gaussian distribution [6]. For the beam steering gain comparison in this paper, the useful direction is defined between the elevation angles of 300° to 270° on the radiation polar plots.

Comparing the performance in the useful direction with WT1, 2 dB, 2.9 dB and 2.1 dB of beam steering gain were achieved from WT2, WT3 and WT4 respectively. WT2, WT3 and WT4 also show significant reduction of power in the direction of the user's head when each configuration was compared with WT1. In Figure 4, the azimuth pattern also shows enhanced gain in the direction towards the base station and reduced power in the direction of the user's head when using WT2, WT3 and WT4.

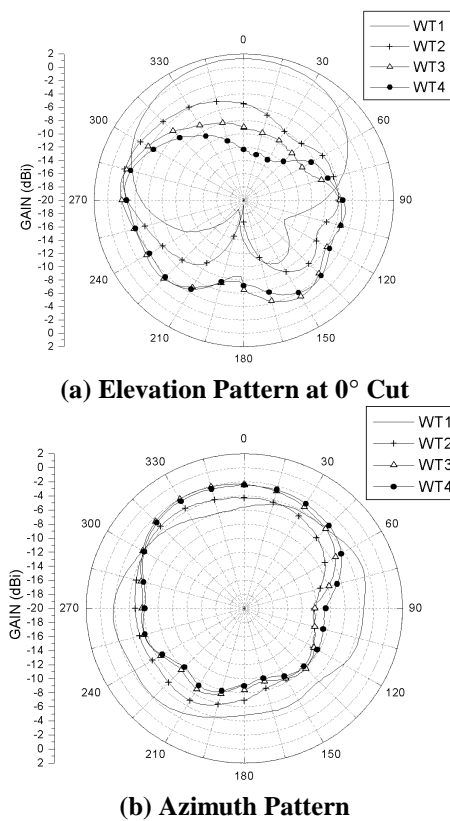


Figure 4. Free Space Radiation Pattern Measurements

Figure 5 shows the radiation pattern comparison for the four different sets of weights with and without the presence of the phantom head. Such measurements are essential since the head is in the near field of the antenna, so the free space trends might not be replicated in the far field in the presence of the head. In the direction towards the head, the gain levels for all four configurations were reduced, this is caused by the shadowing of the antenna by the phantom head. The radiation pattern produced using WT1 did not change drastically compared to that observed for WT2, WT3 and WT4. However, the radiation pattern in the direction towards the base station remains unchanged with the presence of the user's head for all four sets of

