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ELECTRICALLY SMALL ANTENNA FOR BROADBAND OPERATION

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I. Introduction

An electrically small antenna is referred to an antenna for which kr<1, where k is the wave number at the center frequency of the antenna and r is a radius of the smallest sphere that can enclose the antenna. It is well known that an electrically small antenna with high efficiency generally has a narrow bandwidth because the quality factor, Q, is very high. Since the quality factor is inversely proportional to the bandwidth, reducing its value is critical to achieving broad bandwidth. The quality factor of a small antenna is closely related to the smallest sphere that can enclose the antenna, and it can be minimized through the effective use of the given sphere [1]. Several types of small antennas have been investigated to overcome the bandwidth problem based on this theory [2-5]. However, further enhancement of the bandwidth without sacrificing other antenna characteristics is extremely difficult due to fundamental limitations. According to the circuit theory, it always has the effect of lowering the overall Q if the resonant circuit is coupled to the other circuitry, which usually operates as a matching circuit. In the design of an electrically small antenna a matching circuit can be employed, but this makes the antenna structure more complicated and requires additional space. However, if the small antenna has two radiating resonant circuits and one of the circuits is being function as a self matching circuit to the other circuit, then the bandwidth of the antenna can be enhanced by using a mutual coupling between the two radiators that are located in very close proximity to each other.

In this paper, we present an antenna structure that greatly increases the bandwidth of an electrically small antenna with high efficiency. The proposed structure consists of a disk-loaded and a spiral strip-loaded monopole packed within a small cylindrical or cubical structure. Bandwidth enhancement can be achieved partly by cancellation of the reactance between the undriven disk loaded monopole and the driven spiral strip loaded monopole, and partly by a higher order circuit operation due to a mutual electromagnetic coupling between the two monopoles. The experimental results showed that the circular disk-loaded monopole antenna enclosed within a sphere having kr=0.563 has 430 MHz of impedance bandwidth for VSWR<2 with the center frequency at 2.185 GHz, and the rectangular disk-loaded monopole antenna with kr=0.575 has 336 MHz of impedance bandwidth with the center frequency of 2.038 GHz.

2. Antenna geometry and characteristics

The geometry of the antenna is shown in Fig. 1. The circular disk with a radius of ρ is placed at a height of h from the ground plane, and the center of the circular disk is connected to the ground plane by a pin with a diameter of ϕ_1. The antenna is excited through a coaxial probe with a diameter of ϕ_2, which is connected at the end of the spiral strip line located at h_f from the ground plane. The length and width of the spiral strip line are l_s and w_s, respectively. The total length of the probe and spiral strip line is approximately 0.25λ at the resonant frequency. The centers of the pin and probe are spaced d distance apart. The circular disk is placed on a substrate with a dielectric constant of ε_{r1}=10.2 and a thickness of h_1=1.27 mm (RT/Duroid 6010). The substrate for the ground plane has a dielectric constant of ε_{r2}=3.38 and a thickness of h_2=0.81 mm (RO 4003).

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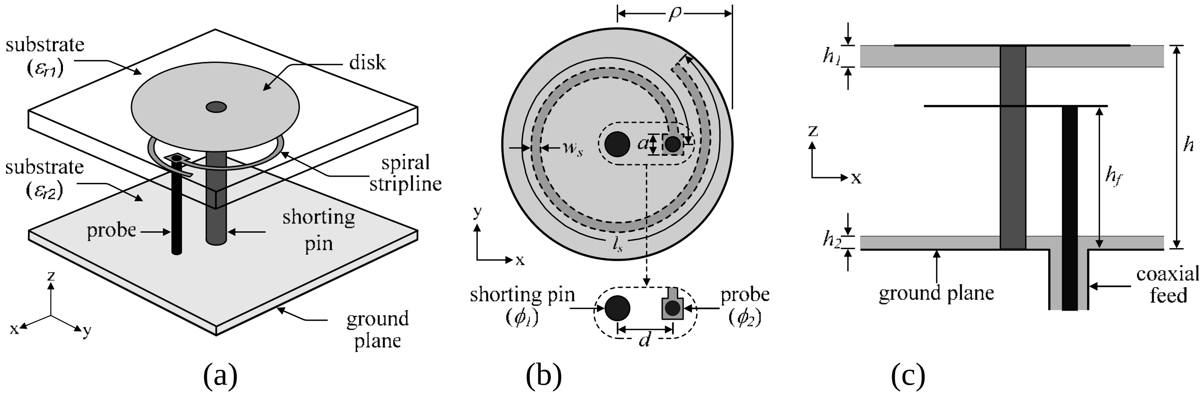

Fig. 1. Circular disk-loaded monopole antenna: (a) 3-dimensional view, (b) top view, (c) side view.

