Efficient, Electrically Small Metamaterial-Inspired Antennas with High Directivity

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***Abstract* - It has been demonstrated that metamaterial-inspired electrically small antennas (ESAs) can be designed to have high radiation efficiencies and even large bandwidths with non-Foster circuit augmentations. However, being electrically small, it still remains a challenge to obtain directivities over interesting bandwidths which exceed those of simple dipoles, especially with only passive constructs. Different classes of passive and active metamaterial-inspired ESAs that have successfully produced higher directivities and higher bandwidths will be reviewed. Recently reported configurations will be highlighted in our presentation.**

***Index Terms* — Bandwidth, directivity, electrically small antennas, non-Foster augmentations, parasitic elements.**

1. Introduction

The desire for yet smaller mobile platforms continues to increase. This trend has generated an intense demand for printed electrically small antennas (ESAs) with superior performance characteristics. Generally, omni-directional patterns are desired and they arise naturally from small, compact electric or magnetic dipole radiators [1]. The latter occur naturally as ESAs, i.e., when the size of the radiating structure is much smaller than the source wavelength. On the other hand, there are a variety of applications for which it is desirable to have higher directivity and/or a large front-to-back ratio, i.e., to have the radiated power emitted primarily into one hemisphere. Examples include biomedical monitoring and on-body systems; point-to-point communications and wireless power transfer; mitigation of cell-phone specific absorption rate (SAR) issues; and radio frequency identification devices (RFIDs).

There have been many approaches reported to obtain higher directivity from ESA configurations. One was enabled by meta-structures and metamaterials acting as in-phase reflectors, e.g., high impedance ground planes [2] and bulk artificial magnetic conductors [3]. A second is to use two or more ESAs to achieve an end-fire array [4]. A third is to introduce additional near-field resonant parasitic elements (NFRP) designed and tuned specifically for directivity enhancement in the broadside direction [5]-[9]. These various approaches will be reviewed; the advantages, disadvantages and peculiarities with them will also be discussed in our presentation.

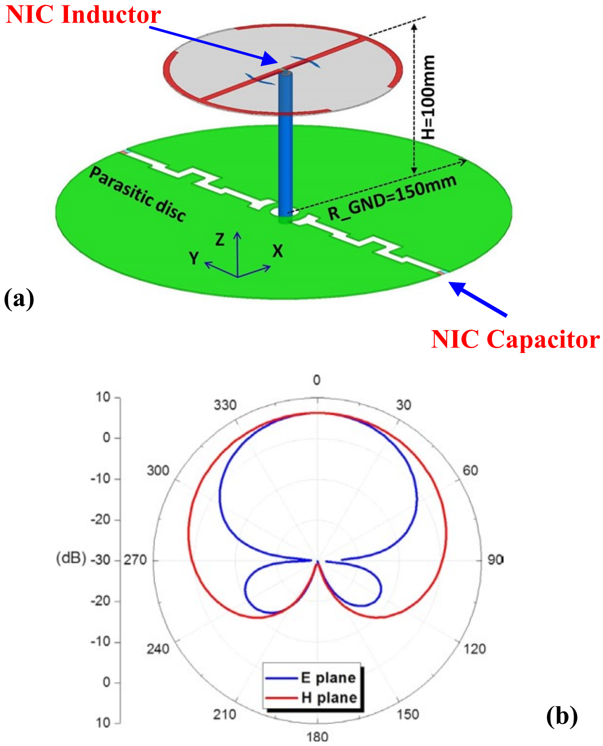

Fig. 1. ESA with non-Foster augmented NFRP elements to achieve high radiation efficiency, large bandwidth, large front-to-back ratio (FTBR) and high directivity. (a) Basic configuration, and (b) the E- and H-plane directivity patterns at 300 MHz. [6]

2. Active NFRP Elements

By introducing more NFRP elements into a metamaterial-inspired electrically small antenna system, one obtains more degrees of freedom which can be used to enhance the directivity. These additional NFRP elements can be either passive elements or they can be augmented with a non-Foster (e.g., a negative impedance convertor (NIC)) circuits to increase the bandwidth of the resulting directivity enhancement effects [6]. This concept is illustrated in Fig. 1.

