Some Initial Results from an Electromagnetic Model of the LWA Station Array

Steve Ellingson*

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*Bradley Dept. of Electrical & Computer Engineering, 302 Whittemore Hall, Virginia Polytechnic Institute & State University, Blacksburg VA 24061 USA. E-mail: ellingson@vt.edu

1 Introduction

It has been known since LWA Memo 67 [1] that the antennas within an LWA station are likely to experience significant levels of mutual coupling. However, it is not yet clear if any special measures are required or useful in the per-stand processing prior to "full RF" beamforming to account for this. The station electronics can be much simpler if the differences in the responses of antennas can be neglected; in particular, if the differences in polarization response as a function of frequency can be neglected [2].

LWA Memo 140 [3] considered the impact of mutual coupling on the ability to perform per-stand calibration prior to beamforming, using the scheme discussed in LWA Memos 106 [4], 107 [5], and 138 [6]. It is found that for a stand near the center of the array, the requirements in terms of the length of FIR filters is about the same, and that the mutual coupling does not seem to have much effect on the ability to convert the "raw" voltage signals provided from each dipole into standard left- and right-circular polarizations. However, this is not the same as saying that mutual coupling does not significantly affect the polarization response; Memo 140 only shows that mutual coupling does not have much impact on the performance of this calibration. Furthermore, only one stand near the center of a 64-stand version of the array was considered. Thus, Memo 140 does not have much to say about the performance of a "full RF" beamforming scheme in which the differences in per-stand polarization response are neglected.

In this memo we present some initial results from an attempt to characterize the stand-to-stand variations in the response of antennas in an LWA station array. The goal is to obtain this information in the form of stand-to-stand variation as a function of frequency, since this is the data needed to make a decision as to whether it is reasonable to abandon per-stand (pre-beamforming) polarimetric calibration, as is proposed in Memo 143 [2]. We present here some initial results at only one frequency, however. This is in part to provide a progress report on the effort, since several CPU-weeks are required to obtain the goal information. This memo also serves as advance notice on the scope, assumptions, and limitations of the study.

2 Array Model

In this study, the LWA station array is modeled as 256 dual-polarization stands arranged according to the same geometry considered in previous memos including Memo 67 (see there for a diagram). This is a pseudorandom geometry in which the 256 stands are contained within a circle of diameter 100 m, and are constrained to have minimum spacing of 4 m. It is understood that an elliptical geometry with semi-major and semi-minor dimensions of 110 m and 100 m respectively, and with 5 m minimum spacing, is currently planned [7, 8]. However, the specific stand locations are not yet decided. The station array will be surrounded by a fence with 5 m minimum separation from the stands [7], and it is known from LWA Memo 129 [9] that the fence can have a significant impact on the antenna patterns. The fence model from Memo 129 will be included in the completed analysis, but is not included in the results shown in this memo. It is also known from LWA Memo 141 [10] that the shelter can also have a significant effect on the antenna patterns. The effects of a shelter are not considered in this memo, but if the size, position, and orientation of the shelter with respect to the array can be determined very soon, it can be included in the completed analysis.

Stand design is not completely determined at present. This is actually not of much consequence in this study since the proposed "tied fork" dipole design, when replicated 512 times, results in a model with prohibitively-large computational burden and high potential for subtle numerical difficulties when analyzed using the moment method (e.g., NEC2 or NEC4). Therefore, a simple dipole model is used instead. In this model, each dipole is a perfectly-conducting cylinder 3.947 m long and 6 cm in diameter. This is roughly equivalent to a "blade"-type antenna having blade width of 2 × 6 cm = 12 cm [11]. The center 15 cm is the feedpoint region, and is horizontal to the ground. The "arms" on either side bend downward at a 45° angle. In the coordinate system used in this memo, dipoles are aligned parallel to the x and y axes, with z pointing toward the zenith. The feedpoint heights of x- and y-aligned dipoles is 2.019 m and 1.929 m respectively; that is, the entire dipole is shifted up or down slightly to prevent feedpoint wires from intersecting or becoming too close to be properly modeled. The ground is assumed to be an infinite flat surface of perfectly-conducting material.

NEC2 is used to perform the analysis. The 15-cm-long feedpoint wire is divided into three segments, and the center segment is loaded with a series impedance of 100 Ω, modeling the FEE input. Each dipole arm is divided into 10 segments, which is appropriate for frequencies up to 88 MHz. The design of the dipole and its segmentation were carefully reviewed with respect to known NEC design guidelines and limitations, and the model was analyzed in a preliminary study to confirm it's numerical stability over the frequency range 10–88 MHz. The complete array model (but not yet including the shelter and fence) uses about 12,000 segments and requires roughly one hour to run (on my 2007-vintage dual-core Centrino-based laptop, running Ubuntu Linux) for each frequency of interest.

