

Spiral Resonator Mu-Near-Zero Substrates for Grounded Slot Antennas

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Abstract— Artificial magnetic material (AMM) slabs composed of spiral resonators (SRs), operating in the mu-near-zero (MNZ) band, $0 < \mu_r < 1$, are investigated as slot antennas substrates for broadside radiation and directivity enhancement. Results for the slot antenna in free-space are compared with the slot antenna in presence of a single-layer and a four-layer SR AMM slabs.

I. INTRODUCTION

Electric sources embedded in grounded low electric permittivity ($0 < \epsilon_r < 1$, epsilon near zero or ENZ) substrates may produce highly directive beams at broadside, leading to the design of a leaky wave antenna (LWA) [1]. This property could also be extended to magnetic dipole sources (e.g., slots) embedded in grounded low magnetic permeability ($0 < \mu_r < 1$, epsilon near zero or MNZ) substrates [2].

Artificial magnetic materials (AMMs) composed of spiral resonators (SRs) were presented in [3]. AMMs are characterized by their mu-dispersive behaviour, presenting a resonant frequency f_0 (where μ_r takes negative values), and a plasma frequency f_p (where μ_r becomes positive again). Thus, there is a region after f_p where $0 < \mu_r < 1$ (MNZ). Some initial results were presented in [4] using a single layer SR AMM slab as MNZ substrate to enhance broadside radiation of a grounded slot antenna.

In this paper, single-layer and four-layer SR AMM slabs have been used to test the broadside radiation enhancement of a grounded slot antenna as LWA, while overcoming some limitations found in [4].

II. MNZ SUBSTRATE DESIGN

The unit cell of the SR AMM slab described in [3] is composed of a two-turn square spiral resonator, with a major width of 5.6 mm, which is printed on a Rogers RO4003C dielectric substrate (thickness is 0.8 mm, ϵ_r is 3.38, and $\tan\delta$ is 0.0027). The AMM slabs are characterised by their resonant frequency f_0 , that is, the frequency where the phase of the reflection coefficient S_{11} is equal to 0° . The resonant frequency of the single layer SR AMM slab is found at 2.6 GHz. Further details about this SR AMM design are found in [3].

The effective parameters of these designs have been extracted using the retrieval method presented in [5]. The extracted relative magnetic permeability μ_r where f_0 is found at 2.55 GHz and f_p is found at 3.17 GHz. So, the MNZ behaviour of these SR AMM slabs is expected above 3.2 GHz.

III. SLOT ANTENNA AND MNZ SUBSTRATE FABRICATION

The slot antenna is placed at the centre of a $400 \text{ mm} \times 400 \text{ mm}$ metallic ground plane. The initial ground plane [4] was only $120 \text{ mm} \times 120 \text{ mm}$, which produced many undesired results due to its small size. The slot has a rectangular shape with dimensions $2 \text{ mm} \times 30 \text{ mm}$ (fed with a waveguide and resonates around 4.8 GHz). The MNZ substrates are then placed just over the slot, with the strips containing the SRs aligned in the direction of the E-plane (x direction) of the slot antenna, in order to properly excite the SR AMM slabs. A sketch of the slot antenna is depicted in Fig. 1, and the same design in presence of a SR MNZ slab is depicted in Fig. 2.

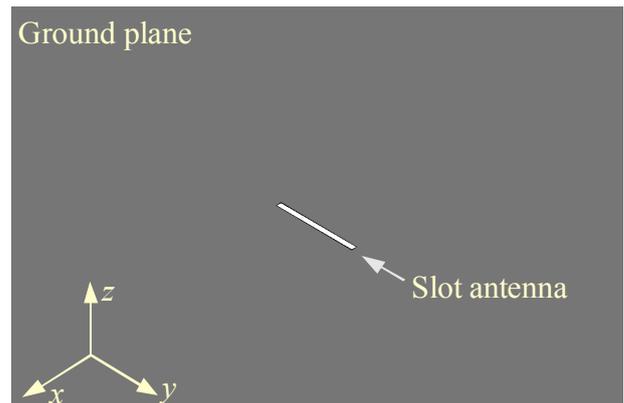


Fig. 1: Sketch of the ground plane with the slot antenna.

