Analytical Estimation of Radar Cross Section of Dipole Array with Parallel Feed

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Abstract— **The scattering characteristics of a phased array depends on its design parameters including its feed. In this paper, the radar cross section of dipole array with parallel-feed network is calculated. The scattered field is obtained by in terms of reflection and transmission coefficients at each component level of the array system. The mutual coupling effect is considered. Scattering till second level of couplers in feed network is taken into account. The analysis presented can be useful in low RCS phased array design.**

I. Introduction

The scattering behavior of phased array depends on its geometry, its frequency of operation and the employed feed network. Moreover for a phased array operating at frequency equal to that of the radar, the effect of array geometry and the feed network become prominent. In general, the feed network comprises of orderly arranged radiators, phase shifters and couplers. As all these devices will not possess identical terminal impedances, significant mismatches might exist at each level of the feed network. This results in the reflection of the incident signal as it propagates from the array aperture towards the receive port. These individual scattered fields at different levels of array system add-up coherently under certain scenarios to yield a significant scattering cross section.

Several techniques have been reported in open domain to estimate and optimize the radar cross section (RCS) of the phased array [1], [2]. However the contribution of each individual components of the array system towards the total RCS is not discussed. This paper presents the estimation of RCS of a parallel fed dipole array in terms of its design parameters, and reflection/ transmission coefficients at each level of array system. In addition, it provides an insight of the dependence of RCS pattern on the array design parameters like dipole-length, inter-element spacing, or terminating impedance.

II. RCS of Parallel-Fed Dipole Array

The scattered field of a x-polarized n^{th} dipole [4] is given by

$$\vec{E}_n^s(\theta,\phi) = \left[\frac{j\eta_0}{4\lambda Z_{a_n}}\left(\int_{\Delta l}\mathbf{cos}(kl)dl\right)^2(\mathbf{cos}\,\theta)\vec{E}_n^r(\theta,\phi)\right]\frac{e^{-j\vec{k}\vec{R}}}{R}\hat{x} \qquad (1)$$

where λ is the wavelength, η_0 is the impedance of free space, k $=2\pi/\lambda$, $\vec{k}$ is the propagation vector, R is the distance between the target and the observation point, l is the dipole length, $\vec{E}_n^r(\theta,\phi)$ is the total reflected field towards the aperture, and Z_{a_n} is the impedance of n^{th} dipole. The RCS of the dipole array is expressed as

$$\sigma(\theta,\phi) = 4\pi\left|F\sum_{n=1}^{N}\vec{E}_n^r(\theta,\phi)\right|^2 \quad ; \; F = \frac{j\eta_o}{4\lambda Z_{a_n}}\left(\int_{\Delta l}\mathbf{cos}(kl)dl\right)^2\mathbf{cos}\,\theta \qquad (2)$$

The total reflected field $\vec{E}_n^r(\theta,\phi)$ in (2) comprises of the fields scattered due to the mismatches prevailing within the feed network. This factor can be computed by moving along the signal as it enters the array feed network; separately at each level. Passing through the radiators and phase-shifters, the signal from each element reaches the input arms of the couplers. In a parallel feed, a single coupler interacts with multiple elements; unlike one element per one coupler in case of the series feed [4]. Further the number of couplers at q^{th} level of an N-element dipole array is given as $N/2^q$. In order to estimate the reflected field due to mismatches at the coupler level, the nature of the couplers, their positions in the feed network and the impedances at their ports are to be considered. The magnitude of reflected field, at any junction mismatch, is expressed in terms of the impedances seen by the signal during its path. These terminal port impedances can be obtained using the two-port analogy for each pair of coupler ports contributing for the reflections. The scattered signals at each of the levels can then be superimposed to arrive at the total RCS of the phased array.

III. Results and Discussion

First the RCS of parallel-fed 32-element equal-length ($\lambda/2$) dipole array is compared with that of random-length dipole array (Fig. 1). The dipoles at odd and even positions in the array are arranged at heights of $\lambda/4$ below and above the reference line, respectively. The dipoles are spaced 0.4λ apart and are excited by uniform distribution. It can be observed that the RCS level in case of random dipoles is lesser (=9.4670 dB) than that for $\lambda/2$ dipole array (=15.3645 dB). Although at other aspect angles, the level of scattering in the random-length array exceeds that of equal-length array, the level is well below 0dB, and hence less significant.

