A New Approach for In-Situ Scan Impedance Characterization of Scanned Antenna Arrays

Thomas E. Christian, Jr
ISR EM & Sensor Tech. Org.
Sandia National Laboratories

University of New Mexico
Dept. of Electrical and
Computer Engineering

Albuquerque, NM, USA
tec@unm.edu

Hung Loui
ISR EM & Sensor Tech. Org.
Sandia National Laboratories
Albuquerque, NM, USA

C. G. Christodoulou
University of New Mexico
Department of Electrical and
Computer Engineering
Albuquerque, NM, USA

Dale F. Dubbert
ISR EM & Sensor Tech. Org.
Sandia National Laboratories
Albuquerque, NM, USA

***Abstract* — Scanned phased array antennas require active scan impedance determination and mitigation. This paper addresses the former by introducing a novel in-situ measurement architecture and associated mathematics for efficiently determining the real-time active scan impedance of arbitrary sized scanned arrays in the field. The in-situ nature of the proposed architecture reduces the need for large numerical simulation and/or estimation of scan impedance variations due to possible diverse antenna array placement in the field. Direct experimental characterization also enables direct validation of numerical simulation. The mathematics developed are for an M by N antenna array utilizing direct in-situ mutual coupling characterization. The mathematical model was implemented in MATLAB and verified through simulation using CST Microwave Studio (MWS) for a 2x2 monopole planar antenna array. The model's robustness is tested by varying the inter-element spacing.**

I. INTRODUCTION

Mutual coupling characterization of scanned phased array antennas is essential in order to determine the impedance mismatch at desired reference locations as a function of scan angle in spherical coordinates (θ, ϕ). The ability to measure mutual coupling as the array is placed in different environments and/or locations benefits from an in-situ mutual coupling measurement system. To illustrate this, a simple 2x2 planar monopole antenna array is retrofitted with single-pole triple-throw terminated RF-switches at each antenna port reference location and connected using two corporate-fed networks to a 2-port PNA (see Figure 1). The concept can easily be expanded out for an arbitrary number of elements, P. The two corporately-fed networks and associated switches essentially become a 2 by P in-situ microwave test set, where P = M x N number of connected elements. The loss and imperfections of the power dividers, feed networks, and RF switch matrices of the test set may be removed using error correction [1]. Impedance renormalization is then used to correct for the imperfect terminations of unused antennas post measurement [2].

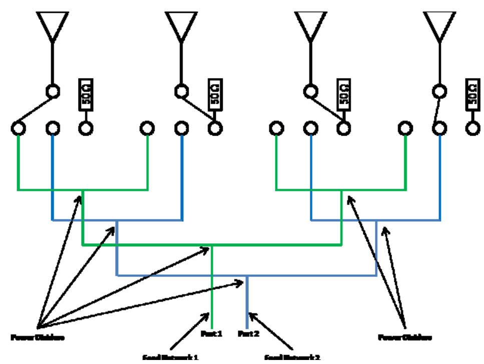

Figure 1. In-Situ mutual coupling measurement system, example configuration.

II. MUTUAL COUPLING, SCAN REFLECTION COEFFICIENT, AND SCAN IMPEDANCE

Scan impedance relates to the scan reflection coefficient by the well-known relationship

$$Z(\theta, \phi) = Z_0 \frac{1+\Gamma(\theta,\phi)}{1-\Gamma(\theta,\phi)}, \quad (1)$$

where, Z_0 is the port impedance and $\Gamma(\theta, \phi)$, is the scan reflection coefficient. The scan reflection coefficient in turn can be expressed in terms of mutual coupling coefficients obtained through scattering parameter simulations or measurements by an elegant matrix formulation. Other forms for a linear array can be found in [3].

In general the voltage reflection coefficient, Γ, can be written as the amplitude of the reflected voltage wave normalized to the amplitude of the incident voltage wave [4],

$$\Gamma = \frac{V_0^-}{V_0^+}. \quad (2)$$

This can be directly related to the diagonal elements within a scattering matrix from a simulation or measurement of an antenna array. In the case of an antenna array, the scattering

