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Mufti, Saad, Tennant, Alan and Seed, Luke (2015) Compact Electrically Small Antenna for Smart Watch Application. In: USES 2015 - The University of Sheffield Engineering Symposium, 24 Jun 2015, The Octagon Centre, University of Sheffield.

10.15445/02012015.103

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Compact Electrically Small Antenna for Smart Watch Application

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Abstract

With the rise in popularity of wearable gadgets and the birth of the internet of things, new challenges are presented to antenna engineers with respect to the design space available. To this end, a compact, electrically small inverted-F antenna is designed for use in a smart watch. The design is carried out in-vitro, using numerical modelling techniques, and is benchmarked against a traditional planar inverted-F antenna from literature. The novel design presented reduces the overall size of the antenna by a factor of 3.5. It has a gain of -12.7 dB, and a half-power fractional bandwidth of 32%, and is shown to operate well within the specific absorption rate regulatory limits when operated at 25 mW.

Keywords Electrically small antennas; Inverted-F antenna; Internet of things; Smart watch; Specific absorption rate.

1. INTRODUCTION

According to research firm International Data Corp. (IDC), the global market for the Internet of Things (IoT) is set to increase to $1.7 trillion by 2020, up from $650 billion in 2014 [1]. Another projection by research firm Gartner puts the total number of connected devices by 2020 at 25 billion, up from 7 billion in 2013 [2]. Clearly, this emerging sector is set to continue its exponential growth over the coming decade.

One of the key driving technologies of this sector are electrically small antennas (ESA) that can be fitted inside the often confined spaces of vanguard electronic gadgets such as smart phones, glasses, and watches. The unique challenge facing antenna designers is that while most electronics can be scaled down - provided power consumption and cooling requirements can be satisfied - antennas operate on a wholly different physical principle which makes them difficult to scale down for a particular desired frequency. As an example, the simplest of antennas, a dipole, is self-resonant when its total length is roughly equal to half the operating wavelength, which is related to the operating frequency by (1):

$$\lambda = c/f \tag{1}$$

where λ is wavelength, c the speed of light, and f the operational frequency.

For example, at 2 GHz, the wavelength is 150 mm, and thus the dipole must be 75 mm in length. Clearly we must look for novel solutions to reduce the antenna's electrical size (i.e. size relative to the wavelength); one solution is to use a type of antenna known as a planar inverted-F antenna (PIFA), which uses a combination of induced "image" currents, amongst other methods which have an effect on how well the antenna is matched to the power source [3]. One such antenna was recently investigated for use in a smart watch [4], where the maximum dimension of the antenna used is 64 mm, for operation at a resonance frequency of 2 GHz.

We present a novel, electrically small antenna, which reduces the total size by a factor of 3.5, and is based on the principle of inverted-F antennas (IFA) [3]. Section 2 gives an overview of this design process; section 3 shows the numerically simulated results of the antenna in-vitro; section 4 concludes this paper.

2. ANTENNA DESIGN

Figure 1 shows the schematic of the novel ESA.

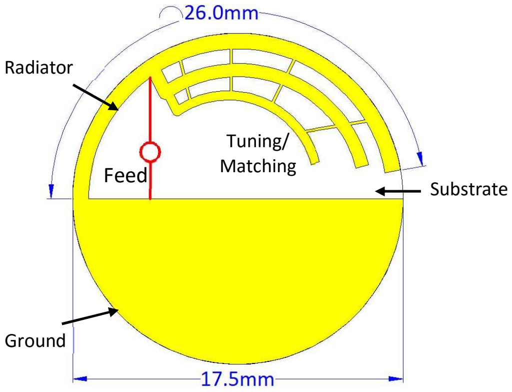

Figure 1. Schematic of ESA, based on an IFA design. The total diameter is 17.5 mm, the arc length of the radiator 26 mm; FR4 is support substrate.

The radiator has a unique structure consisting of two concentric arcs, connected by periodic fingers to the main arm; this allows us to tweak the impedance characteristics of the antenna parametrically, in turn ensuring that the antenna is optimally matched at the desired operating frequency. The input impedance is vital to antenna design, as it determines how much of the received power is accepted (and conversely reflected). Typically, we aim to match the antenna to a characteristic transmission line impedance value of 50 + *j*0 Ω. The characteristic input impedance of an antenna, $Z_{A(\omega)}$ can be expressed as (2):

$$Z_{A(\omega)} = R_{A(\omega)} + X_{A(\omega)} \tag{2}$$

where $R_{A(\omega)}$ *and* $X_{A(\omega)}$ are the resistive and reactive components, respectively. To get the best match to 50 + *j*0 Ω, we would like $R_{A(\omega)}$ to be as close to 50 Ω as possible, and $X_{A(\omega)}$ to be as close to be zero. The reactance, $X_{A(w)}$ consists of capacitive and inductive terms (3):

$$X_\omega = \omega L - 1/\omega C \tag{3}$$

where ω is the angular frequency, L is inductance and C is capacitance. Thus, we ideally want a situation where (4):

$$\omega L = 1/\omega C \qquad (4)$$

which is what the tuning/matching region shown in Figure 1 allows us to do.

