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Miniaturized self-resonant split-ring resonator antenna

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Abstract: A self-resonant miniaturized antenna composed of a broadside-coupled split ring resonator (SRR) and an excitation arc-shaped monopole is presented. The size of the antenna and its resonance frequency is essentially defined by the SRR dimensions and geometry, while the input resistance at the resonance is governed by the arc length of the monopole. Numerical and experimental results are presented for an antenna configuration of 1/23.4 wavelength in diameter (ka~0.134). The antenna is tuned to 50 ohms without any matching network, and its efficiency is measured to be 17.5%.

Introduction: Metamaterial structures are able to sustain strong subwavelength electromagnetic resonances and thus potentially applicable for antenna miniaturization [1]. A recognized practical way to build these artificial materials at microwaves is to distribute resonant metal and/or dielectric elements in a volume. To achieve a reasonable homogenization effect the size of these resonant elements should be much less than the free-space wavelength. On the other hand, an electrically small antenna can be designed using a resonant element itself instead of the metamaterial it is meant for. One of the earliest examples is a dielectric resonator antenna (DRA) [2], which is essentially a resonant dielectric particle excited by a monopole. Recently, this metamaterial-inspired approach was pursued in [3] with very promising results.

In this Letter we report on a miniaturized antenna based on a split-ring resonator (SRR) [4], which is one of the most popular metamaterial building blocks today. Due to their outstanding miniaturization potentialities and ability to produce strong electromagnetic response, SRRs form a very attractive basis for designing electrically small antennas. For our purposes we have selected the broadside-coupled SRR (BS-SRR) due to its favourable radius to wavelength ratio as compared to other SRR structures [5].

Antenna geometry and properties: An SRR-based antenna is composed of a split-ring resonator and an excitation arc-shaped monopole, which is circumscribed about or inscribed in the SRR. We employ the symmetry of the BS-SRR structure and place the antenna on a metal ground plane. The monopole can be made of a wire, or it can be a strip printed on the same substrate as the SRR. Figure 1 depicts the configuration with the strip monopole inside as this is the most compact and robust design, although other configurations demonstrate equally good electromagnetic performance. The antenna operates slightly below the SRR resonance frequency, where a high inductive reactance of the SRR balances a large capacitive reactance of the monopole. Since this is a highly resonant electrically small antenna, it is very sensitive to the geometry and losses in the structure. On the other hand, the proposed design possesses excellent tuning capabilities that by far compensate its sensitivity. As we show below the antenna input resistance at the resonance can be changed in a wide range simply by varying the monopole arc length (parameterised by the angle α in Fig.1). Furthermore, the tuning process does not affect the antenna size, and the resonance frequency remains nearly the same. The tuning can even be done in-place thus compensating for simulation and manufacturing inaccuracies as well as for antenna environment. This is a major advantage of the proposed antenna over a loop-excited configuration [6], where such in-place tuning is not possible and complete redesign of the whole antenna is required if the input impedance needs to be changed.

