HF MIMO measurements using spatial and compact antenna arrays

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Abstract

This paper describes compact antenna arrays for multiple input multiple output MIMO capacity studies in the HF band. These include a three-element receiver array with active electronics to provide broadband non-tuned operation across the entire HF band and a two-channel resonant magnetic loop array for transmitter applications capable of rapid tuning across greater than two octaves. MIMO measurements over a 255 km sky-wave link in the UK using these compact arrays and spatial arrays were performed to estimate the correlation coefficients between the different elements and the resulting MIMO capacity.

1. Introduction

Radio channel capacity enhancement utilising multiple antennas for transmission and multiple antennas for reception, MIMO, requires received signals which exhibit both mutual decorrelation and sufficient signal to noise ratio. Decorrelation of the received signals between the different elements of the antenna array is usually achieved by inter-element spacing in excess of half a wavelength, which is on the order of 5-50 m in the HF band (3-30 MHz). To avoid the requirement for large sites, collocated heterogeneous antenna arrays have been previously proposed for single input multiple output configurations for both angle of arrival estimation and for diversity reception of images [1-4]. As opposed to homogeneous antenna arrays that are composed of the same types of antenna elements, all oriented in the same direction, heterogeneous antenna arrays can either have (1) different types of antenna elements [1], or (2) identical antenna elements with different orientations [1,5].

In the present study, the feasibility of utilising collocated compact multi-antenna arrays at the transmitter and at the receiver for MIMO applications is investigated. At the receiver antennas capable of instantaneous operation across the entire HF band (3 MHz to 30 MHz) were developed using active termination of electrically small antenna elements. Since the measurements were undertaken during a period of relatively low sunspot activity, the transmitting antenna design was restricted to supporting operation in the lower half of the HF band (3 MHz to 15 MHz). Suitable antenna elements developed for the study include balanced horizontal dipole elements with frequency specific matching networks and vertical resonant magnetic loops, as well as an array formed from a pair of crossed resonant magnetic loops.

A trial 255 km link was established with the transmitter located at Durham and the receiver in Leicester to estimate the decorrelation characteristics for a variety of antenna configurations including the designed compact collocated antenna arrays and conventional HF antenna arrays such as crossed wires (at the transmitter and receiver), and spatially matched monopoles at the receiver. In this paper we present a brief description of the compact arrays and examples of correlation and capacity results.

2. Compact antenna arrays

Three magnetic loop arrays were developed, two three element loops for reception and a dual crossed loop for transmission as shown in Figure 1. The first screened magnetic loop receive array consisted of two orthogonal vertical loops and a single horizontal loop, “X-Y-Z” array, as in Figure 1.a The loops were formed into a 1 m by 1 m square. Two co-located loops were formed with the clockwise loop terminated in one amplifier and the counter-clockwise loop terminated by a second amplifier. The outputs of the two amplifiers were combined differentially to provide a single output. The coaxial cables were mechanically supported inside a frame produced from commercial PVC pipes and fittings.

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The “X-Y-Z” loop array has demonstrated useful levels of signal de-correlation; however the signal level recovered by the horizontal loop was generally much lower than for the vertical loops. To overcome the reduced signal level recovered from the horizontal loop an alternative geometry has been used for the array. Massie et al [6] describe a configuration of three inclined loops. The base of the structure is an equilateral triangle in the horizontal plane where each side of the triangle is formed by one side of each of three square loops. The loops are angled in the vertical plane such that the top of the structure is a second equilateral triangle where each side is formed from the opposite side of each of the square loops. Massie describes this structure as a Ground Symmetric Loop (GSL) or “Giselle” configuration. In the original work the loops were formed as open-wire transmission lines to approximate a free space impedance of 377 Ω. Here we have produced the array shown in Figure 1.b using the differential electrostatic screened loop structure described above. This antenna has demonstrated more uniform output signal levels and useful signal decorrelation and hence overcomes the primary limitation of the “X-Y-Z” loop array.