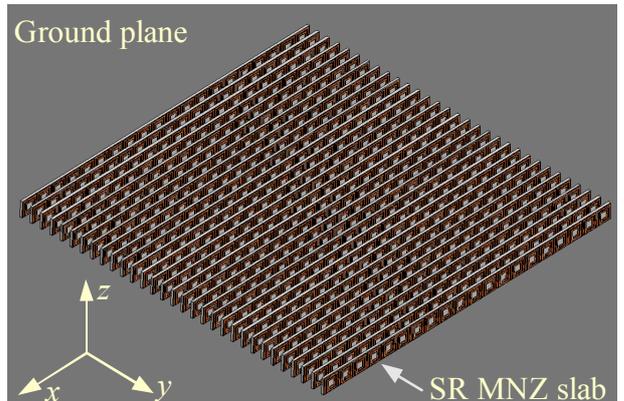


Fig. 2: Sketch of the ground plane with the SR MNZ slab above the slot.

The single layer SR AMM substrate is composed of 31 strips (with 20 SRs printed in each one), with a separation of 4 mm between adjacent strips, forming a $120 \text{ mm} \times 120 \text{ mm} \times 6 \text{ mm}$ slab. On the other hand, the four-layer SR AMM substrate is similar to the single-layer one but contains 4 SRs layers, which increase the overall height from 6 to 24 mm. The fabricated slot antenna and MNZ substrates (single-layer and four-layer) are shown in Fig. 3.

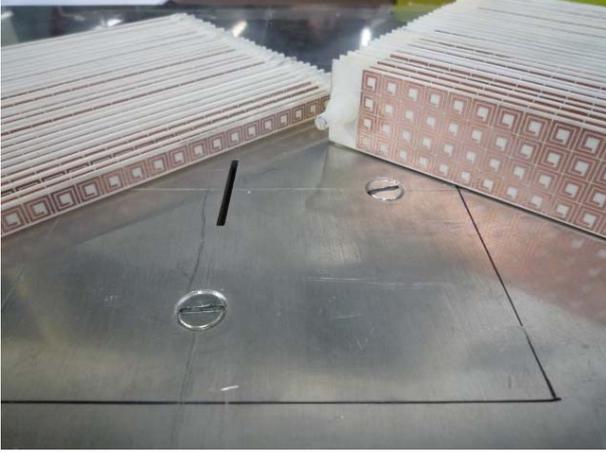


Fig. 3: Fabricated slot antenna and the single-layer and four-layer SR MNZ substrates.

IV. MEASUREMENTS

The fabricated MNZ substrates have been placed over the slot. The input impedance ($|S_{11}|$) has been measured for the three cases: slot antenna (in air), slot antenna with the single-layer MNZ substrate (MNZ1) and with the four-layer MNZ substrate (MNZ4). The measured results are plotted in Fig. 4, where it is shown that the slot antenna matching level is decreased when using the MNZ substrates. However, besides the matching level value, the operational frequency is shifted towards lower frequency as the number of SR MNZ layers is increased.

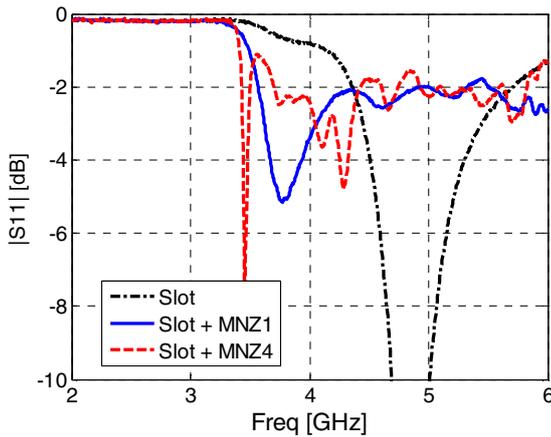


Fig. 4: Measured absolute value of the S_{11} coefficient of the slot antenna alone, and with the MNZ1 and MNZ4 substrates.

The radiated power at broadside has been measured in the UPC anechoic chamber. The results for the three cases are plotted in Fig. 5. It is observed that the slot antenna has its maximum radiated power around 4.8 GHz. When using the MNZ substrates, the radiated power is increased with respect to the slot case. For instance, at 3.46 GHz, the radiated power is increased in about 13.1 dB when using the MNZ1, and in about 19.1 dB when using the MNZ4, with respect to the slot antenna in free-space.