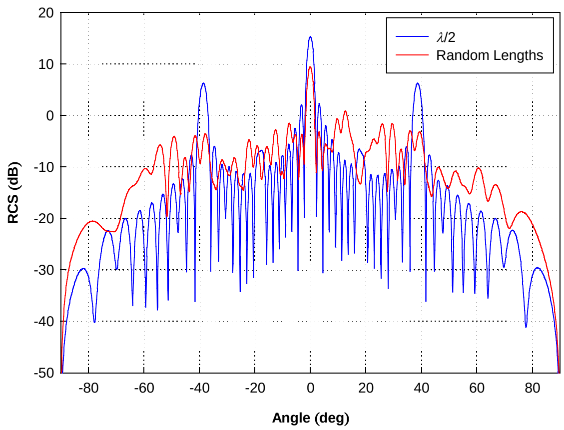

Fig. 1. Comparison of broadside RCS pattern of equal and random length dipole arrays

Next the role of mutual coupling in unequal-length dipole array with parallel feed network is analyzed for a 16-element array with odd-positioned dipole lengths incrementing consistently by $0.01\lambda/3$, starting from $\lambda/3$. Further the dipole lengths at the even-positions decrement consistently in the steps of $0.01\lambda/2$ starting from $\lambda/2$. All the dipole elements are at the height of $\lambda/4$ above the reference plane and are excited as per cosine squared distribution. The inter-element spacing is taken as 0.4λ. The characteristic and load impedances are assumed to be 75Ω and 200Ω, respectively. Fig. 2 shows the resultant broadside RCS pattern with and without mutual coupling.

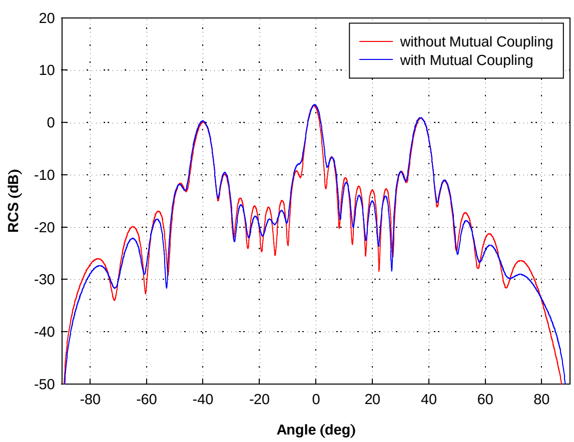

Fig. 2. Comparison of broadside RCS pattern of 16-element unequal length linear parallel-fed dipole array for with and without mutual coupling effect

Next the effect of terminating impedance on the RCS pattern of the dipole array is analyzed. A 32-element array is considered, in which the dipoles are of alternating lengths $\lambda/2$ and $\lambda/3$. The spacing between the array elements, excited by Dolph-Chebyshev distribution (-40 dB SLL) is taken as 0.3λ. The characteristic impedance is 75Ω while the terminating impedance is varied. The RCS levels (Fig. 3) are shown as contour plots for the terminating impedances of 30Ω, 100Ω and 200Ω. It can be observed that the RCS level, indicated by color, decreases, as the impedance value is increased to 100Ω from 30Ω. However when the impedance value is increased further to 200Ω, the level of RCS increases. This indicates that the there is a limiting value of terminating impedance that results in optimum array RCS.

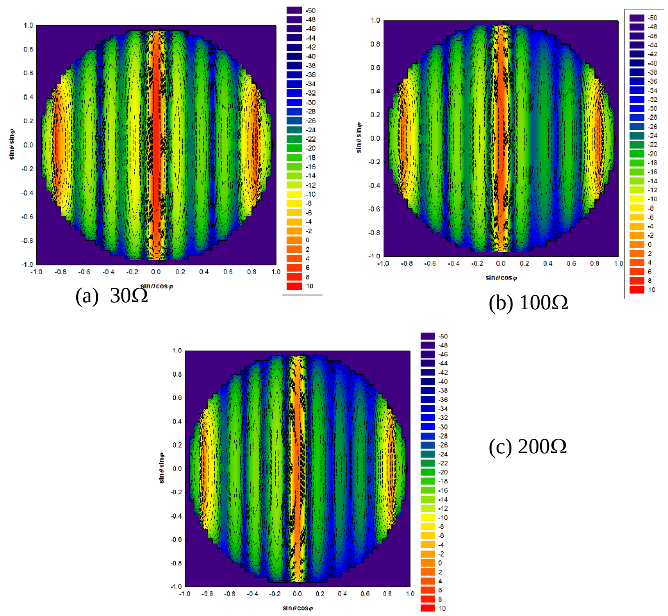

Fig. 3. Broadside array RCS of parallel-fed unequal-length dipole array

IV. CONCLUSION

This paper presents the analytical estimation of array RCS technique to compute the RCS of linear uniform dipole array. The formulation presented holds good for both unequal and equal length dipole arrays arranged in any random configuration. The reflections within the antenna system and the mutual coupling effect are taken into account to arrive at the total RCS of the array. The dipole dimensions, geometric configuration, components, and terminating impedance are the possible design parameters that can contribute towards array RCS control.

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