In-Situ Calibration of Active Electronically Scanned Antenna Arrays Through SAR Imaging

Duncan Madden and Kamal Sarabandi
Electrical and Computer Engineering
The University of Michigan
Ann Arbor, Michigan
Email: dmadd@umich.edu

***Abstract*—*In situ* array antenna calibrations are methods devised to calibrate fielded arrays that cannot be accessed or must be calibrated frequently due to rapidly changing environmental conditions, such as those mounted on air/space-craft. There is no existing method that maintains optimal operation in real time and works for diverse array configurations without relying on extraneous fielded equipment and without requiring modifications to the array hardware. As a solution to this problem for arrays mounted on flying platforms, we propose to use backscatter measurements of the terrain within the array's field of view, along with the relative motion of the array with respect to the ground to form synthetic aperture radar (SAR) images to use as calibration targets. Because the ground below is always visible, calibration can be accomplished at any time. A common transmitter/receiver element (or an ensemble of them) can be used to form an image with each receiver/transmitter element. Corresponding pixels between co-registered images can be used as calibration targets to determine amplitude and phase variations across the array. The measured channel imbalances can be averaged over the many pixel pairs (where each pair is used as a calibration target) to reduce the effects of system noise and fading on the measurements. The proposed method is validated with laboratory measurements where we demonstrate the ability to measure receiver channel imbalances between two antennas using SAR images of a random rough surface distributed target. Amplitude and phase differences in the receivers are recovered within a fraction of a dB and fraction of a degree, respectively.**

I. INTRODUCTION

Active antenna arrays are affected by numerous sources of error, such as gain and phase variations caused by temperature changes, component aging, and physical deformations which degrade their performance. Array calibrations aim to compensate for these errors to restore the array to an optimal performance state. For arrays that operate in transient environments where the sources of error change rapidly or are deployed such that they cannot be easily accessed – such as those mounted on aircraft and spacecraft – the problem of real time calibration becomes more challenging and is still open. Array calibration considerations can become a burdensome design constraint if the system must be modified to accommodate hardware and routines necessary for calibration steps. Therefore, an ideal calibration method would rely on only the signals available at the array during its normal fielded operation.

Array calibration methods can be divided into two categories based on the method through which channel imbalances are measured: internal calibrations and external calibrations. Internal calibrations use measurement channels limited to the vicinity of the array, such as the mutual coupling between elements [1], [2], embedded near-field monitoring probes [3], [4], or dedicated circuitry after the antenna feeds [5]. External calibrations use external signals or targets to equalize the transmitted or received signals at each element [6], [7]. Internal calibration methods have proven to be convenient, however, there are limitations that restrict their application to certain array geometries and conditions. Additionally, internal methods cannot calibrate for external errors, such as the effects of the array platform or the effects of nearby scattering objects. External calibrations are more accurate in that they also account for the effects external to the array as seen by an observer in the far-field. A probe or known target in the far-field is used to sample embedded far-field patterns of each array element, which are then equalized. These approaches are suitable for arrays with irregular geometries or non-identical elements. However, they require the knowledge of the accurate positions of isolated targets in the absence of clutter, which are hard to come by if not strategically placed. These limitations have restricted external calibrations from being viable *in situ*.

We proposed in [8] to form images of distributed targets in the scene below arrays mounted on flying platforms to generate external calibration targets. The ground below will always be visible, so calibration can be accomplished at any time. Images can be formed using pairs of elements, where one element (or ensemble of elements) transmits/receives and each other element receives/transmits. This forms a set of images where each image shares the same reference transmitter/receiver, and thus differences between the complex pixels in the images can be attributed to receiver/transmitter differences. Corresponding individual pixels between co-registered images can be used as calibration targets to measure channel imbalances. Due to the random amplitudes of scattering from random rough surfaces, pixels will have amplitudes above or below the noise floor. Pixels below the noise floor can be rejected, and pixels above the noise floor can be averaged together to reduce the effects of noise. Because thousands of pixels can be generated from a single image, the ability to average significantly enhances estimations of channel imbalances. Here we present experimental results from a laboratory setting that confirm the ability to use this novel approach to measure channel imbalances between antennas.

