ANTENNA COMPRESSION USING BINARY PHASE CODING: AN IMAGING APPLICATION

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1. Introduction

Very often one has a radar experiment with a conflicting demand. On the one hand one would like to illuminate the target with all the high power usually available with a big antenna; but on the other hand one would also like to have the broadest beam possible (i.e., smallest antenna section). Usually both situations are not compatible and one has to compromise one for the other. This problem is present, for instance, when one has a phased array with a single high power transmitter (e.g., the Jicamarca Incoherent scatter radar), where the total high power cannot be transmitted with single antenna elements. A even stronger constrain is present if one has a phased array with distributed transmitters (e.g., the Middle and Upper atmosphere (MU) VHF radar in Japan or the Buckland Park MF radar in Australia). Normally, for a given installation, i.e., fixed transmitter power level per module, and fixed number of modules (antenna size), going to smaller antennas not only implies broader antenna beams, but unfortunately also a reduction on the total transmitter power.

In this paper we present a solution to overcome this limitation, i.e., transmit with a wide beam and all the available power. Our scheme is based on complementary binary phase coding of the antenna elements in a similar fashion to phase coding used in pulse compression [e.g., *Farley*, 1985]. The decoding part is done by software by adding the statistics of each of the coded signal, so no extra burden is added to the processing other than a few summations.

One application of wide-beam forming or antenna compression schemes is the detection and observation of meteor trails. In this case, the use of wider beams and high power would allow the observation of a larger number of meteors. Another application is in radar interferometer/imaging experiments of the neutral atmosphere, where broader beams are needed in order to cover the whole aspect sensitive region, or to see a region that is broader than its structure. Recent radar images of the lower atmosphere have shown that the aspect sensitivity function and structure of the atmosphere usually extends beyond the relatively narrow (<±5°) field of view of conventional radars [e.g., *Worthington et al.*, 1999, *Helal et al.* [2000]].

We have tested the feasibility of antenna compression at Jicamarca by performing imaging experiments of the equatorial electrojet (EEJ) and the upper troposphere and lower stratosphere. In the next section, we present the details of the derivation and implementation of the codes used at Jicamarca along with the EEJ experimental results.

2. Experimental Setup and Results.

Following the analogy to pulse compression, where a wide coded pulse is transmitted and later synthesized into a narrow pulse with equivalent averaged power, we have derived a set of codes that allow us to transmit with a coded large antenna so that one can synthesize a small antenna (wide beam) after reception. It is well known that the illumination brightness is the Fourier transform of the illuminating field produced at the antenna plane, convolved with itself. Therefore, the decoded part is achieved by software after adding the second order moment statistics (i.e., power, cross correlation functions, cross spectra functions, etc.) of each of the coded signals. The signals of each code are processed independently to obtain their statistics. By obtaining the statistics, each pattern of the coded antenna illumination is decoded with itself. Good codes already generate a spike at zero displacement. The complementary nature of the code allows us to remove the sidelobes in the spatial autocorrelation function (i.e., the Fourier transform of the antenna pattern). This will become clearer as we describe one particular implementation of this idea.

Four two dimensional complementary codes are obtained from the four possible combinations of the outer products of the two one dimensional codes C=[1,1,1,-1] and C C'=[1,1,-1,1], i.e., from $C_x \otimes C_y$, $C_x \otimes C'_y$, $C'_x \otimes C'_y$, $C'_x \otimes C_y$ (where $\otimes$ stands for outer product). The four resulting two-dimensional codes are depicted in Figure 1 for our specific example. We will refer to them as CC, CC', C'C', C'C for short. Therefore, codes of more elements can be attained in a similar way by combining complementary codes of more bits. Moreover, when the antenna compression is needed only in one dimension (e.g., studies of field-aligned irregularities), one needs to use only a simple sequence of one-dimensional complementary codes (i.e., codes C and C'). As in pulse compression, "1" represents a 0° phase shift and "-1" represents a 180° phase shift.

