

10 to 40 GHz ultra-wideband magneto-electric phased array

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Abstract

In the past decade, current sheet antenna (CSA) or tightly-coupled dipole arrays (TCDA) have been developed based on current-sheet periodic structure to achieve ultra-broadband impedance performance with wide scanning capability. This paper presents an alternative ultra-broadband periodic array using continuous magneto-electric (ME) currents, which can be implemented using radiating slots and horizontal monopoles. The proposed ME array is scalable from sub-6GHz to millimeter-wave and has the advantage of much simpler feed structure and does not require extremely small capacitive gap between radiating elements.

1. Introduction

Various forms of ultra-broadband phased arrays have been developed in the past based on the principle of current-sheet antenna (CSA), such as the tightly-coupled dipole arrays (TCDA) [1]-[2] and travelling-wave antennas [3]. These types of arrays apply broadband impedance matching/balun techniques to an array of closely-coupled, electrically small dipole elements with very small capacitive gaps between radiating elements. They have shown to exhibit well-behaved impedance and radiation patterns with very wide scanning angles over multi-octave of frequency bandwidth. For a grating-lobe free array, the maximum element spacing is limited to 0.5λ . As a result, a broadband active phased array is typically designed to operate between 0.5λ to 0.1λ , which results in real impedance of dipole elements between 100 to a few hundred ohms. Consequently, these types of arrays require design of a relatively complex feed/balun circuit and a means of achieving the narrow capacitive gaps.

The magneto-electric (ME) phased array was first proposed as a composite-right-left-handed (CRLH) array structure [4] to achieve the ultra-broadband performance with capability of surface-wave suppression in a finite array. Instead of the continuous electric current sheet model in the TCDA, the proposed ME array is based on continuously alternating electric and magnetic currents. This concept results in lower real-part impedance (50Ω at 0.5λ element spacing) and does not require small capacitive gaps between elements. The ME array concept is scalable from sub-6GHz to millimeter-wave frequencies. This paper presents an implementation of the ME array for ultra-wideband (4:1) millimeter-wave applications (10 GHz to 40 GHz).

2. Magneto-electric phased array

Unlike TCDA, the proposed ME phased array is based on alternating magnetic and electric currents, which is implemented using a periodic cascade of monopoles and slots.

Fig.1 shows a detailed dual-cell model of the proposed ME phased array. Each monopole is connected directly to an unbalanced coaxial line from below a ground plane, which induces displacement current across a series-capacitor gap (slot) formed between ground plates. This periodic structure of monopole and slot forms a continuous line of alternating electric and magnetic current along the array axis.

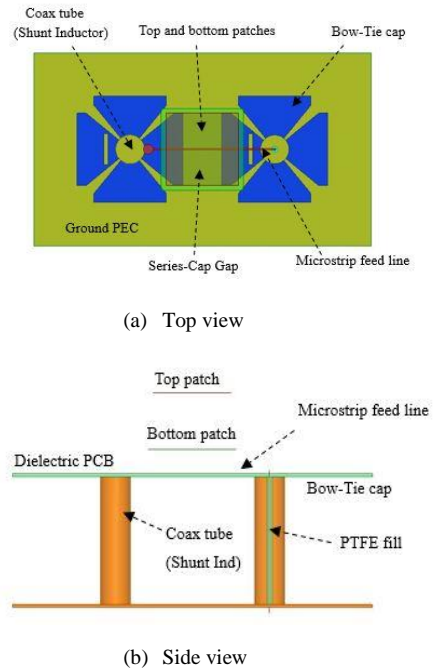


Fig. 1. Dual-cell structure of the magneto-electric phased array

This array structure forms a basic composite-right-left-handed (CRLH) transmission line. Shunt inductors are simply metallic tubing (coax shield) connecting the bow-tie dipole grounds to the antenna ground sheet. Shunt inductors are simply metallic tubing (coax shield) connecting the bow-tie dipole grounds to the antenna ground sheet. Series capacitors are air gaps formed between bow-tie metallic grounds. Monopoles are microstrip feed lines connected directly to the center pins of coaxial lines, which also serves as feed line to the radiating slots.

With proper size of series capacitor gap and shunt coaxial tube the structure can be designed to further suppress unwanted surface waves from edges of the finite array structure.