A reasonable question to ask is "How well does this model describe arrays consisting of stands based on the "tied fork" dipole concept, with each stand over a small ground screen?" The answer, unfortunately, is extremely difficult to answer in a satisfying way. Qualitatively, the behavior is expected to be very similar with similar trends. Quantitatively, based on experience, the results are expected to agree within 10%–20% over most of the frequency of interest, since the antennas are very similar from an electromagnetic perspective. The tied-fork dipole is likely to have somewhat broader impedance bandwidth, so the greatest discrepancies in impedance are likely to occur at the highest and lowest frequencies, and the greatest discrepancies in pattern will occur at the highest frequencies. Regardless of all of these points, the issue is essentially moot as the tied-fork design would require about 3 times as many segments, resulting in computational burden which is roughly $3^3 = 27$ times greater. Changing from an infinite perfectly-conducting ground screen to 256 separate ground screens with intervening exposed earth makes the computation altogether intractable without extraordinary measures; e.g., moving to a computer cluster. An additional issue favoring the use of the simple dipole + infinite ground model over a closer-to-true model is that conventional tests for model "reasonableness" and numerical stability are correspondingly difficult to carry out for the latter. Thus, we are essentially trading off decreased model detail for both speed and increased confidence in the results.

3 Results

The array was analyzed at 38 MHz. H-plane (in this case, $y - z$ plane) co-polarized patterns were determined for the x-oriented dipoles. As a preliminary test to validate the model, this was done three different ways. First, the result was computed for a single stand by itself ("standalone") in *transmit* mode – that is, the gain was determined by applying a voltage source at the feedpoint (in lieu of the load) and measuring the pattern in the far field. Next, the result was computed for the "standalone" case in *receive* mode – that is, by measuring the current induced in the 100 Ω load attached to the antenna terminals (now without voltage source) in response to an incident plane wave. Finally, the receive mode result for a stand near the edge of a *modified version* of the full station array was computed – in this case, the x-y coordinates of the stands is multiplied by 100, such that the minimum spacing between stands is 400 m. If everything is working correctly, the coupling in the third scenario should be negligible and all three results should be very close.

The outcome is shown in Figure 1. First, note that the three cases described above do in fact produce results which are very close. Although this is hardly a comprehensive test for validity, we can have greater confidence that the method produces results which are reasonable; e.g., numerically well-conditioned and consistent with physical intuition. Second, note that the result for receive-mode pattern calculation of the same dipole from case 3 in the *actual* array (i.e., with 4-m minimum