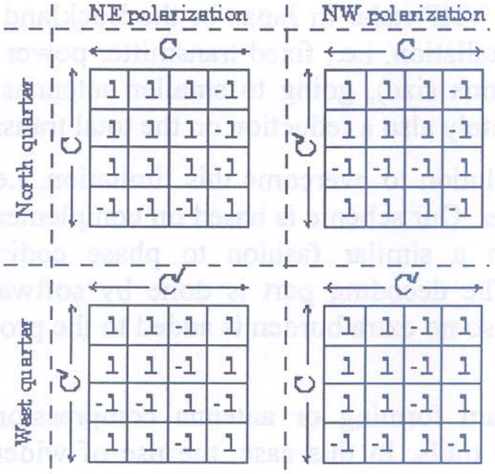

Figure 1. Four complementary binary codes of 4x4 elements. These codes have been obtained from the different combinations of the complementary codes C=[1,1,1,-1] and C'=[1,1,-1,1]. Using the Jicamarca antenna, codes CC and CC' have been implemented with two quarters of the NE (North-East) polarization, and codes CC' and C'C with two quarters of the NW (North-West) polarization, respectively.

The Jicamarca antenna is comprised of 64 modules arranged in an 8x8 module array. Each module has two spatially superimposed antennas, one for each linear polarization (NE and NW). At Jicamarca we cannot flip the phases of the modules from pulse to pulse, since phasing of the modules is accomplished by manually changing the length of the feed cables. We have accomplished the same by dividing the antenna into four sub-antennas of 4 by 4 modules, each coded with a corresponding code of the sequence. They have been grouped in pairs, each pair consisting of the two available linear polarizations. Each pair is energized simultaneously and occupies the same area (one quarter of the array). Two pairs are excited in sequence, from pulse to pulse, and use different quarters of the full array (North and West quarters, respectively). The use of different sections of the antenna to implement different coded antennas, means that we could not use the full 8x8 modules of the Jicamarca array (300~m x 300~m). This has not presented any limitation since we can put as much as 2~MW of peak power into single quarters and therefore, accomplish the equivalent of transmitting 2~MW into a single module. We have used such a transmitting configuration in an imaging experiment. For reception we used the interferometer configuration shown in Figure 2. We used four receiving elements (A, B, C, and D) consisting of two polarizations each. Therefore, there were eight receiving antenna modules, four using the NE polarization and four using the NW polarization. In addition, we used two synchronized PC-based acquisition systems with four complex channels each to record the "raw" data.

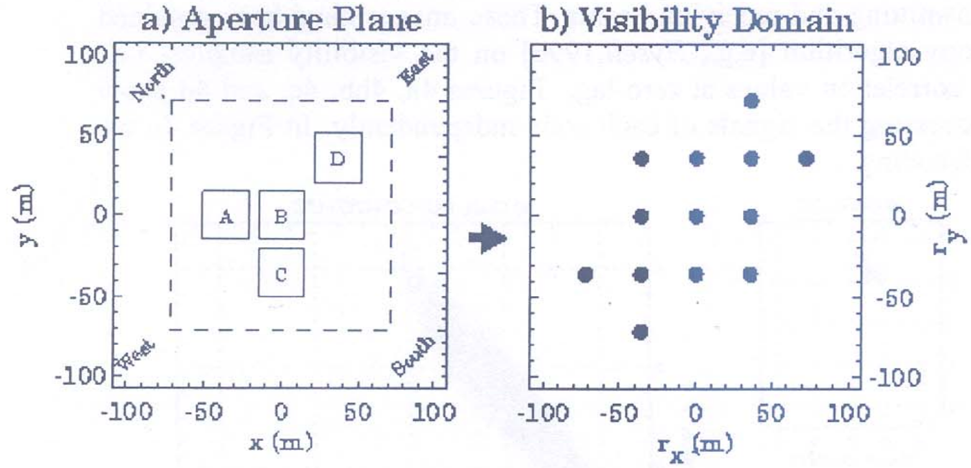

Figure 3. Receiving array and its corresponding visibility domain. Each of the receiving elements consists of two collocated antennas using orthogonal polarizations. The square in dashed lines represents the size of the quarter sections used for transmission.