Multiple layers of small metallic square patches are placed directly above the radiating slots and form layers of impedance-matching meta-surfaces. However, unlike an aperture-coupled stacked patch (ACP), sizes of these metallic patches are significantly smaller than half-wavelength. Together, these patches form layers of reactive meta-surfaces with the sole purpose of enhancing broadband impedance matching of the array. The principle and techniques of such method is well documented by Munk [5]. Fig. 2 shows an equivalent diagram of the broadband impedance matching using the meta-surfaces. Total impedance at the plane of radiating sources is a parallel sum of all discontinuity impedances in the transverse plane, including the complex element impedance, transformed impedance of ground plane, and transformed impedances of capacitive meta-surfaces, i.e.,

$$Z_{ANT} = Z_A + Z_c // Z_{GND} \quad (1)$$

Where,

$$Z_A = R_A + jX_A,$$

$$Z_c = Z_{c1}(d_1) // Z_{c2}(d_1 + d_2)$$

$$Z_{GND} = Z_{PEC}(d_0)$$

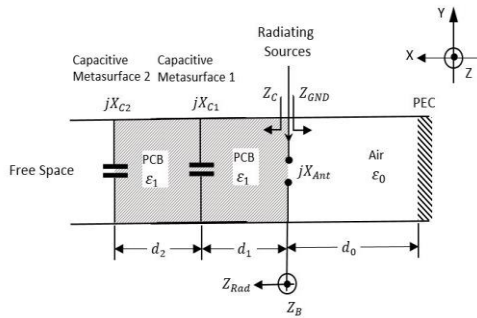


Fig. 2. Impedance matching scheme of the ME phased array

With proper tuning, combined characteristics of capacitive ME sources and meta-surfaces tend to cancel out the large inductive impedance of the PEC ground. This type of array is capable of producing a low constant real impedance near 50-75 ohm and low active VSWR over multi-octave of frequency bandwidth.

3. UWB millimeter-wave ME phased array

A 20-element linear ME phased array with periodicity of 3.7mm is modeled using the commercial EM simulation software ANSYS HFSS. Fig. 3 shows the magnitude of active VSWR for scan angles $\pm 50^\circ$. The active VSWR is below 2:1 for scan angle below $\pm 20^\circ$, and less than 3:1 for scan angle up to $\pm 40^\circ$. However, frequency bandwidth (VSWR 3:1) is reduced to 12 to 37 GHz for scan angle above $\pm 40^\circ$. The 4:1 frequency bandwidth is achieved over scan angle of $\pm 40^\circ$ for active VSWR of 3:1. Fig.4 shows typical co-polar and cross-polar radiation patterns (E-plane) with scan angles between 0 and 50deg. Cross-polar patterns

are typically below -30 dB in the main lobes. Scan loss is in the order of 1dB for scan angle up to 50deg.

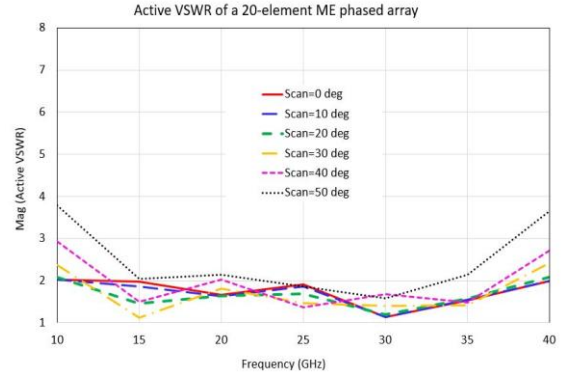


Fig. 3. Active VSWR of the 20-element ME phased array

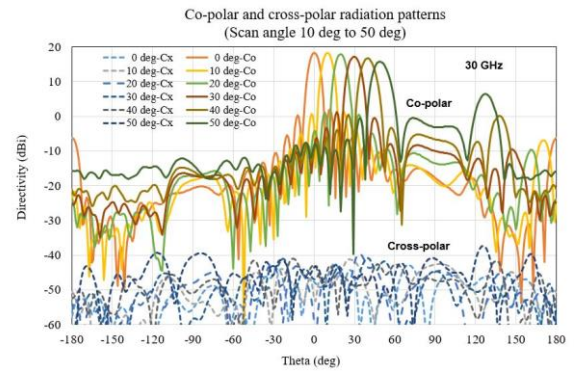


Fig. 4. Typical E-plane scanned patterns of the ME phased array

4. Conclusions

This paper presented an ultra-wideband millimeter-wave ME phased array. It is shown such array can be made to achieve an extremely wide impedance and radiation pattern bandwidth over a wide scan angle. A frequency bandwidth of 4:1 is achievable over scan angle of $\pm 40^\circ$ for active VSWR of 3:1. This enables beam steering over the entire frequency range from 10 GHz to 40 GHz.

References

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