Frequency Selective Surface for Spatial Filtering of Wide-Angle Scanning Phased Arrays

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***Abstract*— We present the design of a multi-layer frequency selective surface (FSS) composed of subwavelength elements, with large harmonic rejection bandwidth. The FSS design is based on an equivalent circuit model, where the inter-layer interaction is only described with a single transmission line representing the fundamental Floquet wave. To ensure the accuracy of this model, we enforce the FSS period to be comparable to the inter-layer distance. The FSS simulated response exhibits good stability over a wide conical incidence range, up to 45 degrees. The FSS is then combined with a wide-scanning connected array of dipoles to implement a phased-array antenna element with integrated filtering properties.**

I. INTRODUCTION

Modern radars operate in an increasingly complex electromagnetic environment, consisting of own signals and signals from other platforms. For phased array antennas in such scenarios it is important to ensure the frequency selectivity necessary to prevent interference with other systems operating in different frequency bands and to protect the radar front-end from unwanted signals. One way to achieve this function is to use a frequency selective surface (FSS) above the array aperture. This approach has the advantages to reduce the complexity of the antenna feed structure, whose filter components can be designed with less stringent requirements. However, FSSs typically suffer from the appearance of higher order harmonics [1] and are strongly dependent on the incidence angle.

FSSs are multi-layer periodic structures designed to achieve a certain frequency and angular filtering behaviour. In the original design approach [1], the FSS is composed by resonant elements and each layer provides a pole of the filter. Covering a typical radar band requires cascading several layers at a distance of about $\lambda/4$. However, the resulting structure is rather thick and strongly angular dependent, with relatively high dielectric losses.

Recently, the concept of miniaturized-element FSSs (MEFSS) was proposed [2], consisting of subwavelength metallized/aperture-type elements. Since the elements of the FSS are much smaller than the wavelength, the behaviour of every layer corresponds to a shunt reactance (inductive or capacitive) over a large frequency range. The main advantage is that the FSS overall thickness is electrically small ($<\lambda/5$) rather than a multiple of $\lambda/4$, with consequent lower losses. A procedure was presented in [2] to design a band-pass FSS and it was then applied to the design of a harmonic-suppressed MEFSS in [3].

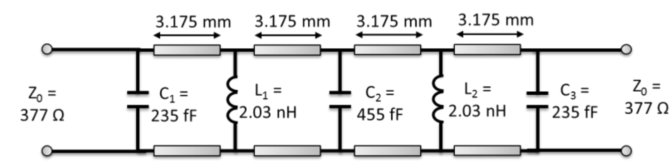

Fig. 1. Equivalent 3-pole Chebyshev filter circuit with the calculated lumped-element values.

In this work, a multi-layer FSS is designed, based on an admittance-inverter topology. The circuit is represented as a transmission line model in which shunt lumped components are used as loads. In the practical implementation of the spatial filter, the transmission lines are represented by dielectric slabs and the shunt components are realized as sub-wavelength periodic structures. The geometrical details of the structure were estimated by using analytical expressions [4]. Each layer was then optimized by using full-wave simulation tools.

A prototype of the FSS was fabricated and measured. Moreover, the FSS is integrated with a connected array of dipoles [5] to show its performance when combined with a wide-scanning phased array. The measurements for the FSS stand alone and with the antenna are currently being carried out and they will be presented in detail at the conference.

II. FREQUENCY SELECTIVE SURFACE DESIGN

The canonical transmission line model of a 3-pole band-pass Chebyshev filter is shown in Fig. 1. The values reported for the shunt lumped impedances were calculated considering a desired fractional bandwidth of at least 20%. The equivalent model in Fig. 1 was used to design the FSS structure depicted in Fig. 2. The reactive shunt loads are implemented by capacitive and inductive grids. The transmission line sections are obtained with dielectric spacers that separate the metal layers. The material used for the dielectric slabs is Nelco 9450, with relative permittivity of $\varepsilon_r = 4.5$. The overall thickness of the structure is about $\lambda_0/5.82$. The unit cell has dimensions of 4.2 mm × 4.2 mm, equivalent to $\lambda_0/17.85$, where λ_0 is the wavelength at 4 GHz.