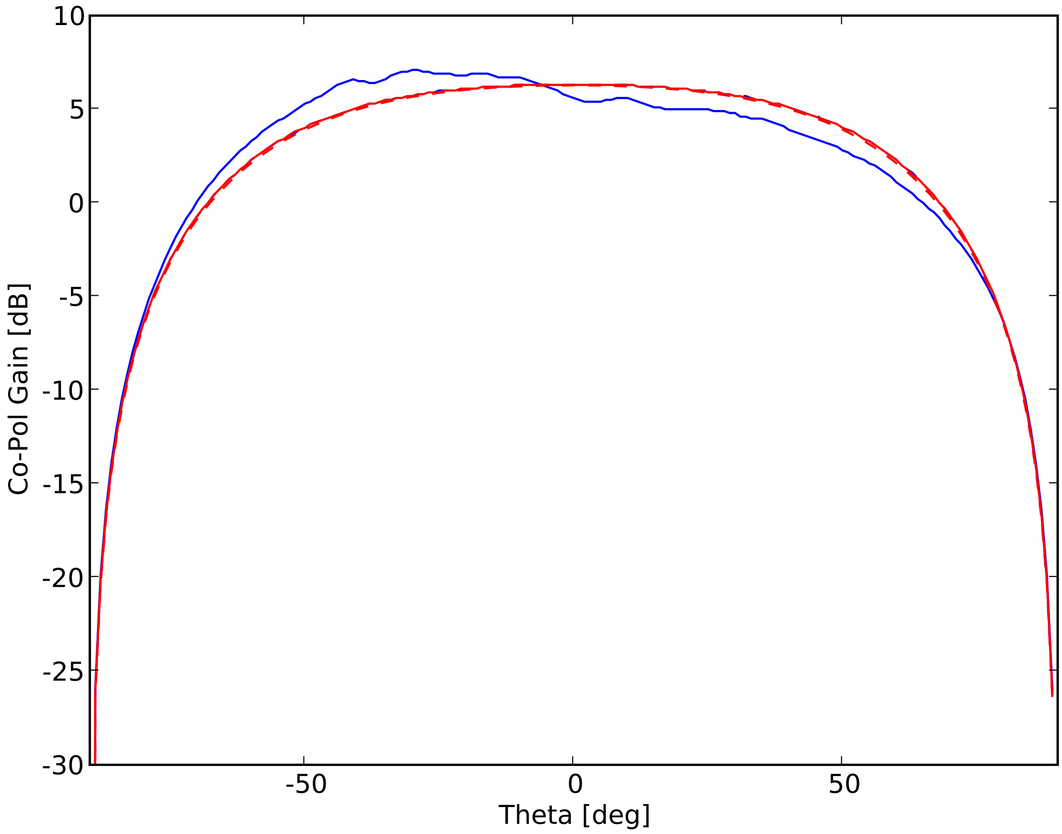

Figure 1: H-plane co-polarized gain for four separate cases. "Theta" is angle measured from the zenith. The first three cases produce curves which lie nearly on top of each other; these are (1) standalone, transmit-mode; (2) standalone, receive-mode; and (3) a stand near the edge of a station array whose spacings have been scaled up by a factor of 100, receive mode. The fourth case corresponds to case (3) repeated except now using the actual spacings, with the result that the coupling is now strong enough to produce an asymmetry in the pattern.

spacings) is also plotted, and is significantly different. The difference can be attributed to mutual coupling. Note that the ripple rate is on the order of 10 degrees, which suggests that most or all of the array contributes significantly to the pattern of this dipole. In other words, it is *not* reasonable to assume that the coupling is determined primarily by just the closest stands.

From this point forward, we consider dipoles in the actual station array, and analyze them in receive mode (i.e., patterns calculated from feedpoint currents induced by incident plane waves). Figure 2 shows the H-plane co-polarized pattern for all 256 x-oriented dipoles in the station array. The gain in each case is normalized by the pattern of the corresponding dipole in the standalone case; so, for example, the gain in the "standalone" case would be a constant value of 0 dB in this presentation. Note that the effect of coupling is quite variable and becomes large in many cases, increasing gain by as much as 2 dB in some places and decreasing gain by as much as 4 dB in others.

Another result from this initial series of tests is shown in Figure 3. In this figure, we consider one value of theta at a time, and each stand is represented as a marker whose coordinates are the gains

