Chapter 2
Metamaterial-Based Electrically Small Antennas (ESAs): A Review

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ABSTRACT

Metamaterial-based electrically small antennas (ESAs) are gaining popularity in RF communication devices and systems due to their appealing features. This chapter attempts to present a compendious and timely review on metamaterial-based ESAs. The metamaterial has been progressively incorporated in different stage-of-the-art techniques to design more compact antennas to a greater extent keeping their radiation Q-factor, bandwidth, and radiation efficiency in acceptable limits. Planar metamaterial loading has shown simplicity, good performance, and more flexibility in designing ESAs for different RF and mobile communication applications. Different types of planar metamaterial split ring resonators have been used to load the microstrip patch antennas. In this chapter, the basics of metamaterial and an extensive review of metamaterial-based electrically small antennas have been presented. Three configurations of metamaterial-loaded rectangular microstrip ESAs designed by the authors have also reviewed.

INTRODUCTION

Nowadays, compact microstrip patch antennas are becoming the backbone of different RF communication systems such as wireless networks, RF tagging, MIMO systems, sensor network, Bluetooth, public safety devices, PDAs, BAN, PAN, wearable devices, etc. to communicate voice, video, data and multimedia information at high data rates (Alu, 2007; Bilotti, 2008; Erentok, 2008; Jin, 2010; Joshi, 2010). Such antennas are also becoming a prime need for future 4G/5G communication technologies. As these

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systems are becoming part and parcel of the everyday activities of human life, size of handheld communication devices is becoming portable. This needs the miniaturized antenna systems to be integrated with the printed chip and functional electronic circuitry involved in the devices. It is a great challenge for the antenna designers to develop miniaturized antennas that should endow high gain, larger bandwidth and high efficiency in compact size as essential for such applications. Electrically small antennas of size significantly lesser than the usual half wavelength are found to be suitable elements in such type of stringent requirements (Erentok, 2008; Jin, 2010; Joshi 2010).

In 1947, Wheeler investigated the fundamental limitations of ESAs and defined ESA as whose maximum dimensions can fit inside a radiansphere that is an imaginary sphere of radius equal to $\lambda/2\pi$ (λ is free space wavelength) (Wheeler, 1947). It specifies that the sphere must enclose the maximum dimensions of an antenna. This is more explicitly expressed by the mathematical relation (1).

$$ka < 1 \tag{1}$$

where; $k = \dfrac{2\pi}{\lambda}$ and a is radius of the sphere enclosing maximum dimensions of the antenna.

Further, Chu derived a fundamental relationship between the size of the antenna and quality factor (Q) referred as Chu limit (Chu, 1948). This limit implies the minimum quality factor (Q) to be attained by an antenna of size ka (Chu, 1948; McLean, 1996; Thiele, 2003; Hansen, 2009). R.G. Hansen and R.E. Collin derived a new approximate form of Chu formula for lower-order TM mode (Hansen, 2009). R.A. Burberry reviewed the applications and limitations of ESAs. In this study, different reasons of impedance mismatch as well as various impedance matching techniques like capacitive loading, notch etc. have been presented to obtain high radiation efficiency (Barberry, 1990). Radiation properties of self-resonant electrically small folded spherical helix antenna with high efficiency have been presented (Best, 2004).

It is well known that for ESA radiation quality factor is of a fundamental interest. It is defined as 2π times the ratio of the maximum energy stored to the total energy lost per period. Chu derived a theoretical relationship of minimum quality factor (Q_{chu}) in terms of antenna size and is re-validated by Mclean which is expressed as Equation (2) (Joshi 2010; Wheeler, 1947; Chu, 1948, McLean, 1996; Thiele, 2003; Hansen, 2009).

$$Q_{chu} = \left(\frac{1}{k^3 a^3} + \frac{1}{ka} \right) \tag{2}$$

The radiation quality factor (Q_{rad}) of the ESA should be adequately large that is greater than 10 (Q_{rad}>10) (Joshi 2010,2014; Wheeler, 1947; Chu, 1948, McLean, 1996; Thiele, 2003; Hansen, 2009; Ziolkowski, 2003,2005, 2005, 2006, 2009; Stuart, 2006; Boratay, 2007,2007; Li, 2008,2008; Kim, 2008, 2010; 2008, 2010; Nakamura, 2008; Kanaya,2008; Kim, 2009, 2010; Duan, 2009; Greegor, 2009; Ouerdraogo, 2010; Pattnaik, 2010; Joshi,2011,2014). The Q_{rad} is derived from the bandwidth (BW) using Equation (3).

$$Q_{rad} = \frac{1}{BW} \tag{3}$$

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