

Overcoming Limitations of Agile Electronically Scanned Array (AESA) Using a Radiating Surface Antenna called Agile Radiating Matrix Antenna (ARMA)

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Abstract

Electronically Agile beam Antennas are able to generate moving radiation patterns to perform Beam Forming and Beam Steering. Today, the design of such antennas is performed by the well-known Array Technique called AESA: Agile Electronically Scanned Array which presents some limitations.

To overcome these limitations, a new approach is proposed in this paper called "ARMA" (Agile Radiating Matrix Antenna). This approach defines Agile Beam Radiating Surfaces that are sampled using rectangular functions instead of Dirac combs for the arrays. The intrinsic advantages are demonstrated and the ARMA-AESA comparison shows a larger accuracy of ARMA approach, which overcomes the limitations inherent in the array technique.

1 Introduction

In 1886, H.R. HERTZ gives us the formulation of the field radiated by an elementary dipole.

From this result, it was easy to bring together many dipoles to build an array; thus, the array theory was born and it is extensively used today. The beam agility is performed by using weighting functions to feed each dipole, and then a lot of radiation patterns can be obtained. But all these patterns present some limitations in terms of bandwidth, steering angles, number of elements, grating lobes, coupling effects...

Therefore, the question is: what is the best solution to obtain an expected agile radiation pattern? Is it always the array technique?

2 Principle of the ARMA Approach

To answer the above question, a rigorous approach must be performed as follows:

- Take Maxwell Equations.
- Establish the equations of propagation (Helmoltz)
- Deduce the free space Green's Function (without the antenna).

- Apply the equivalent principle (Huygens principle) replacing the antenna by currents or surface fields on the surface S which surrounds the antenna (sometimes the surface of the antenna itself) .This surface, is called the "radiating surface".
- Finally perform [1] the convolution product between the free space Green's function and the fields on the closed radiating surface "S" to obtain the radiating integral on S (2).
- For planar low profile antennas, the closed surface S surrounding the antenna is a parallelepipedshaped one (fig 1), where the main part of the energy flows through the upper part of S. The radiation through the lateral surface is neglected. The same approximation is used for the study of aperture antennas, which leads to the same equation; then (2) is often called the "aperture" radiating surface integral.

$$\vec{E}(P) = \frac{jk}{4\pi} \psi(R)(1 + \cos\theta) (\cos\varphi \ \vec{e_{\theta}} - \sin\varphi \ \vec{e_{\phi}})SFT$$

=K .SFT
With:

$$SFT = \iint E_s(x, y) e^{j(k x \sin\theta \cos\varphi + k y \sin\theta \sin\varphi)} ds$$

SFT is the Spatial Fourier Transform and: $\psi(R) = \frac{e^{jkR}}{R}$

This integral shows that the radiated field E(P) is approximately a 2D spatial Fourier transform of the field Es(x,y) on the radiating surface S (fig 1).



Figure 1. Radiation pattern obtained directly from the radiating surface limited to its upper part

To perform the agility, this surface field must be sampled to obtain many radiation patterns; consequently, the approach becomes no longer a rigorous one.

1- The most basic sampling procedure to sample an Es(x,y) field is to use a Dirac comb [1] that leads to the following expression : F(P)

$$= K \sum_{i} \sum_{j} E_{s}(x_{i}, y_{j}) e^{j(kx_{i}sin\theta cos\phi + ky_{j}sin\theta sin\phi)} dxdy$$

That is the Array solution; the total radiated field is the sum of the fields radiated by small antennas located at xi, yj.

2- To obtain a better approximation of the radiating surface S, we can introduce a more accurate sampling procedure, using a rectangular function along the x and y directions:

$$\overline{E(p)} = K \iint_{s} E_{s}(x, y) e^{j(k*x*\sin\theta *\cos\varphi + k*y*\sin\theta *\sin\varphi)} ds$$

$$\overline{E(p)} = K \sum_{i} \sum_{j} \iint_{s_{i,j}} E_{i,j}(x, y) e^{j(k*x*\sin\theta *\cos\varphi + k*y*\sin\theta *\sin\varphi)} ds$$

$$\overline{E(p)} = K \sum_{i} \sum_{j} \iint_{s_{i,j}} A_{i,j} e_{i,j}(x, y) e^{j(k*x*\sin\theta *\cos\varphi + k*y*\sin\theta *\sin\varphi)} ds$$

$$\overline{E(p)} = K \sum_{i} \sum_{j} A_{i,j} \iint_{s_{i,j}} e_{i,j}(x, y) e^{j(k*x*\sin\theta *\cos\varphi + k*y*\sin\theta *\sin\varphi)} ds$$

The radiated far field is obtained by adding the radiated fields generated by a lot of elementary joined radiating surfaces sij, called "Pixel" [2] [3] [4] fed by a signal which gives the Aij weights.

For example, to build a low profile planar antenna, this formulation suggests that the whole structure can be considered as a matrix of MxN pixels, each characterized by a weighting function (different colors) as shown in figure 2. Each given pixel is able to generate a contribution to the building of the whole field E(P).