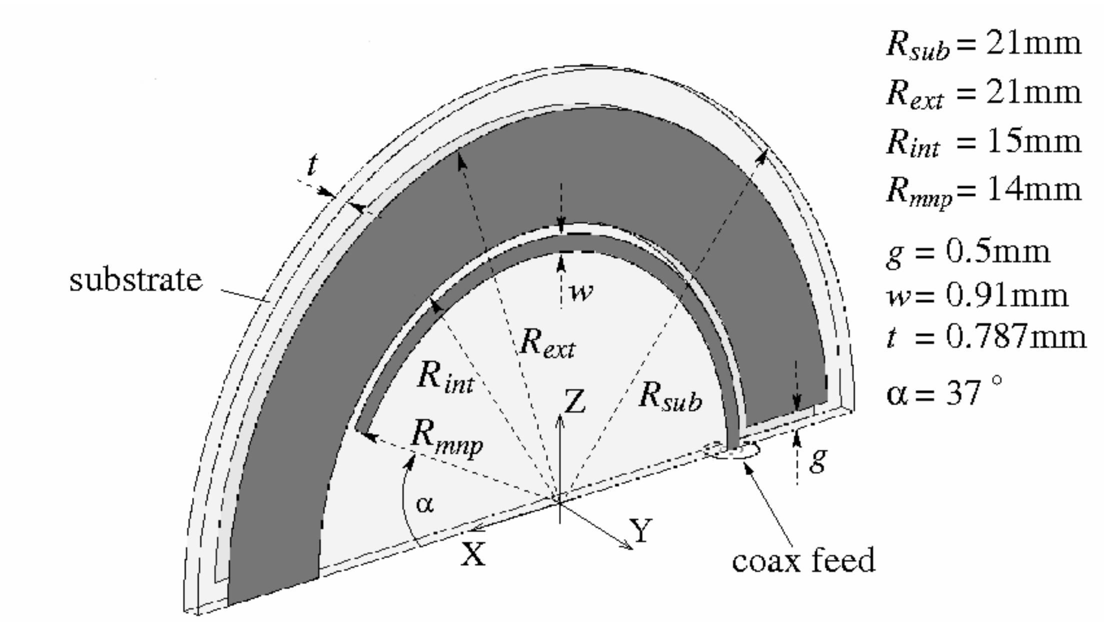

Fig. 1 Geometry of the SRR-based electrically small antenna

Simulations and measurements: Our antenna design utilises Rogers 5870 Duroid 31 mils (0.787 mm) thick substrate with 17 μm copper cladding. The ground plane is made circular and limited to 400 mm in diameter. For the geometrical parameters summarized in Fig.1 and a 50-ohm coaxial feed line, HFSS predicts the return loss plotted in Fig.2. In the simulations the geometry resolution was set to 0.05 mm while the conductivity of the metal parts was assumed to be that of copper - 5.7×10^{7} S/m. The maximum radius of the antenna (excluding the ground plane) is a = 21 mm, which corresponds to an electrical size of *ka* ~ 0.134 (*k* is the free space wavenumber). The resonance frequency (f_0), the quality factor (*Q*) calculated using [7,eq.(86)], the Chu limit value [8] (Q_{Chu}) for an antenna with *ka* ~ 0.134 and the radiation efficiency (η), and the peak directivity (*D*) are given in Table 1.

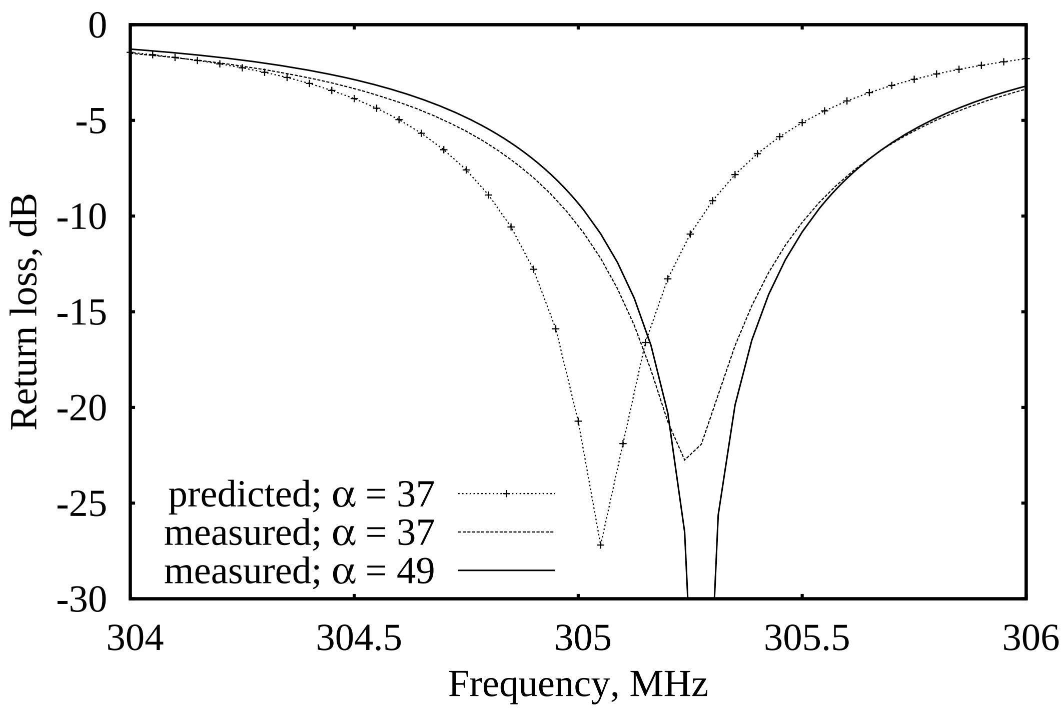

Fig. 2 Predicted and measured return loss

Table 1: Predicted and measured electrical characteristics of the antenna with α=37°.

	f_0, MHz	Q	Q_{Chu}	η, %	D, dB
Predicted	305.06	437.9	71.5	17	4.67
Measured	305.22	407.0	73.5	17.5±1.5	4.3±0.1

A prototype of the designed antenna was manufactured (Fig.3). First, the SRR and the excitation strip monopole were printed on the substrate using photolithography. Then, they were cut out and soldered to the copper ground plane. Soldering in three places provided enough stiffness so the antenna did not require any additional support. Measurements were performed at the DTU-ESA Spherical Near-field Antenna Test Facility and the results are presented in Fig.2 and Table 1 for comparison. It is observed that the measured results agree very well with the simulations. The measured radiation pattern corresponds to that of a Y-directed magnetic dipole with a crosspolarization level below -20 dB for θ<±70°.

