Polarization Insensitive and Transparent FSS for Flexible Electronics Applications

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Abstract— This paper proposes a polarization-insensitive, dual-band FSS reflector with a 45° maximum stable incident angle. A novel design, which evolved from fractal cross dipoles, is presented for GSM bands shielding. Due to the quadruple symmetry structure, the response of the proposed FSS is consistent for both TE and TM incident waves. A prototype, realized through a custom silver nanowires based transparent ink on a flexible PET sheet, demonstrates over 80% optical transparency. Simulations and measurements are in agreement, showing good reflection performance from 0.71 to 1.25 GHz and from 1.73 to 2.16 GHz. The printed FSS is a good candidate for various shielding applications in flexible transparent electronics.

Keywords— Frequency Selective Surface, Fractal Cross FSS, Dual Band, Polarization Insensitivity, Screen Printing.

I. INTRODUCTION

With the proliferation of wireless devices adapting new frequency bands, there are growing concerns related to radio interference as well as the effects of electromagnetic energy on human health. In medical applications, for example, GSM band signals, located at 0.9 and 1.8GHz with approximately 10% bandwidth, have been reported to cause EMI interference with medical devices [1]. Therefore, novel solutions for EM shielding are being sought. Frequency selective surface (FSS), as the name indicates, is a suitable candidate for shielding at the desired frequency bands only [2]. To shield glass surfaces, such as window glass in a car or home, or a baby incubator, from GSM signals, optically transparent and mechanically flexible FSS structures are highly desirable.

For efficient GSM shielding, FSS is required to be as insensitive to the angle of incidence as well as the polarization of the incident EM wave as possible. For example, in [3], two independent periodic copper patterns with 90° rotational symmetry are laminated and etched on the glass window, providing dual-band rejection and polarization insensitivity. But if the pattern is adjusted for GSM bands, the oblique conductor will cover a larger area of the glass window, reducing the transparency. In [4], H-shaped fractals have greatly reduced the unit size and increased angular stability. A dual-band compact design combining self-similar double square loop and 2.5D convolution is reported in [5]. The 2.5D meandering techniques, however, increases cost and fabrication difficulty compared with single-layer designs. Covering the 90° rotational symmetry, fractal size reduction, and self-similar dual-band design concepts, the classical cross fractal dipole [6] is one of the most suitable single-layer template for FSS with balanced angular and

multi-band performance. However, it is still challenging to design FSS structures that are insensitive to polarization as well as the angle of incidence variations, particularly for multiple bands operation.

In this paper, we propose a novel single-layer fractal cross dipoles design, with, dual-band, polarization insensitivity, and large stable incident angle features. An 80% transparent prototype has been fabricated and tested. Both the simulation and measurement results show good GSM shielding with a maximum 45° incident angle for both TE and TM polarizations.

II. FSS DESIGN AND SIMULATIONS

The proposed FSS structure and the design evolutions are shown in Fig. 1. During the first design step, the common joints of the fractal branches in stage one are adjusted towards the center, forming a star shape to tune the resonant frequencies. In the second design step, stubs are attached from the endpoint of each branch along the unit border to increase the inter-coupling capacitance and therefore lower the resonant frequencies.

Fig. 1. Design Evolutions leading to final design. Dimensions are in mm.

The tuning mechanism from design stage 1 to stage 2 can be explained by the reflective mode current distribution plotted in Fig. 2. Red lines in Fig. 2 indicate high current distribution. After point A is moved towards the unit center, the current path of lower frequency reflection mode is shortened. Thus, the equivalent resonance inductance is lowered and the resonance frequency increases from 1.09 GHz to 1.23 GHz. The high-frequency mode works oppositely. Stretched 11, 12, and 13 increase the current length of high-frequency reflection, and the frequency ratio of the high band to the low band frequency decreases from 2.88 to 2.13, which is closer to the GSM bands.

Fig. 2. Reflective mode current distribution comparison.

After the resonant frequency ratio is settled in stage 2, capacitance stubs are added in the final design to reduce the unit size. The final design parameters are shown in Fig. 1. The simulation has been done in HFSS with floquet port excitation and periodic (master-slave) boundaries. The conductivity of the printed silver nanowires is 5×10^5 S/m. The PMMA substrate has a permittivity of 2.3 and a loss tangent of 0.01 at around 1 GHz. A 0.3 mm gap has been inserted between the FSS and the substrate to represent film attachment error.

Fig. 3. Polarization and angular simulation.

The simulated transmission coefficients are plotted in Fig. 3, with both TE (Y polarized) and TM (X polarized) modes. At normal incidence, the TE and TM curves overlap each other, showing polarization insensitivity. With the incident angle increasing from 0° to 45°, the resonant frequency fluctuates very little, but the TM resonance peak is reduced from -18.0 dB to -15.8 dB at 0.96 GHz and from -14.0 dB to -10.6 dB at 1.9 GHz. TE response shows greater reflection as the incident angle increases, but a new reflection mode at 1.4 GHz and reflection changes around 3 GHz arise after an incident angle of 45°. Thus, taking the GSM requirement of 10% bandwidth into account, the maximum stable angle for GSM reflection is 45°.

III. FABRICATION AND MEASUREMENTS

The screen-printing process is operated on a commercial screen printer (AUREL screen printer 900PA). The layout of the

final design was defined by a stainless steel screen with a mesh count of 325 threads per inch, a mesh opening of 53 μ m, and a mesh angle of 22.5°. The film prototype and measurement results at normal incidence are shown in Fig. 4. From the prototype photo, we can clearly see through the FSS-PMMA layer and read “Transparent FSS” in the lighter part of the background, while in other parts printed in deep color, the pattern shows a white color. The measured transparency of the structure is up to 80%. Also, flexibility has been demonstrated by bending the printed thin film.

Fig. 4. Prototype and the measurement result.

The structure has been measured in a near-field measurement setup, where a pair of wideband horn antennas face each other closely and the FSS structure has been inserted between them. A direct measurement without the FSS is also needed for normalization. The measurement data have a similar trend with that of the simulations, with some insignificant variations, which may be due to the low conductivity or system calibration.

IV. CONCLUSION

We proposed a single-layer, dual-band, transparent FSS reflector with polarization insensitivity and a large stable incident angle. Both the simulation and measurement results show the GSM signal shielding capability. The prototype is screen printed on transparent thin films with silver nanowires and can be applied to many applications requiring transparency and flexibility.

V. REFERENCE

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