II. Validation Measurement Setup and Results

To validate the proposed approach, we construct a system with two antennas, where "Antenna 1" acts as a transceiver and "Antenna 2" acts as a receiver. A distributed rough surface target is rotated over a range of angular positions inside of an anechoic chamber to form a SAR imaging setup where the antenna appears to move along an arc of constant radius. Two backscatter measurements are collected in each position. Antenna 1 is transmitting for both cases, but the receiver is switched between Antenna 1 and Antenna 2 to collect a monostatic measurement and a bistatic measurement. The back-projection algorithm is used to form images of the rough surface from this data. A baseline comparison image is formed by comparing respective pixels in the monostatic and bistatic images, which are averaged to measure channel imbalances between the antennas. Then, an attenuator is inserted into the receiver of Antenna 2 to introduce a measurable change to the channel imbalances. The insertion magnitude and phase of the attenuator are measured in isolation. The measurements and image formation steps are repeated with the attenuator inserted, then compared to the baseline to verify that the change in channel imbalances indeed matches the measurements of the attenuator in isolation. The system operates from 7.75 GHz to 10.75 GHz in 401 frequency steps. The antennas are identical horn antennas, each about a meter long. The target is a 0.9 meter diameter circle of pea-rocks glued to styrofoam and sprayed with conductive paint.

Fig. 1 shows histograms of the amplitude and phase channel imbalances measured by comparing corresponding pixels in co-registered images. In each plot, there is a histogram which shows the baseline measurement (before an attenuator is added to the receiver of Antenna 2) and a histogram which shows the same measurement after the attenuator is added. Seen in plot (a), the mean amplitude ratio between pixels in the monostatic and bistatic images shifts by -2.808 dB. Similarly in plot (b), a mean phase difference shift of -55.024 degrees can be seen. The attenuator insertion amplitude and phase were measured in isolation and averaged over frequency, and are -3.164 dB and -54.217 degrees, respectively. Clearly, the procedure is able to recover the change in channel imbalances between the receivers accurately.

III. Conclusion

The experiments presented here validate the effectiveness of a novel method to measure channel imbalances between active antenna array elements for *in situ* external calibration. The potential to use this approach to calibrate arrays mounted on aircraft and spacecraft anywhere and in real time is an exciting development in array calibration methods which avoids array shape constraints, does not require modification of the array hardware, and does not require calibration targets in known locations. Because the ground below is an external target, the calibration can include all decohering effects on the array. The ability to average over many generated pixels allows amplitude and phase channel imbalances to be measured within a fraction of a dB and fraction of a degree, respectively.

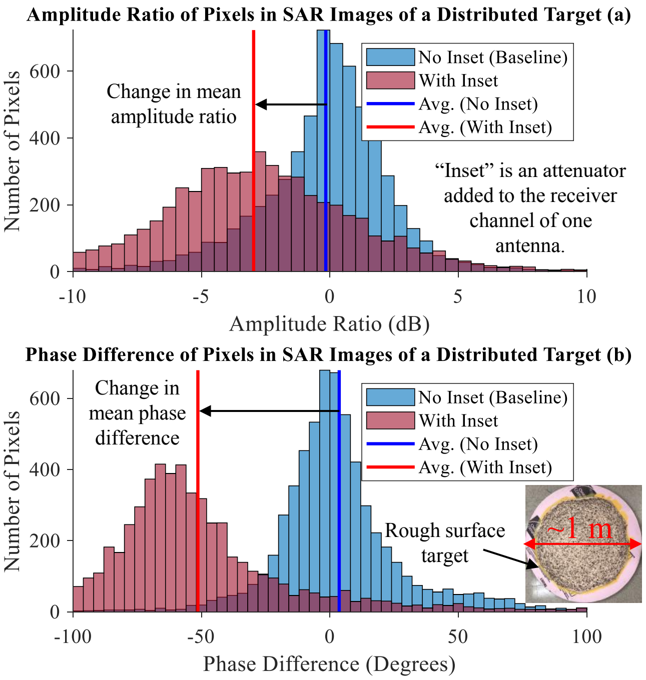

Fig. 1. Monostatic and bistatic images are compared at respective pixels. This produces a comparison image, which shows the amplitude ratios and phase differences at each pixel. These histograms show: (a) the histogram of amplitude ratios among pixels before and after an attenuator is added to the receiver of Antenna 2. The measurement made before the attenuator is added acts as a baseline, and the attenuator introduces a measurable shift to channel imbalances. (b) shows the same, but for phase differences among pixels. The mean amplitude ratio and phase difference each shift according to the channel imbalance added by inserting the attenuator. The distributed target used to form the images can be seen in the corner of (b).

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