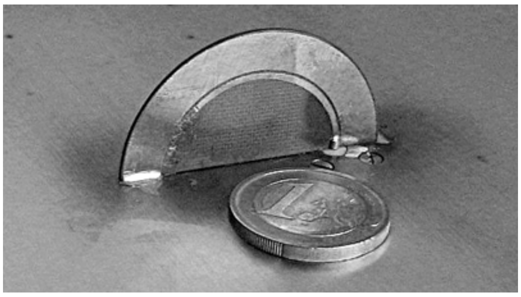

Fig. 3 Manufactured prototype of the SRR-based electrically small antenna

To verify the tuning capabilities of the antenna the initial arc length of the monopole was made longer than necessary. Then, the length was gradually reduced by cutting away short pieces while the input impedance of the antenna was measured. The obtained input resistance and the corresponding resonance frequency are plotted in Fig.4 as functions of the angle α. It is observed that the resistance is inversely proportional to the arc length of the monopole, while the resonance frequency stabilizes for $\alpha > 20°$. The later dependence reveals that the resonance frequency of the antenna is essentially determined by the SRR resonance, and the input impedance of the antenna is independently controlled by the monopole arc length. For instance, by changing the angle α from 37° to 49° we tuned the antenna virtually exactly to 50 ohms without affecting the resonance frequency as illustrated in Fig.2. Thus, experimental results positively confirmed our expectations with respect to the outstanding tuning capabilities of the antenna.

Conclusions: The proposed electrically small antenna is self-resonant and can be tuned to a wide range of feed line impedances without any extra matching network. The size of the antenna and its resonance frequency is essentially defined by the SRR. With the broad-side coupled SRR the antenna can theoretically be matched at any size. The practical limit is set by available material losses and manufacturing accuracies. By building a $\lambda/23$ antenna with excellent matching characteristics and relatively high efficiency we have shown that the proposed antenna structure is feasible and especially attractive for practical applications due to its unique tuning capabilities which allow simulation and manufacturing inaccuracies to be compensated in-place.

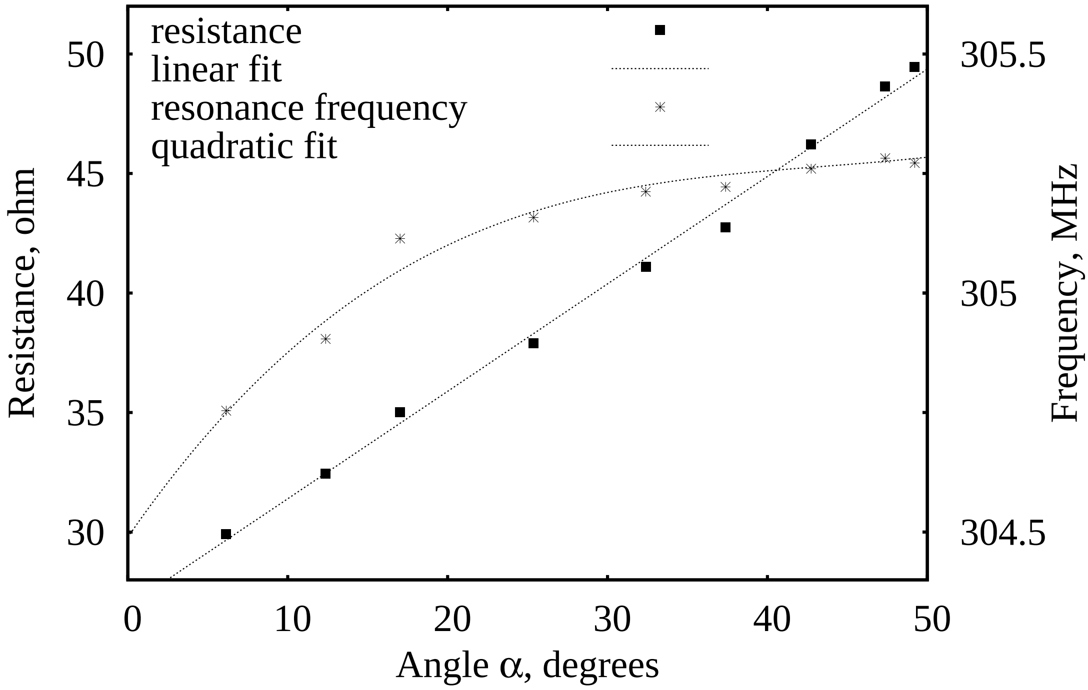

Fig. 4 Measured resonance frequency and input resistance at the resonance

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