

Ultra-Wideband, Miniaturized, Low Profile, Omnidirectional Antenna Using A Novel Reactive Loading Approach

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Abstract—This paper presents a novel approach based on reactive loading of a resonant structure to achieve ultra-wideband operation for a low-profile omnidirectional antenna. The use of the proposed reactive elements generates new resonances in lower frequency band than the original antenna resonant frequency. The key feature of the reactive load design pertains to its frequency response so that while the input impedance of the reactive load is seen as ‘infinite’ at the original resonant frequency, it is seen as ‘capacitive’ at newly generated resonant frequency. Proper combination of these resonant frequencies and their harmonics leads to a very wide bandwidth operation. A circuit model for the reactive load is first proposed and the realization of its electromagnetic model is followed. To implement the proposed method to antenna design, a $\lambda/2$ resonant folded monopole antenna exhibiting wider bandwidth than a $\lambda/4$ resonant monopole antenna is chosen. It is discussed that 10dB fractional bandwidth (FBW) of the antennas with the proposed reactive loads can be 45% and omnidirectional radiation pattern with vertical polarization be obtained in the operating frequency band.

I. INTRODUCTION

Low profile antennas with omnidirectional radiation pattern are widely used in many applications due to their small size and robustness in multipath environments. Inverted F Antenna (IFA) is most common low profile omnidirectional antenna but its 10dB fractional bandwidth (FBW) is less than 10%. Several low profile wideband antennas with omnidirectional radiation pattern are reported in literature [1-3]. In [1-2], multiple resonant structures are designed using parasitic elements whose size is similar to IFA, leading to FBW of 26%. It is also known that the bandwidth of IFA can be increased up to 18% by extending, folding and shorting the end of IFA to the ground [3], which is called by a $\lambda/2$ resonant folded monopole antenna in this paper. This is similar to a $\lambda/2$ folded dipole antenna that has a better bandwidth than a single $\lambda/2$ dipole antenna.

In this paper, a new design method for wideband enhancement of low profile omnidirectional antennas using reactive loads is introduced. This proposed reactive load provides desired impedance characteristics to obtain multiple operating frequencies and impedance matching at the frequencies. This design can lead to ultra-wideband operation of the antenna with operation bandwidth well above multiple octaves. It is shown that the reactive load can generate other

resonances at the lower frequency bands without extending the physical dimension of the original antenna. Details about the realization of antenna structure using this approach and antenna performance will be presented.

II. WIDEBAND LOW PROFILE OMNIDIRECTIONAL ANTENNAS WITH REACTIVE LOADS

A circuit topology with desired impedance characteristics is proposed and analyzed. Based on this circuit model, an equivalent structure having the same electromagnetic model is realized and its performance as a radiating element is examined.

A. Design and Analysis of Reactive Load

The goal is to design a reactive load with proper frequency response so that additional resonant frequencies can be obtained when combined with a resonant planar antenna structure. Let's consider a $\lambda/2$ folded monopole antenna with the resonant frequency f_1 , as shown in Fig. 1(a) and (c). In this structure, one end of a $\lambda/2$ transmission line (TRL) is shorted to the ground and the other end is connected to the feeding port. Two vertical elements at both ends are responsible for vertically polarized radiating fields with omnidirectional radiation pattern if the transmission line is meandered. From the fundamental relation between frequency and wavelength, at $f_2 (< f_1)$ in Fig. 1(c), electrical length of the TRL is shorter than $\lambda/2$ because of $\lambda_2 > \lambda_1$. The short electrical length can be effectively extended using a shunt capacitance without the change in physical length of TRL, as shown in Fig. 2(b). Fig. 1(c) describes the shift in the resonant frequency from f_1 to f_2 due to the shunt capacitance, which exhibits size reduction effect. However, in order to obtain multiple resonant frequencies, a reactive load capable of providing two operations described in Fig. 1(a) and (b) at the same time must be invented.

In this paper, a circuit topology satisfying this condition is proposed, as shown in Fig. 2(a). Using (1), the input impedance of this circuit is seen as ‘open’ at $f_1 = 1/(2\pi\sqrt{LC_2})$, supporting the operation shown in Fig. 1(a). On the other hand, at $f_2 < 1/(2\pi\sqrt{L(C_1 + C_2)})$ input impedance (Z_{in}) of this circuit is a negative reactance (=capacitance), supporting the operation shown in Fig. 1(b). Fig. 2(b) depicts these characteristics of

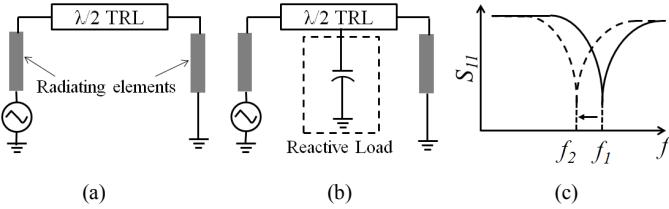


Figure 1. (a) $\lambda/2$ folded monopole antenna, (b) $\lambda/2$ folded monopole antenna with a shunt capacitance and (c) resonant frequencies f_1 and f_2 corresponding to (a) and (b).

