Broad Bandwidth Electrically Small Antennas Augmented with Internal Non-Foster Elements

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Abstract—Electrically small electric and magnetic antennas augmented with non-Foster elements to enhance their impedance bandwidths have been designed, characterized numerically, fabricated and tested. Internal non-Foster elements, which produce broad bandwidth inductive and capacitive responses specifically tailored to design specifications, are introduced into the near-field resonant parasitic (NFRP) components of their narrow bandwidth counter-parts. This internal non-Foster element approach leads to nearly complete matching of the entire system to a 50 \textOmega source without any matching network and high radiation efficiencies over their FBW\textsubscript{DMB} bandwidths that surpass the fundamental passive bounds.

I. INTRODUCTION

With the explosion of wireless platforms and their applications in recent years, electrically small antennas (ESAs) have become a topic of great research. However, because of their compact size, ESAs are generally not efficient radiators and they have narrow bandwidths. There have been many efforts to overcome the conflicting performance characteristics of ESAs using various meta-structures. These include designs to enhance their efficiencies, bandwidths, and directivities. Successful miniaturized antenna designs have been reported recently (see, e.g., [1] and the references therein) based on some type of meta-structure. We note that throughout, the term “electrically small” will mean: \(ka < 1\), where \(k = 2\pi/\lambda\), \(\lambda\) being the free space wavelength corresponding to the operational frequency of the entire antenna system, and \(a\) is the radius of the smallest sphere that encloses it. By introducing a negative impedance convertor (NIC) based reactive element into the near field resonant parasitic (NFRP) element of these metamaterial-inspired ESAs, it has been demonstrated [2-5] that frequency bandwidths can be obtained which are substantially larger than the known fundamental passive upper bounds based on the electrical size of the antenna.

II. NIC-AUGMENTED ELECTRICALLY SMALL ANTENNAS

We have designed, simulated, fabricated and tested two NIC-augmented antenna types. The process involves selecting an NFRP ESA whose bandwidth is near the fundamental passive limit and whose NFRP element can be modified to allow for the introduction of a reactive element to achieve the same resonance frequency with only minor, if any, performance characteristic variations. A frequency dependent version of the reactive element is then introduced. The resulting frequency agile version of the antenna is then simulated with an electromagnetic solver, such as the ANSYS/ANSOFT high structure frequency simulator (HFSS). The resonance frequencies corresponding to the various values of that reactive element are thus obtained, and the corresponding reactance versus frequency curve is determined. A NIC-element is then designed with the circuit simulator, Agilent’s Advanced Design System (ADS), to match this curve as closely as possible. If realistic values of the lumped elements and transistors are incorporated in the NIC model, it will produce not only the desired reactance values, but also resistances. These resistances have to be minimized to maintain the desired high radiation efficiencies. This is accomplished by optimizing the various circuit components in the NIC element. The resulting NIC-element values are co-simulated with the antenna model to ensure that the design will produce the desired performance characteristics: bandwidth, radiation efficiency, and directivity over the enhanced frequency bandwidth.

III. REALIZED DESIGNS

Two such designs will be described in our presentation. Both were fabricated with 31 mil (0.7874 mm) thick, 0.5 oz copper (0.017 mm thick), Rogers Duroid\textsuperscript{TM} 5880 board material. Both were designed to operate near 300 MHz.

The first design is the electrically small protractor antenna shown in Fig. 1a. A coaxially-driven monopole is coupled to the protractor NFRP element in such a manner that the current induced in it is a loop mode. Thus it acts as an elemental magnetic dipole antenna. It required the introduction of a capacitive NIC (C-NIC) element to achieve its large instantaneous bandwidth. This design was experimentally validated in [4]. The resulting active NFRP element did provide the means to surpass the fundamental passive limits. The predicted results with measured component values are compared against the experimental results in Fig. 1b. The measurement results for this non-Foster protractor antenna showed a 10dB bandwidth of 14.8 MHz at 275.5 MHz (5.37\% 10dB fractional bandwidth for \(ka = 0.444\)), which was more than a 10 times increase of the 10dB fractional bandwidth.
(FBW_{10dB}) of the original passive version (0.53\% at 300 MHz). The corresponding half-power bandwidth (BW_{3dB}) was more than 8.24 times the passive upper bound [4]. While the simulated 10dB bandwidth with the measured components was considerably larger at 87.9 MHz, we learned many experimental and simulation techniques from this first result.

The second design tested was the Egyptian axe dipole (EAD) antenna shown in Fig. 2a. A coaxially-driven top hat loaded dipole is coupled to an EAD NFRP element. At resonance, the current flows mainly along the handle of the NFRP EAD element. Thus, it acts as an elemental electric dipole antenna. It required the introduction of an inductive NIC (L-NIC) element to achieve its large instantaneous bandwidth. This design was experimentally validated in [5]. The measurement results showed approximately a 25.3 MHz 10dB bandwidth around 300 MHz for the active system $(ka=0.49)$, which is 6.02 and 3.89 times greater than, respectively, the simulated and measured values of the original passive design, whose $Q$ value was 1.26 times the passive bound. Thus, the resulting L-NIC based, active NFRP element also provided the means to surpass the fundamental passive limits by a factor of 3.09.

Fig. 1 Electrically small protractor antenna augmented with a C-NIC element. (a) Fabricated protractor antenna with the C-NIC, and (b) simulated and measured $S_{11}$ values [4].

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Fig. 2. Electrically small Egyptian axe dipole augmented with an L-NIC element. (a) Fabricated EAD antenna with the L-NIC, and (b) simulated and measured $S_{11}$ values [5].

IV. CONCLUSION

We will report our proof-of-concept designs, simulations, and their corresponding experimental validation studies in our presentation. It will be demonstrated that electrically small antennas augmented internal non-Foster circuits have surpassed the fundamental passive bounds on their impedance bandwidths. Non-trivial practical difficulties to achieve these results will be discussed.

REFERENCES