4th URSI AT-RASC, Gran Canaria, 19-24 May 2024

A Tunable EZ Antenna Concept for HPEM Applications

Zubair Akhter [(1)], Fernando Albarracin*[(1)], Evgeny Gurnevich[(1)], Ernesto Neira[(1)], Felix Vega[(1)] and Chaouki Kasmi[(1)]
[#1]Technology Innovation Institute, Abu Dhabi, United Arab Emirates, http://tii.ae

Abstract

This work presents the design and preliminary experimental results on a novel concept of a compact and tunable electrically small antenna for high-power electromagnetic, HPEM, applications. The antenna is inspired in a modified version of the metamaterial based magnetic EZ-antenna, and includes 3D printed dielectric blocks mechanism which enables fine tuning around the resonant frequency. A >5% tunability around the central frequency in the lower UHF band has been verified experimentally, with a sensibility of 0.5 MHz-per-mm of dielectric material insertion.

1. Introduction

Intentional Electromagnetic Interference (IEMI) studies have gained special attention in the last decades due to the increasing dependance of critical infrastructures on micro-electronics-based technologies. Fast risetime high-peak pulses from ultrawideband radiators, damped sinusoids from mesoband sources, and pulse-modulated sinusoids from solid state amplifiers are the waveforms commonly used in IEMI studies [1] [2]. Helices, monopoles, discones, and impulse radiating antennas are the usual options to be integrated with HPEM radiators due to its high voltage handling capability. When the application scenario demands compactness, these commonly used antennas become a drag for the whole radiator. Electrically small antennas are a viable option once the bandwidth, efficiency and high-voltage capabilities are engineered. From the generator side, the quarter-wavelength oscillator, also known as the Switched Oscillator (SWO) [3] is a device that can generate intense electric fields, with fractional bandwidth 1%< b_r< 100% [4] and allows the integration with a compact antenna [5]. This work presents a modified version of the metamaterial inspired, magnetic EZ-antenna [6], in which frequency agility is incorporated in the form of near-field coupling with dielectric slabs. The purpose of the antenna is to be integrated with a high-voltage generator working at the lower UHF band. Manufacturing tolerances and deviations from the center frequency of the HPEM generator, once fabricated, can be easily compensated by fine tuning the antenna impedance band to that of the source by using the introduced sliding dielectric slabs mechanism.

2. EZ antenna design

The underlying idea of the EZ antenna is to conjugate matching the highly reactive impedance of an electrically small dipole, in its magnetic or electric version, (i.e. a short monopole or a semi-loop antenna) by means of near field metamaterial inspired resonant unit cells. The real part of the resulting impedance can also be matched to the system impedance by modifying the geometry of the inclusion [6]. The angle of maximum radiation is intended to be parallel to the HPEM source axis (see Figure 1a), so a semi-loop is selected as the driving element of the antenna. The inductive nature of the semi-loop impedance at low frequencies is compensated by introducing a capacitively loaded loop (CLL) placed in the near field [6]. The proposed tunable EZ antenna is shown in Figure 1b. The electrical size of the antenna is ka =0.5, where k is the free space wavenumber at the introduced resonant frequency, and a is the radius of a sphere containing the EZ antenna.

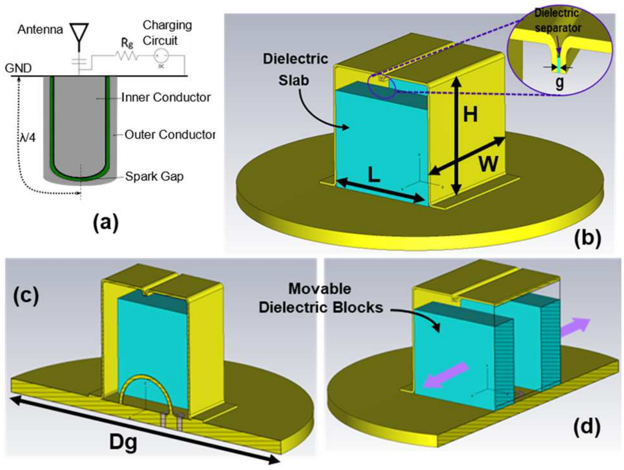

Figure 1. **(a)** Quarter wavelength oscillator (SWO) scheme, (b) Proposed tunable EZ antenna configuration (L=40 mm, H=46 mm, W= 49 mm, g=0.5 mm and Dg = 160 mm), (c) and (d) are the cut views of the antennas.

3. Dielectric Tuning Mechanism

The proposed tunable EZ antenna 3D EM simulation model is shown in Figure 2. As illustrated in Figure 2, the EZ-antenna resonance frequency is tuned with the help of two-identical movable dielectric blocks which provide dielectric loading to the antenna structure. In the simulated impedance response, it is observed that by moving the dielectric blocks close to each other, the resonant frequency moves towards low frequencies. This is a result of the increase in the capacitive loading. In a similar way, if the dielectric blocks are moved away from the center, the resonant frequency of EZ antenna moves towards a higher frequency (i.e. a decrease in the capacitive loading). As the EZ-antenna inherently has a narrowband impedance response, BW < 2% [6], the presented approach allows us to tune EZ antenna to a desired frequency of operation with a certain frequency range.

4. Tunability Exploration

In this section, a simulation study is presented to see the viability of the proposed tuning approach. In Figure 2, return loss of the unloaded EZ-antenna is plotted with return loss of the proposed loaded EZ-antenna for various displacements of the dielectric blocks. The simulations results indicate around 16.5 MHz of maximum shift with respect to the unloaded EZ-antenna can be achieved with this configuration. The simulated radiation pattern for one of the loaded configurations is shown in Figure 3 that indicates a realized gain value above than 3 dB, which is an acceptable value given the electrical size of the antenna. Notice that a slight increase in ground plane can increase the gain of the proposed antenna, nevertheless we kept our antenna ground plane $Dg = 16$ cm, due to the application limitation.