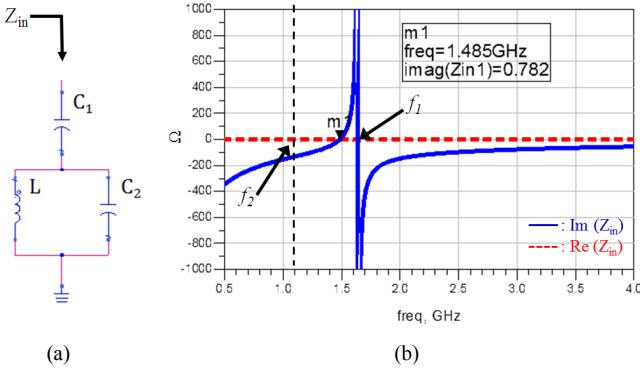


Figure 2. (a) Equivalent circuit model for desired reactive load and (b) its input impedance (Z_{11}) characteristics.

$$Z_{\text{in}} = \frac{1 - w^2 L(C_1 + C_2)}{jwC_1(1 - w^2 LC_2)} \quad (1)$$

input impedance (Z_{in}) of the circuit topology shown in Fig. 2(a). Fig. 3 shows how to realize electromagnetic structure based on this proposed circuit topology. Electrical coupling through a gap, a shorting sheet and a trapezoid-shaped capacitive load correspond to C_1 , L and C_2 in Fig. 2(a), respectively. From desired values of the lumped elements, gap distance, the width of the shorting sheet, and the geometry and area of the trapezoid-shaped capacitive load are chosen. Details about the parametric study will be presented at the conference.

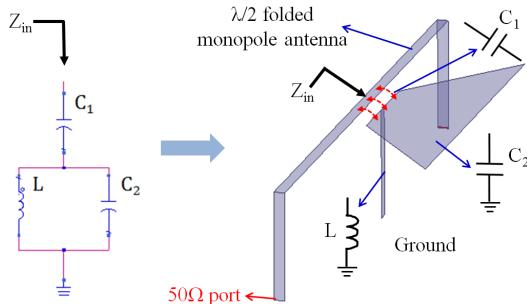


Figure 3. $\lambda/2$ folded monopole antenna with electromagnetic structure corresponding to circuit topology shown in Fig. 2(a).

B. Antenna Design and Results

The reactive load discussed in the previous section is utilized for bandwidth enhancement of a meandered $\lambda/2$ folded monopole antenna. The geometries of the meandered $\lambda/2$ folded monopole antenna (denoted by Antenna1), Antenna1 + one reactive load (=Antenna2) and Antenna1 + two reactive loads (=Antenna3) on an infinite ground plane are shown in Fig. 4. Fig. 5 shows S_{11} of the antennas. The dimension of Antenna3

is $\lambda/5 \times \lambda/5 \times \lambda/15$ at 2.262 GHz, which is much smaller than those of most ultra-wideband omnidirectional antennas. As expected, the proposed reactive loads introduce new resonant frequencies in much lower frequency band than the original resonant frequency (=2.687 GHz), resulting in compact size as well as broad bandwidth. The center frequencies of Antenna1, Antenna2 and Antenna3 are 2.687, 2.426, 2.262 GHz, respectively. It should be noted that the design parameters of two reactive loads in Antenna3 are slightly different to further enhance the bandwidth by generating slightly different 3 resonant frequencies. 10dB FBW of 45% is obtained from Antenna3. It is shown that the antenna have omnidirectional radiation pattern due to its symmetric geometry.

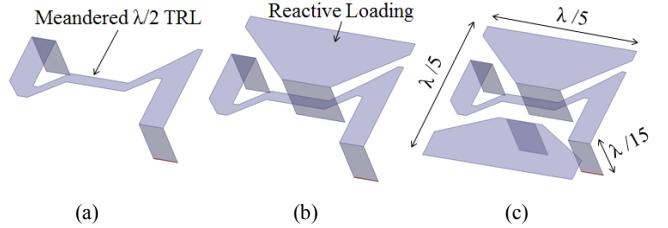


Figure 4. (a) Meandered $\lambda/2$ folded monopole antenna (=Antenna1), (b) Antenna1 + 1 reactive load (=Antenna2) and (c) Antenna1 + 2 reactive loads (=Antenna3).

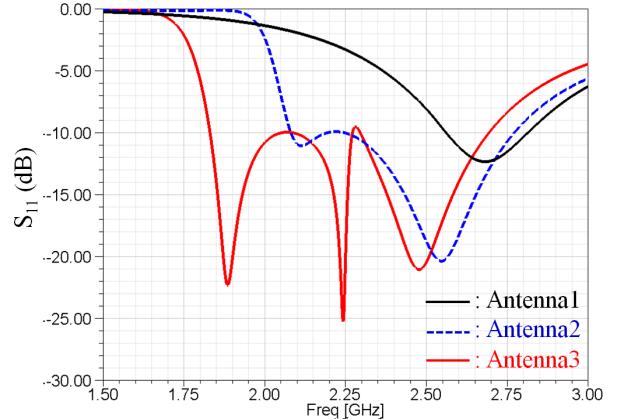


Figure 5. S_{11} of Antenna1, Antenna2 and Antenna3 in Fig. 4.

III. CONCLUSION

A novel technique using reactive loads for developing a very wideband, miniaturized, low-profile omnidirectional antennas is introduced. This enables compact size as well as broad bandwidth of 45%, while maintaining omnidirectional radiation pattern. Details about antennas design and measurement results will be presented.

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