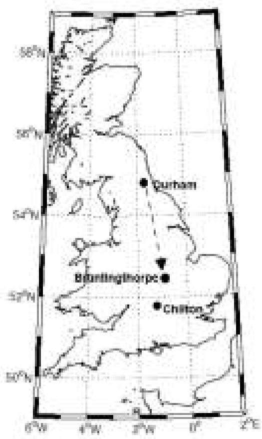
A resonant magnetic loop was selected as a candidate transmitting antenna. The inductance formed by the loop is resonated using a capacitor. Here a 1.5 m octagonal loop was used with a power limit of 250 W. The loop supports frequencies in the range 3.5-15.5 MHz without adjustment of the feed network. To reduce feeder radiation and coupling, the feed network to the loop is balanced using a transmission line unbalanced to balanced transformer constructed using coaxial cable wound onto a large toroidal carbonyl-iron core. Using the method described by Underhill [7], the calculated efficiency of the loop is 88 % at 3.5 MHz rising to 98 % at 15.5 MHz. Using a central aluminium tube, an array of two orthogonal vertical loops has been constructed as shown in Figure 1.c. The loops have independent feed networks and resonating capacitors. The coupling between the antennas has been observed to be approximately -13 dB.

(a) (b) (c)

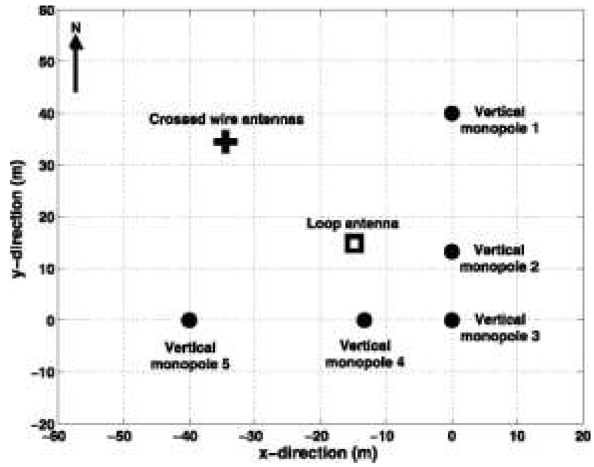
Figure 1. Collocated magnetic loop arrays, (a) “X-Y-Z” array, (b) “GSL” array, (c) dual crossed resonant array.

3. **Measurements**

Measurements were performed in the UK over a 255 km path with the transmitter at Durham and the receiver at Bruntingthorpe near Leicester, as shown in Figure 2.a. The measurements were performed using CW transmissions offset by 10 Hz to distinguish the different transmit antennas. In addition to the compact antenna arrays, spatial antenna arrays were used at the receiver as shown in Figure 2.b. where five vertical monopoles in L shape were set up as well as crossed-wire antenna array and a loop antenna. At the transmitter, two crossed wires (E-W and N-S), vertical loop and a dipole were used. The received data were filtered to identify the CW signals, and analysed for correlation at the transmitter and at the receiver as well as estimating the MIMO channel capacity for different antenna combinations. An example of correlation analysis for the four by eight element measurement using the two cross-wire arrays and the eight receive antenna elements is displayed in Figure 2.c. The measurements were performed at 5.25 MHz and show a decrease in correlation as a function of spatial separation between the elements and for different orientations of the antenna elements.



(a)



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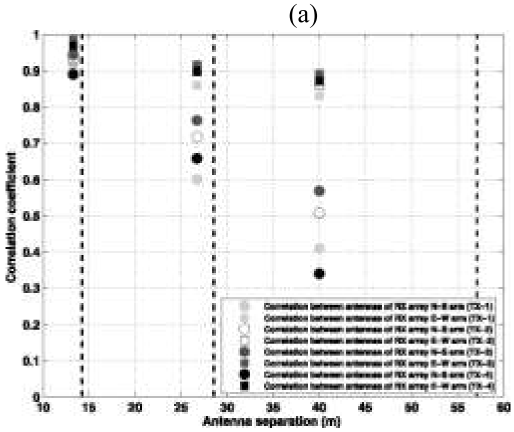


(c)

Four transmit antennas made up of crossed-wires oriented E-W and N-S.

