2017

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Recommended Citation

A. Narbudowicz, M. J. Ammann and D. Heberling, "Electrically small antenna with switchless pattern reconfiguration," 2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2017, pp. 1201-1202, doi: 10.1109/APUSNCURSINRSM.2017.8072643.

Electrically Small Antenna with Switchless Pattern Reconfiguration

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***Abstract*—An electrically small pattern reconfigurable antenna is proposed. It allows adjustment of the radiation pattern by applying a phase shift between its two ports. The structure is a cylinder with λ/5 diameter. Simulated results show good operation at 2.44 GHz and three different radiation patterns are demonstrated by applying three different phase shifts. The antenna's principles of operation and limitations are explained based on the theory of spherical modes.**

Keywords—reconfigurable antenna; electrically small antenna; antenna miniaturization; dielectric loaded antenna; smart antenna

I. Introduction

Antenna miniaturization and Electrically Small Antennas (ESA) are becoming more and more popular, mainly due to increasing need for compact wireless devices (e.g. as required for Internet of Things). If the design of standard ESA is challenging [1], than the design of ESA with pattern reconfiguration is even more so. Standard techniques rely on the use of switches (e.g. pin-diodes), which re-route the aperture current. This however strongly limits the use of digital beamforming or MIMO techniques.

Switchless reconfigurable antennas have been proposed to allow radiation pattern reconfiguration without the above limitations [2]. This is typically realized by a multi-port antenna, where each port generates a radiation pattern with similar amplitude (i.e. omnidirectional) but linear phase variation as a function of angle θ. By varying phases at each port's excitation one can superimpose the patterns and therefore control the direction of radiation. The antenna offers resolution similar to a small array, but with reduced size as it does not require any spacing between elements.

The dimensions of the original antenna in [2] are slightly below is λ/2 however the conclusions [2] outline a potential for much greater miniaturization. This paper presents preliminary results, obtained with CST Microwave Studio, that show the reconfigurable antenna implemented as an electrically small antenna, with cylinder that has λ/5 diameter.

This work was supported by Irish Research Council under "ELEVATE: Irish Research Council International Career Development Fellowship – co-funded by Marie Curie Actions", grant no. ELEVATEPD/2014/79.

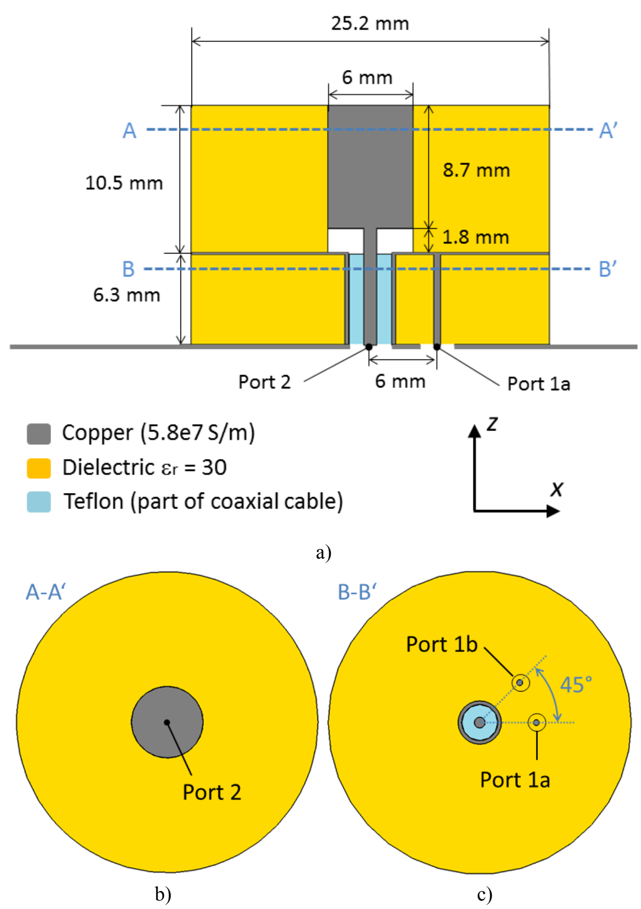

Fig. 1. Proposed antenna: a) cut in *xz*-plane (vertical) with key parameters; b) horizontal cut along A-A' line (upper section); c) horizontal cut along B-B' line (lower section).

II. Antenna

Fig. 1 depicts the proposed antenna. It comprises of two sections (upper and lower), each built with copper and dielectric material of relative permittivity $\varepsilon_r = 30$.

The upper section is a dielectric loaded monopole. It consists of a copper cylinder which is 8.7 mm high and has

6 mm diameter. It is soldered to a 50 Ω coaxial cable (port 2), where the inner conductor protrudes by 1.8 mm above the ground plane separating upper and lower sections. The ground plane is connected to the outer conductor of the coaxial cable. The structure is surrounded by a cylinder made of high-permittivity dielectric ($\varepsilon_r = 30$). The cylinder has a diameter of 25.2 mm (λ/5) and its central section was removed to accommodate the copper monopole.