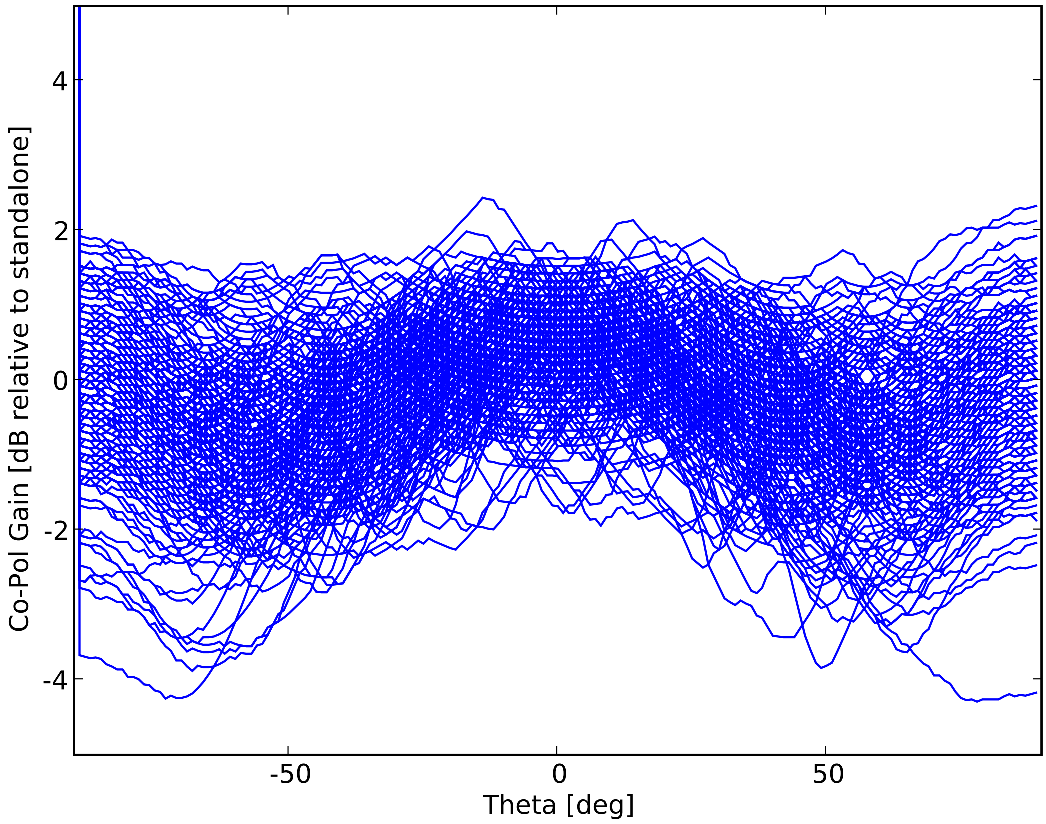

Figure 2: H-plane co-polarized gain for all 256 x-oriented dipoles in the station, normalized with respect to the gain of the corresponding dipole in the standalone scenario.

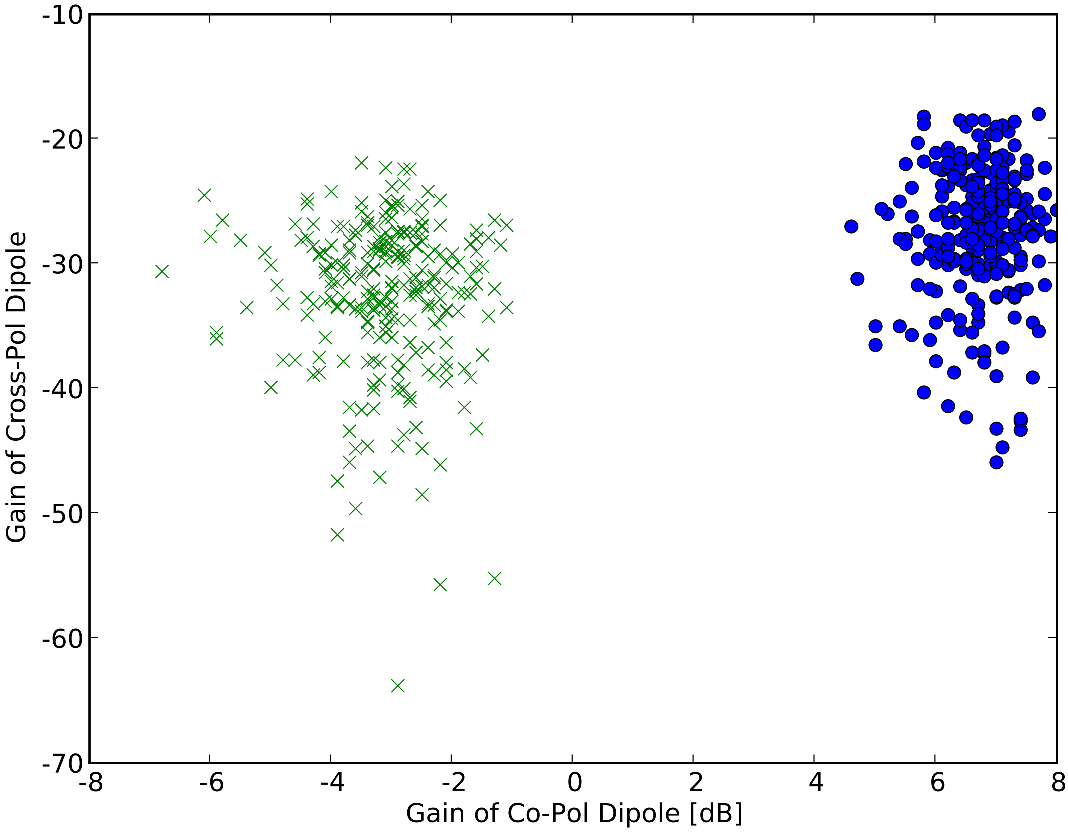

Figure 3: The gain of the cross-polarized dipole vs. the gain of the co-polarized dipole of the same stand, with each marker representing one stand in the array. The blue circles are for a plane wave arriving from the zenith, whereas the ×'s are for a plane wave arriving 74° from the zenith.

of it's x- and y-oriented dipoles for that pattern angle. Two pattern angles are considered: The zenith, and 74° from the zenith, both in the H-plane. The extent of scatter in these points indicates the extent to which mutual coupling affects the polarization of each stand separately. That is, in the absence of mutual coupling, there would be only one marker visible for each pattern angle since all stands would in that case have the same response.

4 Concluding Remarks

As explained in the introduction, these results do not yet provide an answer to the question of whether per-stand polarization is required prior to full-RF beamforming, since the frequency dependence is a big part of that question. As discussed above, that work is underway and the intent of this memo is only to provide a progress report with some initial results.

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