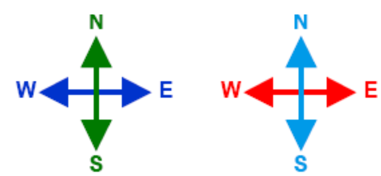
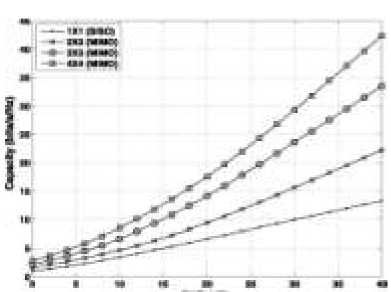
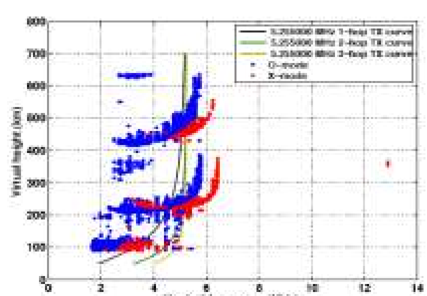


Figure 2 (a) Link of transmission, (b) antenna array arrangement at the receiver site, (c) correlation analysis for each transmit and receive antenna.

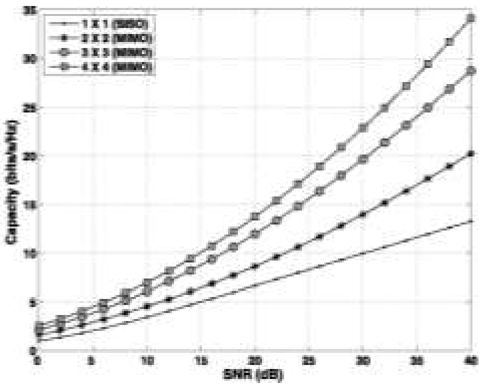
The corresponding capacity estimates for these measurements are displayed in Figure 3.a for 2x2, 3x3, and 4x4 MIMO configurations. While the capacity figures do not show a linear relationship with the number of antennas, the capacity is seen to increase as the number of antennas is increased. This can be related to the number of multipath components (1E, 2E, 3E, 1F2, 2F2 and 3F2 with O and X wave splitting) as seen from the ionogram displayed in Figure 3.b. A small number of modes increases the correlation between the different received signals and reduces the MIMO capacity. Figure 3.c. shows the achieved MIMO capacity using the "X-Y-Z" array at the receiver with a single loop element displaced from the collocated array. The capacity results show that although the capacity has been reduced with the compact array, it still provided significant capacity gain. Figure 3.d shows the received signal on the GSL antenna from two crossed wire antennas at the transmitter. These figures also show that the signals are not correlated, which illustrates the successful deployment of the collocated antennas for MIMO applications in the HF band.



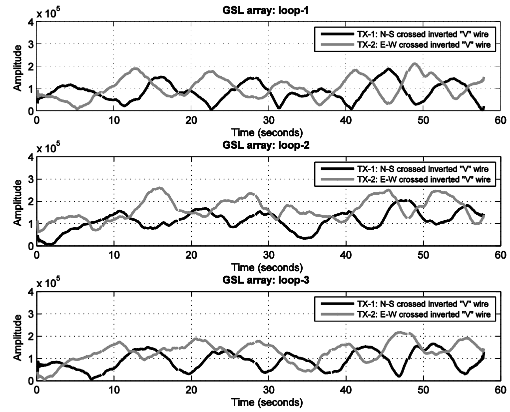
(a)



(b)



(c)



(d)

Figure 3. (a) capacity of spatially separated array, (b) example ionogram over the Durham-Leicester link, (c) capacity of collocated antenna array, (d) received signal strength on the GSL elements.

4. Conclusions

MIMO measurements using both spatially separated antennas and a number of collocated compact antennas especially designed for the study show the feasibility of deployment of MIMO in the HF band. The compact arrays gave reasonable capacity increases and decorrelation, which is encouraging for future deployment of MIMO technology.

Acknowledgements

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