The antenna patterns of the coded quarter sections are shown in Figure 3. In addition, in Figure 3e we show the antenna pattern obtained after adding the power of each of the coded patterns. This resulting pattern is equivalent to the pattern of a single antenna module, as expected. The North and West antenna quarters are not collocated, but this separation has no effect for the resulting pattern in the far field (above 15 km). Below 15km the resulting pattern is not perfectly symmetric and there are some angular deviations (from the pattern of a module) along the direction of the antenna displacements (i.e., the West-North direction), however, these deviations are a fraction of a degree and could be considered negligible above ~7.5 km (far-field boundary for a quarter section).

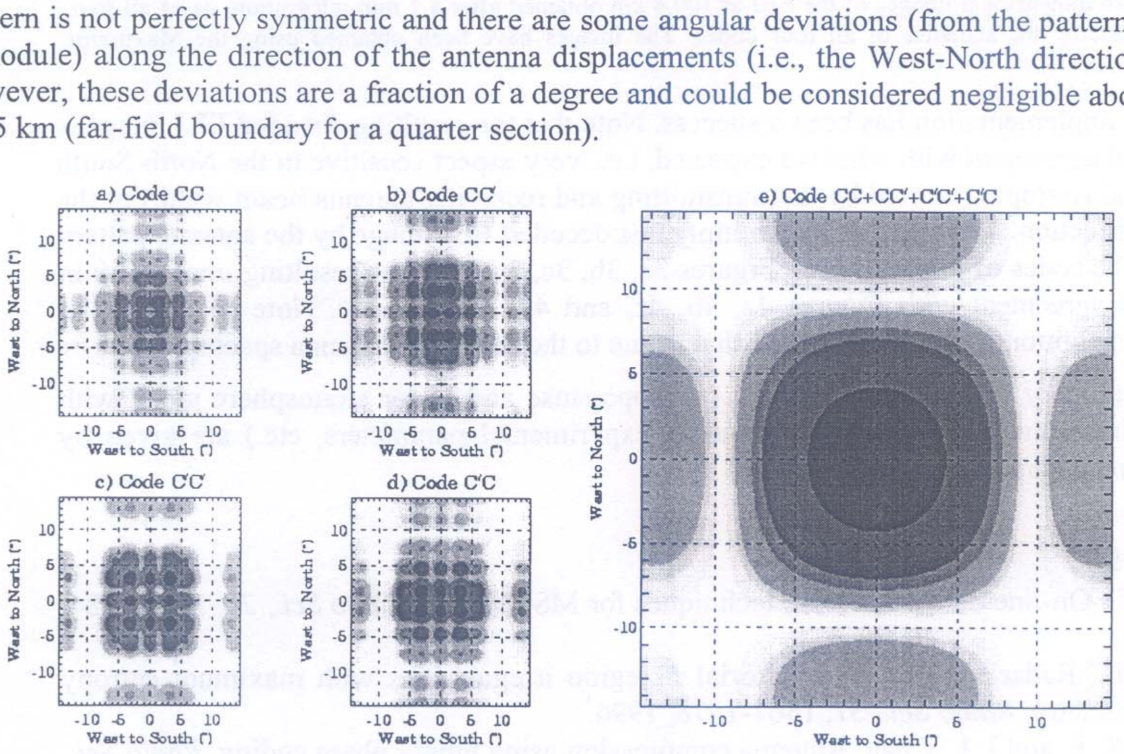

Figure 2. Theoretical antenna patterns of quarter sections (i.e., 4x4 modules) of the Jicamarca antenna using all four codes, along with the resulting pattern of adding them all, which is identical to the pattern of a single Jicamarca module.