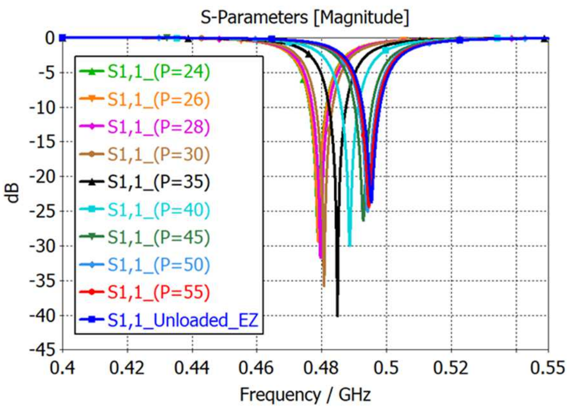

Figure 2. Simulated return loss of the antenna for different dielectric block insertion positions *P* (in mm) from the antenna center.

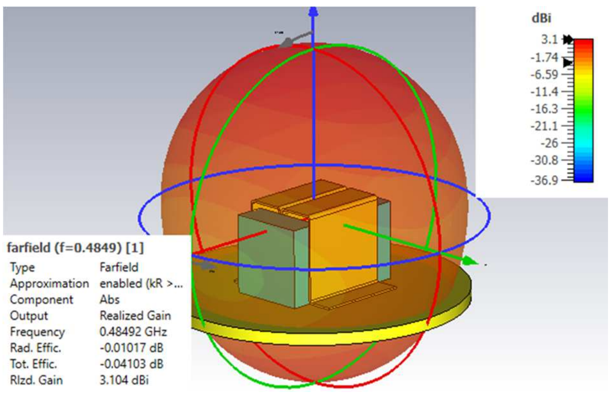

Figure 3. 3D radiation pattern of the EZ reference antenna

The proposed antenna was then fabricated and tested in a semi-anechoic environment. The dielectric blocks with sliding mechanism are 3D printed in nylon ($\varepsilon_r \approx 3$) with selective laser sintering (SLS) printing process as shown in Figure 4 (inset). Two conditions i.e., low loading and moderate loading, depending on the relative position of dielectric blocks with respect to the antenna center are measured. The measured return loss for both loading conditions is plotted in Figure 4. The measured results indicate similar trends and validate the concept of tuning of EZ-antenna with the proposed approach. It is to be noted that the measured fractional change, i.e. frequency agility, in the inserted band is higher compared to the simulation: 11% measured and 5% simulated. The authors are still investigating the possible reasons for enhanced tunability. A wider impedance bandwidth has also been observed, this can be associated with the losses of the dielectric material.

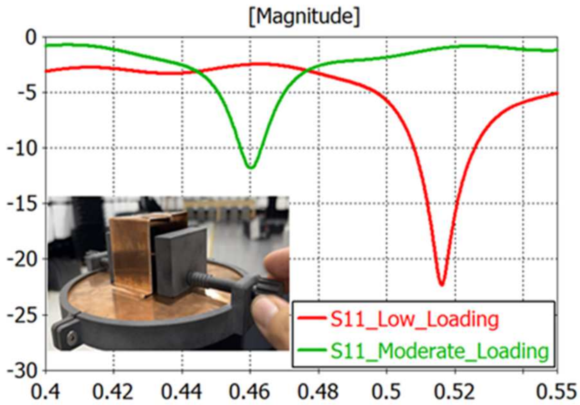

Figure 4. Measured reflection coefficient under low and moderate dielectric loading conditions

5. Conclusion

A novel version of the magnetic EZ-antenna for HPEM applications has been presented. A fine-tuning mechanism has been developed using additive manufacturing. The tunable impedance performance has been verified experimentally. The simulated radiation performance at the introduced low-band is not degraded by the dielectric inclusions as symmetry is kept by the 3D printed sliding mechanism. Further experimental validation will lead to finding the impact of the losses of the dielectric material in the overall efficiency of the antenna. The measured radiation patterns will be presented during the conference.

References

[1] N. Mora, F. Vega, G. Lugrin, F. Rachidi, and M. Rubinstein, "Study and Classification of Potential IEMI Sources," *Syst. Des. Assess. Notes Note 41*, 2014, Accessed: May 31, 2018.

[2] D. V. Giri and F. M. Tesche, "Classification of intentional electromagnetic environments (IEME)," *IEEE Trans. Electromagn. Compat.*, vol. 46, no. 3, pp. 322–328, Aug. 2004.

[3] C. Baum, "Switched Oscillators," *Circuit Electromagn. Syst. Des. Notes 45*, Sep. 2000.

[4] F. Vega, “Analytical Methods for the Study and Design of Integrated Switched Oscillators and Antennas for Mesoband Radiation,” PhD, FACULTÉ DES SCIENCES ET TECHNIQUES DE L’INGÉNIEUR, ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, 2013.

[5] E. S. Ramon, J. S. Tyo, R. W. Ziolkowski, M. C. Skipper, M. D. Abdalla, and J. Martin, “Integration and Operation of an Electrically Small Magnetic EZ Antenna With a High-Power Standing Wave Oscillator Source,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 15, pp. 642–645, 2016.

[6] A. Erentok and R. W. Ziolkowski, “Metamaterial-Inspired Efficient Electrically Small Antennas,” *IEEE Trans. Antennas Propag.*, vol. 56, no. 3, pp. 691–707, Mar. 2008.