Investigation of the High Frequency Radiative Capabilities of a Two Mast Canonical Superstructure

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***Abstract*— This paper investigates high frequency (HF) radiation capabilities of a two mast, canonical ship using characteristic mode theory and distributed array design. Two ring arrays of 18 electrically small dipole radiators (.1λ) are designed to be circularly distributed between a two mast canonical shipboard structure. Consequently, the entire superstructure becomes the main radiator where its radiative capabilities can be controlled from its two mast superstructure. The two masts are spaced approximately .3λ from one another at the design frequency of 3.4 MHz. Numerical simulations are performed using MATLAB, HFSS, and FEKO computational electromagnetics software in order to demonstrate and examine the radiative and beam steering modal pattern characteristics.**

I. Introduction

Distributive (collaborative) beamforming is developing as one of the most popular techniques in applications of wireless communications and array technologies [1-2]. A necessity is growing for networking with multi-functionality, and integrated value into many modern applications such as communications, data-links, and radar systems. To create a distributed antenna environment, one applies the necessary phase coefficients to each of the radiators. Once each stand-alone transmit/receive module is phased appropriately, the array's ability to beamform can be exploited for enhanced range and bandwidth capability (compared to more modern periodic and thinned array architectures). For this work simulated beamsteering capabilities of a two mast canonical shipboard superstructure is investigated using characteristic mode analysis.

I. Expected Value of a Ring Topology

The mathematical derivation (1) for a circular bound, ring distributed array (RDA) with radius A has been shown in previous works [1-2] and explains the process for determining the performance characteristics of such array topology.

$$\bar{U}(\theta,\phi) \overset{Ring}{=} \frac{1/N + (1-1/N)}{\neg\mathrm{rinc}(x) = J_0(x)} \left[|\mathrm{rinc}(u)|^2 \, |\mathrm{rinc}(v)|^2 \right]$$

$$u = \hat{\mathrm{x}} \cdot \cos\vec{\psi},\ v = \hat{y} \cdot \cos\vec{\psi},\ w = \hat{z} \cdot \cos\vec{\psi},\ 1 = \sqrt{u^2 + v^2 + w^2} \quad (1)$$

$$\cos\vec{\psi} = kA\left(\hat{\mathrm{r}}(\theta,\phi) - \hat{\mathrm{r}}(\theta_0,\phi_0)\right)$$

The Jacobi polynomials are orthogonal with respect to $(1\text{-}x)^{\alpha}$ $(1+x)^{\beta}$ on the interval [-1, 1] and produce special cases of the Gegenbauer, Legendre, Zernike and Chebyshev polynomials. For example, the Gegenbauer polynomials (ultraspherical harmonics) are provided in (2) and will be utilized in the following section for its unique ability to orthogonalize the circular topologies.

$$f_X(x) = \alpha\left(1 - x^2\right)^{\lambda - 1/2} C_n^{\lambda}(x) \quad (2)$$

II. Characteristic Modes a Ring Topology

The ring distribution ($\lambda = 0$) of (2) naturally exploits the Chebyshev modes of the 1st kind as provided in (3). These Chebyshev polynomials form an orthonormal basis on the appropriate Sobolev space bounded between $-1 \le x \le 1$. Hence, they are an orthogonal polynomial set with respect to the weighting function $(1\text{-}x^2)^{-1/2}$. The characteristic modes found from taking the expected value of (3) grow in increasing normalized Bessel order for even distributions (4). A visual representation of the distributions of which excite these modes is provided in Figure 1.

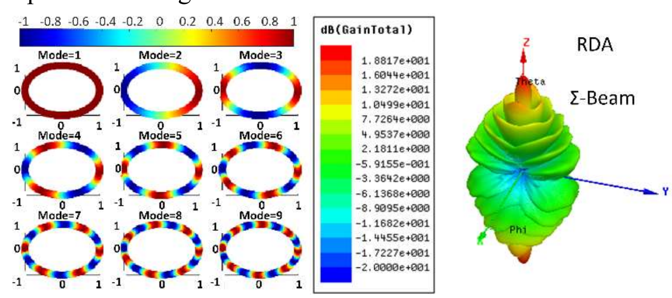


Figure 1. Characteristic distributions of a ring (left); and characteristic function (n=1) (right).

$$f_X(x) = (-j)^n \, T_n(x) \Big/ \left(\pi\sqrt{1 - x^2}\right) \quad (3)$$

$$\Lambda(\Psi)_{Even} = J_n(\Psi) = \int_{-1}^{1} f_X(x) \exp(-jx\Psi)\,\mathrm{d}x \quad (4)$$

III. System Model and Simulated Results

We investigate a two mast canonical ship in the high frequency band using two RDAs with design frequency of 3.4 MHz as shown in Figure 2. This makes the associated separation between the two mast structures to be spaced approximately .3λ apart with normalized aperture radii (A/λ) of approximately .07. These two masts approximate a theoretically synthesized quarter wave two-element array distribution. Hence, the beamsteering capabilities of this design is shown in Figures 3 - 4. Results were obtained from applying characteristic mode and pattern behavior of (1) with each antenna array composed of $N = 18$ center fed small dipole elements (.12λ). Each excitation point is approximately a height of .06λ above the ship's deck, making each vertical element approximately double in length and improving its radiation capabilities.