The IE3D simulator of Zeland Software was used to study the characteristics of the antenna. The design parameters of the antenna are ρ=5.5 mm, h=11 mm, ϕ_1=1.6 mm, ϕ_2=0.86 mm, h_f=8.0 mm, l_s=31.5 mm, w_s=0.4 mm, and d=3.4 mm. The input impedance characteristics with these design parameters are represented on Fig. 2 as the solid line. To determine the influence of top loading on an undriven monopole, we simulate the input impedance characteristics with the presence of only the stripline loaded monopole (without the circular disk-loaded monopole), and the result is shown as the dashed line in Fig. 2. The impedance characteristics of this monopole are not very good because the height of the spiral strip line is much lower than a wavelength of the resonant frequency. However, the impedance characteristics in the presence of both the spiral stripline loaded monopole and the circular disk loaded monopole show dual resonance at 2.02 GHz and 2.28 GHz with good impedance matching. To see this more closely, we changed the distance *d* between the shorting pin of the circular disk and the probe on the spiral strip line from 2.5 mm to 12.5 mm. As can be seen from Fig. 3, the distance of *d* has a strong influence on the electromagnetic coupling between the two monopoles. The impedance locus in the Smith chart moves to the right and its loop of the impedance locus enlarges as *d* increases from 2.5 mm to 8.5 mm, so the coupling between the two monopole is maximized approximately when *d*=8.5 mm. At that point, however, the loop of the impedance locus begins to shrink as *d* continues to increase, and thus the coupling begins to decrease. This clearly indicates that the electromagnetically coupling between the two monopoles makes the dual resonances resulting in broadband operation.

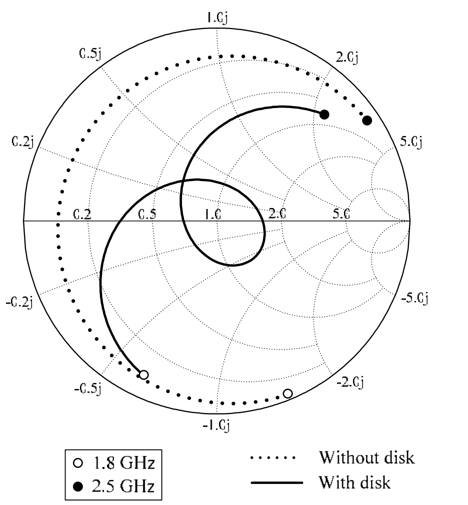

Fig. 2. Impedance characteristics of the antenna with and without a shorted circular disk.

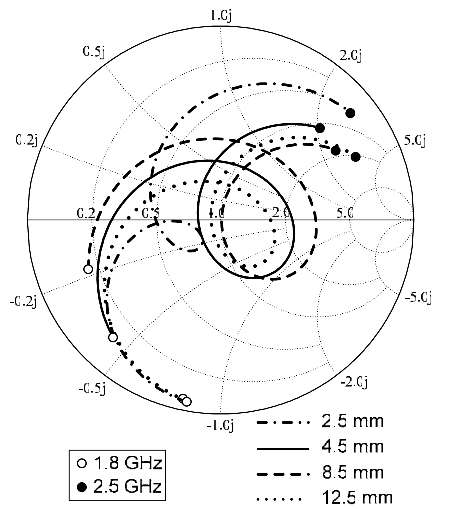

Fig. 3. Impedance characteristics with respect to the distance between two monopole.

Table 1. Comparison of the properties of the electrically small antennas.

	kr (VSWR<5.8)	Bandwidth (VSWR<2)	Bandwidth (VSWR<5.8)
Goubau's antenna	1.0	62.0%	82.0%
Foltz's antenna	0.729	9.52%	41.12%
	0.630	12.9%	21.85%
Dobbins' antenna	0.710	10.9%	28.6%
Rectangular disk	0.575	16.5%	27.5%
Circular disk	0.563	19.7%	30.2%

4. Measured results

The antenna was fabricated on a ground plane with the size of 50 × 50 mm^2, and the measurement was carried out by using an HP8510C network analyzer. Figure 4 shows the return loss of the circular disk monopole antenna. The measured results match well with the EM simulation. The measured impedance bandwidth for VSWR<2 is from 1.97 GHz to 2.40 GHz, which is approximately 19.7% at the center frequency of 2.185 GHz. The design parameters of the rectangular disk-loaded monopole antenna are L=11mm, W=11 mm, h=11 mm, ϕ_1=1.6 mm, ϕ_2=0.86 mm, h_f=7.5 mm, l_s=37.2 mm, w_s=0.5 mm, and d=3.6 mm. The measured impedance bandwidth for VSWR<2 is from 1.87 GHz to 2.206 GHz, which is approximately 16.5% at the center frequency of 2.038 GHz. The center frequency of the rectangular disk-loaded monopole antenna is 185 MHz lower than that of the circular disk-loaded monopole antenna. If the length and width of the rectangular disk is equal to the diameter of the circular disk, the area of the rectangular disk is larger than that of the circular disk. Thus, the parallel capacitance of the disk-loaded monopole has a higher value and the resonant frequency of the antenna with the rectangular disk is lower than that of the antenna with the circular disk. Figure 5 shows the measured efficiency of the antennas. Efficiency is an important concern in the design of electrically small antennas. The Wheeler cap method is the standard method of measuring the efficiency of a small antenna [2]. The measured efficiencies of the circular and rectangular disk-loaded antennas are 98% and 95%, respectively, at their center band regions.