We have conducted basically two antenna compression experiments: (1) coded EEJ, and (2) coded upper troposphere and lower stratosphere (ST). In Figure 4 we show an example of two-dimensional images of the EEJ at 100.4 km obtained after 1~min integration. The long integration has been used so that any East-West structure in the scattering medium would be averaged out, so that the brightness would correspond to the combined effect of the transmitting and receiving beams. These images have been obtained using the Maximum Entropy algorithm [e.g., *Hysell*,1996] on the visibility samples, i.e., normalized çomplex cross correlation values at zero-lag. Figures 4a, 4bb, 4c, and 4d show the images obtained by processing the signals of each code independently. In Figure 4e we show the EEJ image after decoding.

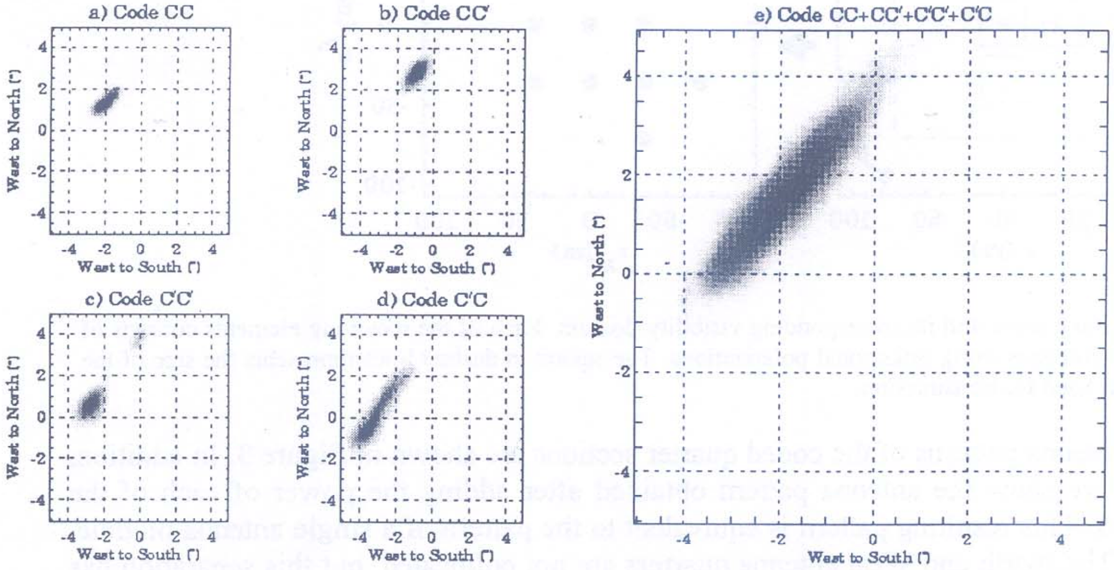

Figure 4. Two dimensional images of the EEJ at 100.4 km obtained after a 1 min integration, using all four codes, and adding the statistics of all four codes. The images have been obtained using the Maximum Entropy method.

Our implementation has been a success. Note that the resulting decoded EEJ image is in very good agreement with what we expected, i.e., very aspect sensitive in the North-South direction and isotropic (limited by the transmitting and receiving antenna beam width) in the East-West direction. Moreover, if we multiply this decoded EEJ image by the antenna pattern of each of the codes of Figure 3 (i.e., Figures 3a, 3b, 3c, and 3d), the resulting images are in pretty good agreement with Figures 4a, 4b, 4c, and 4d, respectively. Note some angular aliasing at the bottom right of all panels, that is due to the receiving antenna spacing used.

Preliminary imaging results from the tropopause and lower stratosphere along with more details on the experiments (calibration, experimental parameters, etc.) are given by *Woodman and Chau* [2000].

Bibliography

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