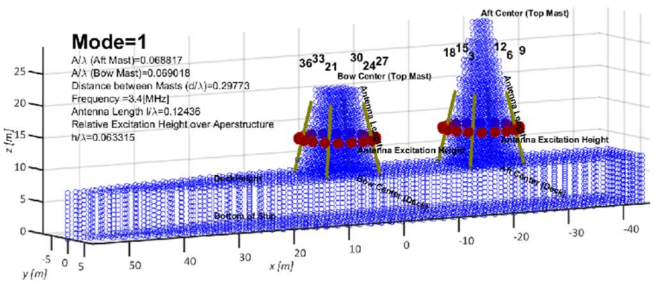


Figure 2. Two mast canonical shipboard structure with ring distributed antenna arrays of N=18 center fed dipole elements.

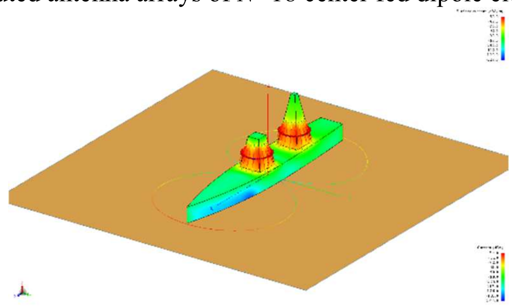


Figure 3. Mode 1 steered at θ_0=90° and ϕ_0 = 0°.

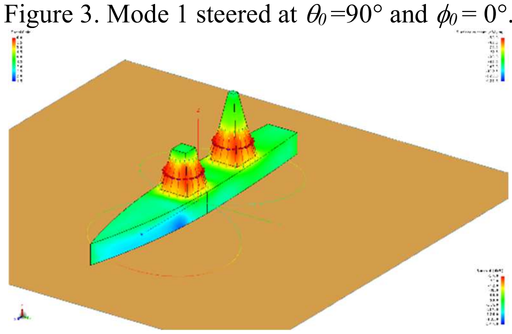
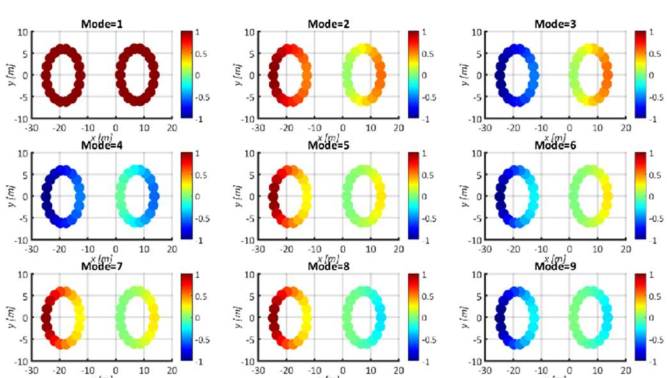


Figure 4. Mode 1 steered at θ_0=90° and ϕ_0 = 45°.

As a last point of comparison for the analytical results of (4), we examine the Chebyshev tapers applied to the two RDA's as illustrated in Figure 5.



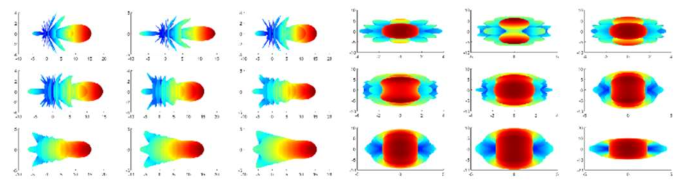


Figure 5. Characteristic distributions of two rings (top); and characteristic functions (side and front view-bottom).

Results from these tapers are seen to reduce front end sidelobe levels pushing the associated radiative energy to the rear of the pattern. In addition, these results were found in ideal settings. Therefore adding the shipboard structure into the complete design we observe how blockage and other undesirable effects changed the associated pattern behaviors in Figure 6 – 7.

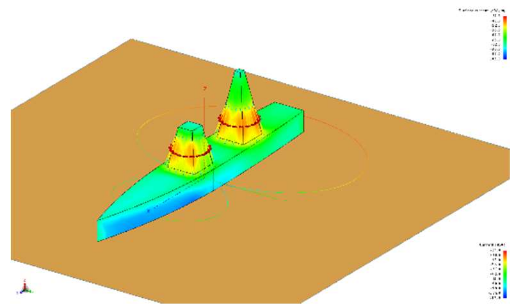


Figure 6. Mode 2 steered at θ_0=90° and ϕ_0 = 0°.

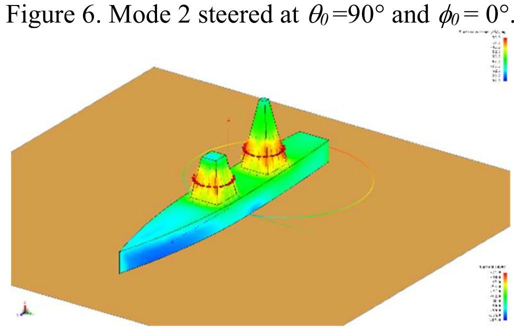


Figure 7. Mode 3 steered at θ_0=90° and ϕ_0 = 0°.

CONCLUSION

This paper discussed the high frequency (HF) radiation performance capabilities of a two mast canonical shipboard design using characteristic mode theory and distributed array design. The beamsteering capabilities of a simple shipboard structure can be controlled from applying different current distributions (i.e. characteristic modes) to its two mast superstructure. Consequently, the entire superstructure becomes the main radiator, and its radiative capabilities can be controlled from its two mast superstructure.

REFERENCES

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