Figure 3 shows the reflection and transmission coefficients over a wide frequency range for broadside, transverse electric (TE) and transverse magnetic (TM) oblique incidence at 45°.

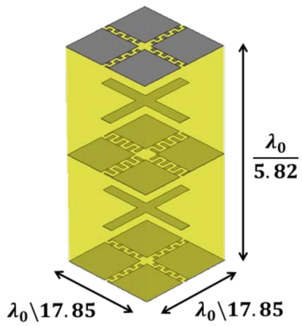

Fig. 2. Perspective view of described MEFFS with capacitive and inductive grids.

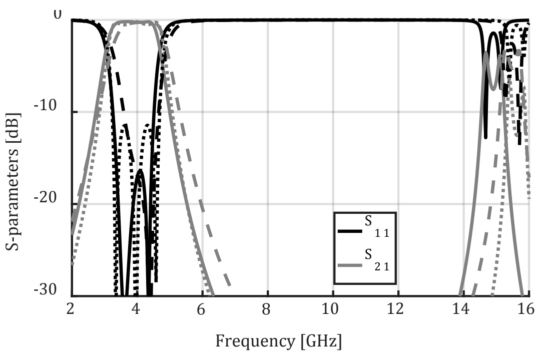

Fig. 3. Amplitude of the S-parameters for broadside (solid line), 45° TE (dotted line) and 45° TM (dashed line) plane wave incidence.

For all planes a rejection of at least 20 dB for frequencies lower than 2.15 GHz and from 5.9 to 14.3 GHz is achieved. Considering both principal planes with scanning up to 45°, the MEFSS maintains a good performance (S11 < −10 dB, corresponding to a transmission higher than −0.5 dB) over a bandwidth of 24% around the central frequency of 4.1 GHz.

III. Manufacturing and Measurements

In order to manufacture the FSS a minimum gap of 0.15 mm in the interdigitated capacitance was fixed to use standard printed circuit board technology. A photo of the FSS prototype is shown in Fig. 4. Figure 5 shows the measurements for the reflection coefficient at broadside, compared with simulations. It can be noted that the measured filter response resembles the predicted one. However, a shift of about 10% is observed. This shift can be explained with the manufacturing tolerances, which include the permittivity of the materials, the dielectric and metal thickness, the width of the metal tracks and gaps (which mostly influences the inter-digital capacitance). The measurement results in Fig. 5 also highlight the wideband rejection capability of the designed FSS, as the first higher order harmonic is occurring at 13.5 GHz. Moreover, the bandwidth of the prototype is around 15% scanning up to 45°.

Additional measurements results for oblique incidence will be presented at the conference. Moreover, the use of the FSS in close proximity of a connected array of dipoles will be experimentally demonstrated.

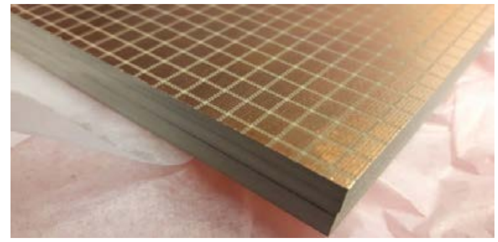

Fig. 4. Manufactured FSS photo.

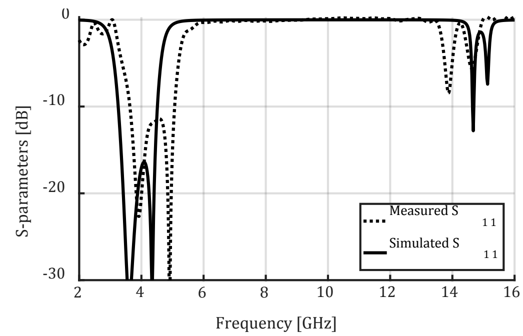

Fig. 5. Measured and simulated reflection coefficient of the MEFSS at broadside.

IV. Conclusions

A miniaturized-element FSS based on a three pole Chebyshev band-pass filter is presented. The MEFSS was manufactured and tested and achieved a bandwidth of 15% around the central frequency of 4.3 GHz. A large rejection of higher order harmonic was achieved with the first harmonic at the frequency of 13.5 GHz.

Further investigation of the FSS in combination with a previously developed connected-dipole array [5] will be performed and reported at the conference.

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