Figure 2. Radiating surface sampled by joined square pixels.

Usually, there are no restrictions on the surface S and the pixels can have any shape, but must be connected together. Like for the agile arrays, the pixels must be fed by a Beam Forming Network (BFN) to apply appropriate weights [3] in order to obtain the expected radiation patterns.

Finally, the whole antenna is constituted by a lot of pixels forming a Matrix which is called ARMA (Agile Radiating Matrix Antenna) (fig 3).



Figure 3. Some ARMA Matrix architectures.

3 Pixel Design

The "pixel" [2] is built from a simple EBG large size antenna (fig 4a) characterized by a ground plane, an air cavity and a Partially Reflecting Surface (PRS) which is usually a frequency selective surface (FSS) [5] [6] [7] [8]. Metallic walls (fig 4b) are introduced around the feeding probe (usually a patch) of the EBG antenna [2]. The final structure is shown in figures 5a and 5b. Due to the radially vanishing mode, the surface EM field is almost constant on the top of the pixel (fig 5c) generating a directive radiation pattern [2].



Figure 4. (a) High gain EBG Antenna (b) Vertical metallic walls inside the EBG Antenna.



Figure 5. Pixel antenna fed by a patch: (a) Perspective view, (b) Cut view along X-axis, (c) E-field cartography on the pixel radiating surface.

4 ARMA – AESA Comparison

4.1 Structural advantages:

- The pixel dimensions in an axial beam ARMA can easily reach 1.2λ x 1.2λ. Then, for a given antenna surface, the number of feeding ports can be well limited, highly reducing the cost of the BFN. An array with the same surface usually needs approximately 4 times the number of ports because the periodicity is limited at 0.8λ to avoid grating lobes [2].
- Frequency Band: Due to the properties of the original low profile EBG antenna, the pixel bandwidth can easily reach 40% [9] and the coupling effects between 2 ports are usually limited under -20dB [10] in TE polarization. Consequently, an ARMA with 14 x 14 pixels has approximately the same bandwidth as the pixel shown in figure 6 for the 196 pixels.



Figure 6. Sii active parameters evolution as a function of the frequency for a 14 x 14 pixel ARMA.

In millimeter range frequencies (Ku or Ka), ARMA solution can also be designed [11] with the same performances, particularly the same kind of bandwidth is obtained. For example, a pixel built with a very simple PRS (Partially Reflective Surface) constituted by a homogenous Zirconia slab and fed by a wide band dipole (fig 7) gives a 47.8% bandwidth.



Figure 7. (a) Pixel antenna with a homogenous PRS slab. (b) S11 parameter as a function of frequency.

• The ARMA surface: There are no strict restrictions on the pixel shape, which may or may not be planar [12], with any surface shape: square, rectangular, triangular, circular and trapezoidal. For example, circular and trapezoidal pixels are combined (fig 8) to keep a good circular symmetry in an ARMA isoflux radiation pattern around 8.2 GHz.



Figure 8. Rotational-symmetric low profile antenna with pixels fed by four port patches (circular polarization): (a) Global views with and without the radome, (b) without the FSS.

To illustrate this behavior, the circularly polarized radiation pattern obtained from this circular symmetrical ARMA (fig 8) is presented in figure 10 and compared with one obtained from a square ARMA solution [13]. The square shaped low profile ARMA with 5X5 pixels [13] shows in figure 9a a strong non uniformity of the gain of about 2.75 dBi, otherwise the circular symmetrical ARMA exhibits a pattern (Fig 9b) with a good uniformity (0.7 dBi). A comparison with an array with the same dimensions was not performed because in the case of the array it was impossible to obtain a maximum of gain near θ =60° with 5x5 elements.



Figure 9. (a) Radiation pattern obtained with a square ARMA with 5 x 5 pixels (b) Isoflux radiation pattern obtained with the circular symmetrical ARMA.

4.2 Beam Steering Performances

A comparison [2] was performed between two (1D) agile beam antennas with the same surface (fig 10) and the same periodicity: an AESA one and an ARMA one as shown in figure 10.



Figure 1. 1D antennas used to compare the AESA and ARMA steering performances.

The gain obtained for a steering angle of θ =70° is very much higher for the ARMA than for the AESA (fig 11).

This advantage, shown on beam steering, can be conserved for beam forming. For example, an X band isoflux earth coverage from a CubeSat located on a LEO orbit is possible with a maximum of gain near θ =60° [13].



Figure 2. Comparison of AESA and ARMA radiation patterns for a beam steering procedure in the θ =70° direction.

5 Conclusion

This paper introduces a new agile beam antenna technique called ARMA which can replace the array one (AESA) when strong limitations appear.

Pixels with small restrictions on the shape, dimensions and band, increases the flexibility of its applications.

The advantage of ARMA is particularly significant for beam forming and beam steering in many research areas: earth and satellite communications, electronic warfare, radars etc.

6 References

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