Table 1 shows comparison of the proposed antennas with other electrically small antennas. The size of the antenna is defined by *kr*. In order to compare the resulting bandwidth to the fundamental limit derived by [1], we plot the performance based on half power bandwidth (based on VSWR<5.8) as shown in Fig 6. The solid line (loaded) and dash line (unloaded) are based on the fundamental limits for small antennas. The rectangular disk-loaded monopole shows a half power bandwidth that closely approaches to the fundamental limit. Moreover, the circular disk-loaded monopole antenna shows superior bandwidth characteristics that slightly pass over the fundamental limit.

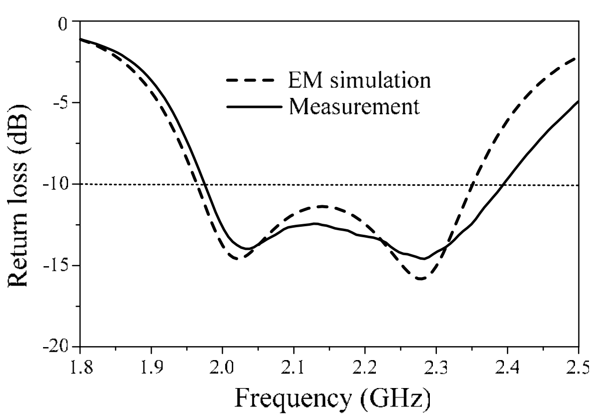

Fig. 4. Measured return loss of the circular disk loaded antenna

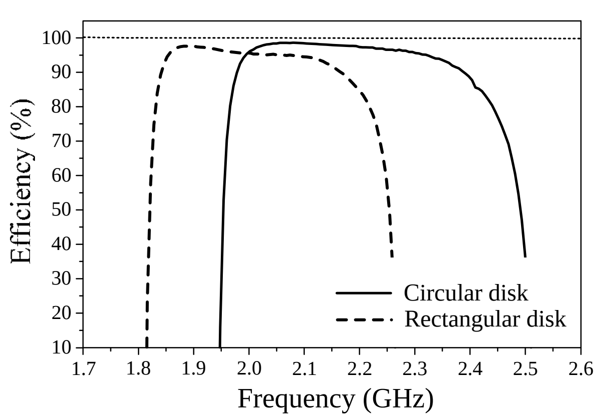

Fig. 5. Measured efficiency using the Wheeler cap method.

4. Conclusion

A small broadband antenna consisting of a disk-loaded monopole and a spiral strip line loaded monopole was presented in this paper. The proposed antenna was able to control the resonance frequency by varying the capacitance and inductance of the two monopoles. Broad bandwidth was achieved through an electromagnetic coupling between these two monopoles that is able to generate two resonances spaced closely together in frequency. The circular disk antenna fits within *kr*=0.563 and the rectangular disk antenna fits within *kr*=0.575. Although the electrical dimensions of antennas are very small, the measured impedance bandwidth of the circular disk-loaded monopole antenna is 430 MHz (VSWR<2) with the center frequency at 2.185 GHz and the bandwidth of the rectangular disk-loaded monopole antenna is 336 MHz with the center frequency at 2.038 GHz. The half power bandwidth of the rectangular disk-loaded monopole antenna closely approaches to the fundamental limit while the circular disk-loaded monopole antenna slightly pass over the fundamental limit. It also shows that both antennas have good measured efficiency of over 95% around their center band.

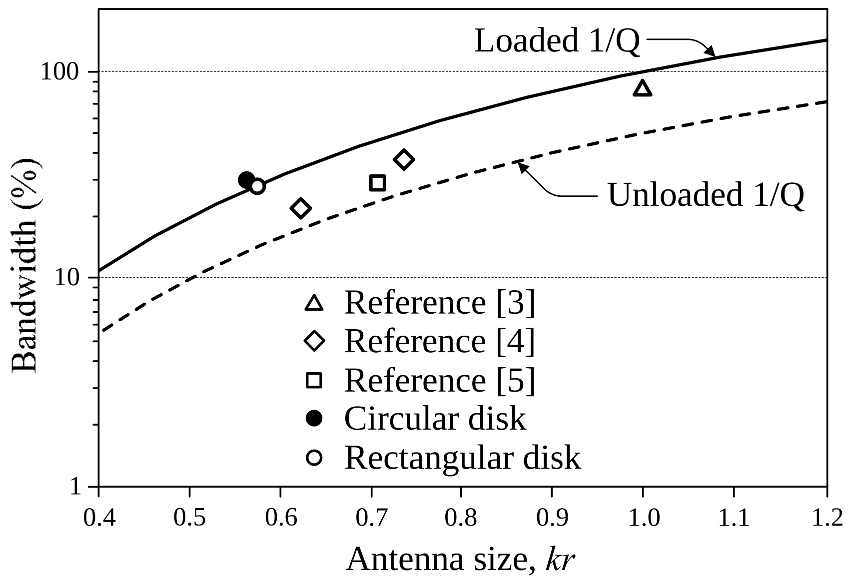

Figure 6. Comparison of half-power bandwidth for electrically small antennas.

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