The lower section is a patch antenna operating in TM_{21} mode. The circular patch is 6.3 mm high and 25.2 mm in diameter. It is loaded with high-permittivity dielectric ($\varepsilon_r = 30$). It has two feeding pins oriented at 45° in order to excite two orthogonal TM_{21} modes. Each pin is connected to a 50Ω coaxial port, denoted as 1a and 1b. To generate phase variation around the outer perimeter of the patch ports 1a and 1b are fed with 90° phase shift with respect to each other and combined into a single port 1. The whole structure is placed on a circular copper ground plane of 40 mm radius.

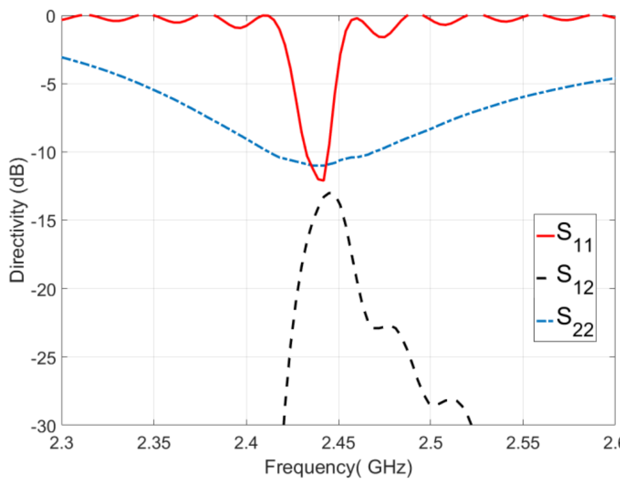

Fig. 2. Simulated S-parameters of the proposed antenna.

III. Results and Discussion

Fig 2 illustrates the S-parameters of the proposed antenna. It can be seen, that the antenna operates at 2.44 GHz with good impedance match. The lower section (port 1) exhibits much narrower bandwidth than the upper section (port 2). The simulated radiation efficiencies for the antenna with lossless dielectric are 55% for port 1 and 93% for port 2. Since the dielectric is lossless, those losses originate solely due to the antenna's small size and are consistent with observed bandwidth. Such a big discrepancy between port 1 and 2 (for both bandwidth and efficiency) might be at first surprising, given that upper and lower sections are of comparable sizes and operate same frequency. The reason for this is that the lower section is designed to generate phase variation across its pattern. The phase variation requires radiation that comprises of higher order spherical modes. Those modes exhibit greater "cut-off radius", i.e. a minimum radius of a sphere enclosing antenna that can support given spherical mode. On the contrary, the upper section is a monopole and thus generates one of the basic spherical modes, i.e. torus-shaped amplitude

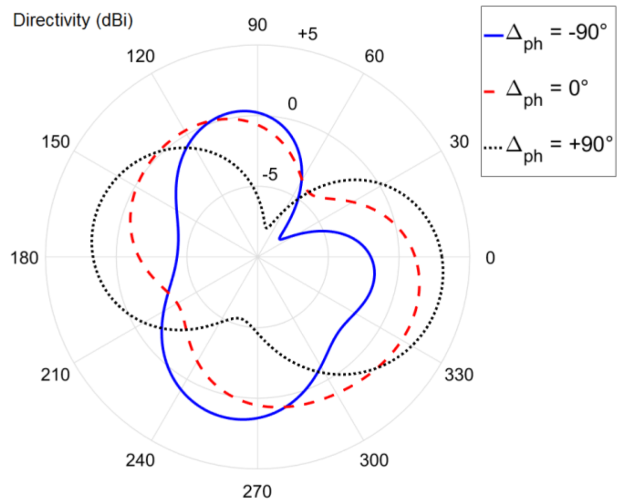

Fig. 3. Directivity of the proposed antenna for various phase shifts Δ_{ph} (xy-plane; 2.44 GHz).

with no phase variation. It is known from the literature (e.g. [3]) that this mode can be supported by structures much smaller than λ/5, hence relatively wide bandwidth and no significant losses at port 2.

The antenna's efficiencies with lossy dielectric are respectively reduced to 23% and 91% at ports 1 and 2. This additional loss at port 1 comes due the operating principle of patch antenna. To compensate for this the signal fed to port 1 uses 4-times stronger amplification. Fig. 3 demonstrates directivities of the antenna for three cases, where Δ_{ph} denotes the phase shift between port 1 and 2. It can be seen that the phase shift Δ_{ph} rotates the radiation pattern, albeit some perturbations and irregularities are observed as compared to bigger version in [2]. This is most likely due to the reduced size and inability to form linear phase variation at the outer perimeter of the lower section.

IV. Conclusion

The paper discusses preliminary results to miniaturize the switchless reconfigurable antenna proposed in [2]. The structure was reduced to a cylinder of λ/5 diameter while preserving its reconfiguration capabilities, albeit at the price of increased losses and reduced bandwidth. It was also demonstrated that the main limitation for this type of reconfigurable antenna is its reliance on higher spherical modes, which require greater "cut-off radius" as compared to standard electrically small antennas relying on lowest spherical modes.

References

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