3. RESULTS AND DISCUSSION

The return loss parameter for this antenna is given in Figure 2, and compared with the simulated results for the traditional PIFA design in [4].

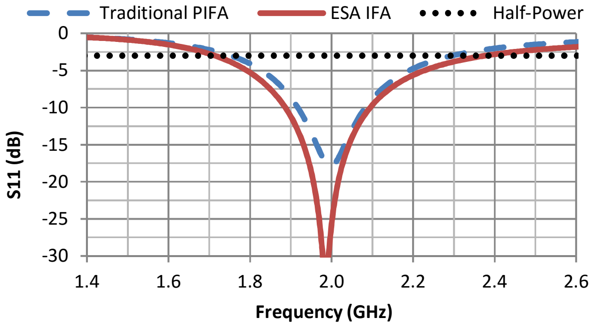

Figure 2. Return loss (S11) in dB for ESA-IFA compared with traditional PIFA, for a resonance frequency of 2 GHz. The lower the value, the better the match [3]. Fractional half-power bandwidth is region below -3 dB.

Figure 3 shows the specific absorption rate (SAR) for the ESA-IFA on a sliced 2D plane through the simulation setup, which consists of a human body phantom (skin, fat, muscle) model, and a rubber strap and plastic casing which houses the antenna, normalized to dB maximum. Table 1 shows the simulated and maximum SAR values, adhering to the IEEE C95.1-1999 standard [5].

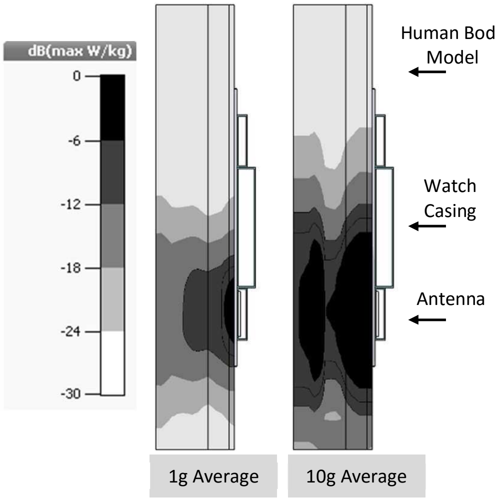

Figure 3. SAR cut-plane for ESA-IFA, showing the antenna, watch casing and body phantom, simulated for two different averaging methods (1g and 10g of tissue); normalized to maximum values as shown in Table 1.

SAR is essentially a measure of how much radiation is directed at, and thus absorbed by the body tissues when exposed to electromagnetic radiation; high values could lead to harmful long-term effects. Values are quoted in W/kg, and averaged over a certain mass of tissue.

Table 1. Simulated SAR (1 W input power) values for the antennas

Averaged Mass	Traditional PIFA	*Novel ESA-IFA*	Maximum Allowed	Regional Prevalence
1g	9.5 W/kg	*58.7 W/kg*	1.6 W/kg	US, Canada
10g	3.9 W/kg	*15.6 W/kg*	2.0 W/kg	EU, Japan

Both limits are satisfied by the ESA-IFA when driven with a typical input power of 25 mW. Finally, the gain of the ESA-IFA also suffers in comparison to the traditional PIFA design; at the operating frequency of 2 GHz, this is -12.7 dB versus -3.7 dB. However, using a dedicated comparison metric for electrically small antennas, described in detail in [6], namely the ratio of the quality factor (Q_{ratio}), we get an improvement by a factor of 2.4. Q_{ratio} is especially useful as it is a measure of the antenna's efficiency, fractional bandwidth, and electrical size; thereby making it easier to compare antennas of differing electrical dimensions.

4. CONCLUSIONS

A novel, compact, electrically small antenna design is described, for use in smart watch type applications, where the design space is prime real estate. The antenna, designed in-vitro, and compared with a traditional design, shows a reduction in size by a factor of 3.5. It is shown that the simulated SAR (measure of how much radiation is absorbed in the body) is well within regulatory limits for typical low-power applications. The gain (measure of directed power), of the novel antenna suffers due to this reduction in size, but using a performance metric widely used for ESA, the quality-factor ratio, we see an improvement over the traditional design of a factor of 2.4. Our future work will include measurements and SAR reduction techniques for this antenna setup.

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