In particular, the coax-fed driven element is a curved top-hat electric dipole. The EAD NFRP element is augmented with a non-Foster circuit, a NIC inductor, to enhance the overall impedance bandwidth. The meanderline-slotted metallic NFRP disk was designed as a NFRP element and tuned specifically for directivity enhancement. It is located $\lambda/10$ away from the dipole. It has two NIC capacitors incorporated into it at the outside ends of the slots. These increase the directivity bandwidth. The overall size of this particular design was $ka = 0.94$ [6]. It achieved the directivity over quality factor more than 10 times the fundamental bound: $D/Q > 10\times(D/Q)_{\text{bare EAD}}$. In particular, with a center frequency at 300 MHz, it simultaneously achieved high radiation efficiencies (>81.63%), high directivities (>6.25 dB), and large front-to-back-ratios (>26.71 dB) over a 10.0% fractional bandwidth [6].

3. Passive Huygens Source

The Huygens equivalence principle [1] provides yet another means to achieve higher directivity. By combining together an electric dipole and a magnetic dipole, one can obtain a Huygens source, i.e., an antenna that radiates primarily into one of the half spaces bounded by the plane that contains both elements. The key design issues are to achieve the same phase center for both radiating elements and to have them both radiate equivalent amounts of power. Additional tuning is necessary to direct the radiated power into the desired half space.

A recently reported design [7] is shown in Fig. 2(a). It consists of a coax-fed printed dipole antenna and a set of near-field resonant parasitic (NFRP) elements. The electric dipole response is achieved with an EAD NFRP element. It has an inductor embedded in its center. The magnetic dipole response is obtained with the two capacitively loaded loop (CLL) NFRP elements. Each CLL has a capacitor across its gap. The lumped elements facilitate miniaturization, frequency and impedance tuning, and frequency agility.

The antenna is matched to its 50 Ω source at 299.17 MHz. It is electrically small ($ka = 0.45$) and very low-profile (height ~ $\lambda/80$). As illustrated in Fig. 2(b), this Huygens source antenna produces the desired broadside cardioid pattern. Its front-to-back ratio: FTBR = 58.04 (17.64 dB); its maximum directivity: $D_{max} = 3.15$ (4.98 dB); and its maximum realized gain: $RG_{max} = 2.76$ (4.41 dB). Its 3dB impedance bandwidth is only 0.59 MHz (FBW = 0.20%). At the resonance frequency, its accepted power is AP = 0.998 W, and its radiated power is RP = 0.877 W, giving an 87.9% radiation efficiency. An experimentally verified prototype related to this design has been reported [8].

4. Conclusions

In contrast to the active antenna shown in Fig. 1, the passive Huygens source antenna shown in Fig. 2 achieved the desired cardioid response with a very low-profile design. However, it suffers from a very narrow bandwidth. Using the concepts associated with the antenna in Fig. 2, a non-Foster based, broad bandwidth, Huygens source antenna has been reported and will be discussed in detail in our presentation [9].

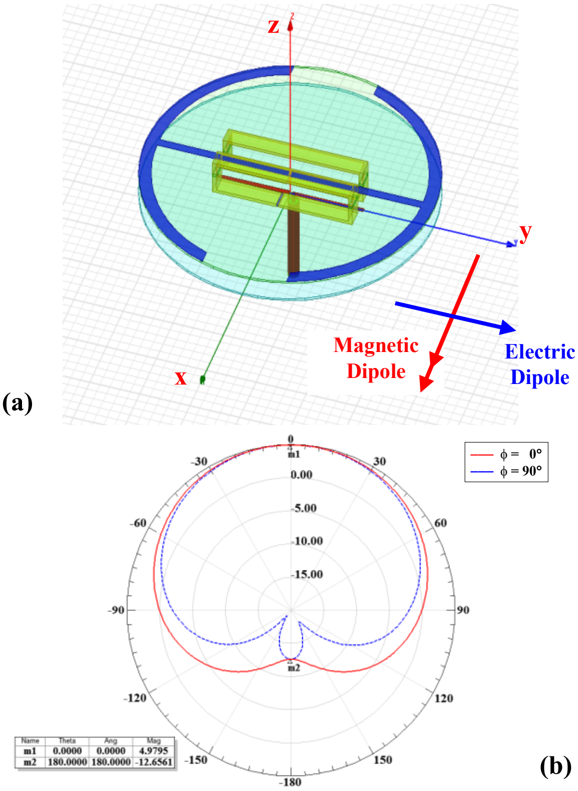

Fig. 2. Passive, low profile, efficient Huygens source antenna. (a) Basic configuration, and (b) the E- and H-plane directivity patterns at 299.17 MHz. [7]

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