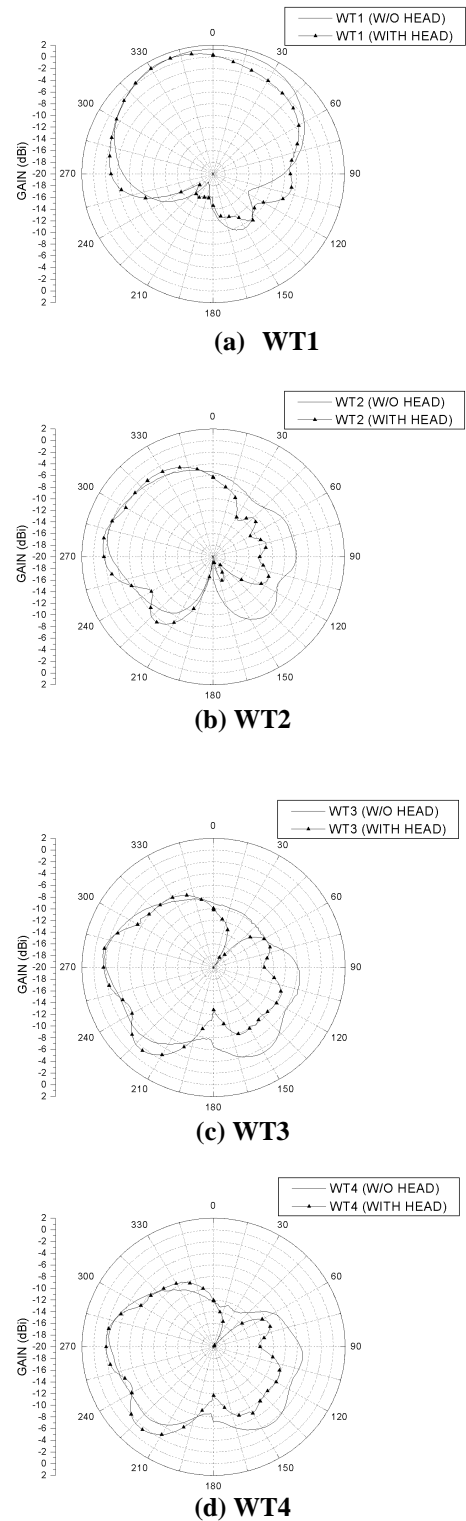


Figure 5. Measured Radiation Pattern at 0° Elevation Cut with/without Head

weighting configurations. WT3 and WT4 produce almost identical radiation patterns in free space and with the phantom. This is because the feed arrangements for WT3 and WT4 were almost the same.

TABLE 3 – SAR Measurements

Name	Test Position	SAR 1g (mW/g)	SAR 10g (mW/g)
WT1	Touch Cheek	1.4	0.8
WT2	Touch Cheek	0.55	0.30
WT3	Touch Cheek	1.03	0.63
WT4	Touch Cheek	0.92	0.59

SAR MEASUREMENTS

The Specific Absorption Rate (SAR) of the MPQHA for different weighting configurations was measured for an input power of 1 W. The maximum averaged SAR over masses of 10g and 1g were observed. The SAR measurement is first carried out with a coarse 2D scan throughout the entire region of tissues next to the handset and its antenna to determine the peak SAR locations near the surface of the phantom. Following this, a fine resolution volume scan is carried out at the peak SAR locations to determine the 1g and 10g average SAR. The results are averaged over a 1cm³ volume in the shape of the cube for 1g SAR. For 10g average SAR value, a cubic tissue volume of side 2.15 cm can be used to produce a conservative estimation. In this paper, the SAR measurements are carried out in the touch cheek position.

Results and analysis

The measured SAR values for all the configurations are summarised in Table 3. The SAR values displayed in Table 3 are all within the IEEE and ICNIRP recommendations [7] limit of 1.6mW/g and 2mW/g respectively. The SAR values from WT2, WT3 and WT4 were observed to be lower than the SAR values of WT1. WT3 and WT4 produce almost the same SAR values as this correlates with the results in the previous section that the two sets of weights produce identical radiation pattern.

This produces the potential of increasing the transmit power in the useful directions while maintaining the SAR at acceptable levels. For example, the transmit power in WT2 can be increased by 4.0dB with the same SAR as in WT1, with essentially all of this increase contributing to useful directions for improved communication quality.

CONCLUSION

The idea of using intelligent beam steering to direct the power of a MPQHA towards a more useful direction is demonstrated in this paper. The comparison of measured radiation patterns for different weighting configurations in free space and in the presence of the phantom head were presented. The SAR was also measured and the results show SAR values within the

limits of IEEE and ICNIRP recommendations. Using different weighting configurations has been shown to steer the beam towards the base station and to produce the anticipated associated reduction of power in the direction of the user's head. These effects can be exploited to substantially improve communication quality without degrading the SAR level. Future work will focus on achieving this automatically in any configuration of the handset relative to the user.

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REFERENCES

1. Agius, A.A. and Saunders S.R., 1998, "Adaptive Multifilar Antenna", U.K. Patent No. 9803273.3.
2. Chew K. C. D. and Saunders S.R., 2002, "Improvements Relating to Multifilar Helix Antenna", U.K. Patent Filing, Application No. 0204014.5.
3. Agius A.A., Leach, S. M., Ma L., Hilton G and Saunders S.R., 2000, "Mobile VCE research in the area of antennas for 3rd generation mobile terminals", invited paper in the International Conference on Antennas and Propagation (AP2000), Davos, Switzerland.
4. Noguchi K., Ando M., Goto N., Hirose M., Uno T. and Kamimura Y., 1996, "Directional Antenna for Portable Telephones", IEICE Transaction on Communications, vol. 79, 1234-1241.
5. Leach S.M., Agius A.A. and Saunders S.R., 2000 "Intelligent Quadrifilar Helix Antenna", IEE Proceedings in Microwave, Antenna and Propagation, vol. 147, No. 3, 219-223.
6. Taga T., "Analysis for mean effective gain of mobile antennas in land mobile radio environments", 1990, IEEE Trans. Veh. Tech., vol 39, No. 3, 117-131.
7. James J.R. and Fujimoto K., 2001, "Mobile Antenna Systems Handbook", Artech House, London, U.K., 344-345.