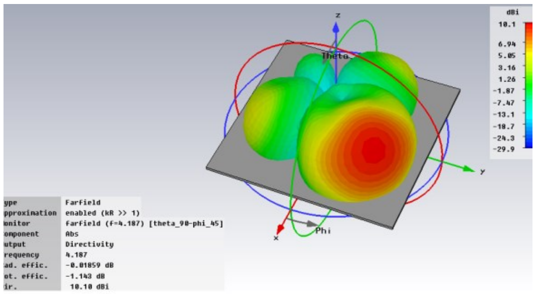

Figure 2. Main beam at θ = 90° and ϕ = 45°.

matrix diagonals represent the reflection coefficients at each antenna port and the other elements of the scattering matrix represent the coupling or transmission between antenna elements. Normal scattering parameters are determined while loads/terminations are applied to non-active ports, but the scan reflection coefficient takes into account the effects of the other ports while they are “active”. The scan reflection coefficients at each antenna port can be solved for by the following relationships using the generalized scattering matrix formulation,

$$\begin{bmatrix} b_1'' \\ \vdots \\ b_m'' \end{bmatrix} = \begin{bmatrix} S_{11}' & \cdots & S_{1n}' \\ \vdots & \ddots & \vdots \\ S_{m1}' & \cdots & S_{mn}' \end{bmatrix} \begin{bmatrix} a_1'' \\ \vdots \\ a_m'' \end{bmatrix}. \tag{3}$$

Where b'', S' and a'' represent respectively the active reflected wave, the standard scattering parameter matrix of the antenna, and the active incident wave. The active reflected wave, b'', can be solved for using S' and a'', where a'' is defined by the array factor’s magnitude and phase at each element in terms of θ, and ϕ in spherical coordinates. At this point it is rather straightforward to solve for the scan reflection coefficient, Γ'', by using the following matrix equation where the “./” operator indicates element-wise division. Scan impedance can then be determined by (1)

$$\begin{bmatrix} \Gamma_1'' \\ \vdots \\ \Gamma_m'' \end{bmatrix} = \begin{bmatrix} b_1'' \\ \vdots \\ b_m'' \end{bmatrix} ./ \begin{bmatrix} a_1'' \\ \vdots \\ a_m'' \end{bmatrix}, \tag{4}$$

III. CST MWS Results Compared to MATLAB

CST MWS was used to generate the scattering matrix (S') from the model of a 2x2 monopole array antenna. CST MWS was also used for simultaneous excitation of all antenna ports with a specific amplitude and phase (or time delay) to generate “active” scattering parameter results which are equivalent to scan reflection coefficients, as well as scan the radiation pattern of the array to specific direction θ, and ϕ. S' was then exported and read into MATLAB where the scan reflection coefficients are determined using (3) and (4). Example results are shown in Fig. 2 – 4 with the main beam of the monopole array pointed at θ = 90° and ϕ = 45°.

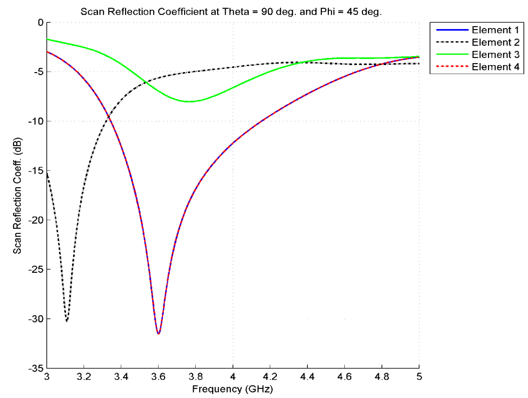

Figure 3. CST MWS Scan Reflection Results

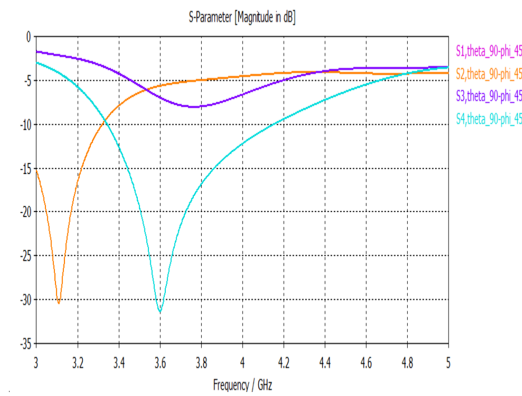

Figure 4. MATLAB Scan Reflection Results

IV. Monopole Spacing Study

In addition to this topic, the scan reflection coefficient mathematics have been used for a monopole spacing study. The study uses the effects of mutual coupling to determine the optimal array element spacing required to minimize mutual coupling effects while maintaining impedance match.

References

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