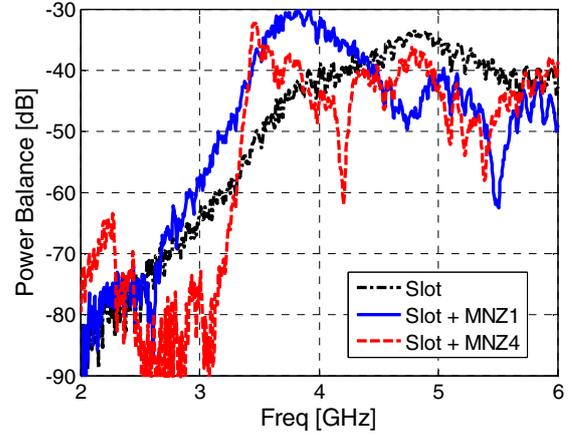


Fig. 5: Measured radiated power at broadside as a function of the frequency.

In [2], they stated that when using a MNZ substrate there is not only a power enhancement, but also a directivity enhancement. We have to note that we are using suboptimal MNZ substrates (thickness is smaller than λ) with 1 and 4 layers (the optimum would have about 16 layers), so the leaky waves responsible of the directive beam would not be completely excited. However, the E-plane (xz -plane) and H-plane (yz -plane) radiation patterns have been measured at 3.46 GHz, where there is the maximum broadside radiated power enhancement, and they are plotted in Fig. 6 and in Fig. 7. From the results, it is concluded that a slight directivity is found for the E-plane, which corresponds to the direction of SRs excitation.

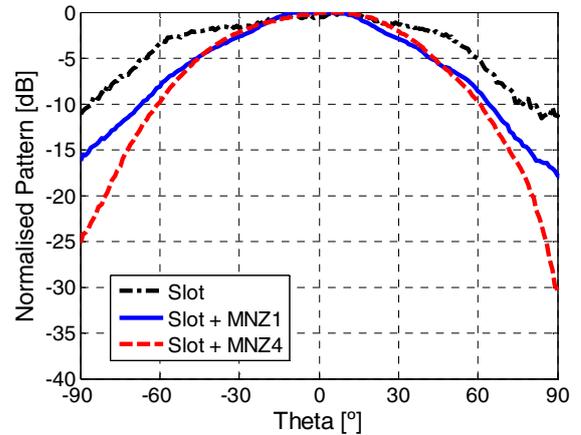


Fig. 6: Measured E-plane (xz -plane) at 3.46 GHz.

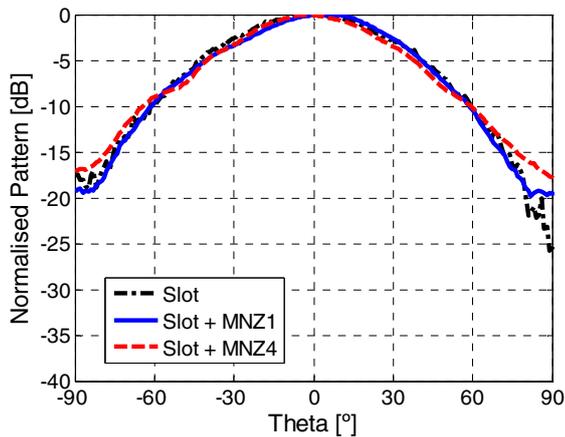


Fig. 7: Measured H-plane (yz-plane) at 3.46 GHz.

Moreover, the overall directivity of the slot antenna in presence of the MNZ slabs could be computed using the half power beam width from each main radiation plane. At 3.46 GHz, the slot has a directivity of 7.8 dB, whereas the MNZ1 and MNZ4 have a directivity of 10.4 dB and 10.3 dB, respectively.

V. CONCLUSIONS

The use of spiral resonator MNZ substrates to enhance broadside radiation of a grounded slot antenna has been experimentally verified. The radiated power at broadside, when using the MNZ4 substrate, is increased in about 19 dB with respect to the slot antenna in free-space. However, the directivity enhancement is poor at these frequencies, although it is expected to be higher if thicker MNZ substrates (more than 4 layers) are used.

ACKNOWLEDGMENT

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