A New Class of Bandpass Frequency Selective Structures

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I- Introduction

Frequency selective surfaces are formed by the two-dimensional periodic arrays of the resonant elements. The resonant frequency and the spectral behavior of an FSS is determined not only by the geometry and size of the elements, but also by the inter-element spacing and the topology of the array grid [1]. Usually, the design and optimization of an FSS is a cumbersome task that requires the iterative use of computationally extensive full-wave analyses. As the computational complexity is immensely increased by adding more layers, design of the higher order frequency selective surfaces is generally performed by combining the individually designed FSS layers. The FSS layers are stacked using thick (~ $0.2\lambda_0$-$0.3\lambda_0$) dielectric spacers, which are designed based on simple filter concepts. However, as the layers are designed separately, the conventional method offers little flexibility, and the design procedure generally has to be followed by an elaborate optimization.

A simpler design approach can be conceived by introducing antenna-filter-antenna cells as the building blocks of the FSS. Each AFA is composed of a receive antenna, a bandpass resonant structure, and a transmit antenna. This is to some extent similar to what has been used in [2] and [3] for designing the second order FSS, except that using the resonant structure allows an arbitrarily high order response. The concept of using AFA for forming a bandpass FSS is presented in Fig. 1. The resonant structure which is sandwiched between two antenna layers, is generally composed of a number of planar transmission line resonators in a single- or multi-layer structure. The receive and transmit antennas and chosen as the resonant type elements and their resonant properties are absorbed in the filter structure, thus allowing a higher order response with the fewer number of layers. In the case of a 3-pole bandpass AFA, shown in Fig. 1, patch antennas are used as the radiating elements and a simple co-planar waveguide (CPW) transmission line resonator made in the ground plane is used for the resonant structure. The 3-pole bandpass filter is formed between the radiation resistances of the two patches using an integrated antenna-filter design similar to what is proposed in [4].

II- Design Examples

Layout of a 35 GHz 3-pole Chebyshev AFA is shown in Fig. 2a. The radiating elements are hexagonal patch antennas which are made on 500 μm-thick glass substrates with $\varepsilon_r = 4.6$ and $\tan\delta \cong 0.005$. The common ground plane, lying between the two substrate layers, accommodates the CPW quarter-wave resonator (the U-shaped slot in Fig. 2a). The coupling between the radiating elements and the resonator takes place in the open end of the CPW resonator. Circuit model for this three-layer AFA structure is shown in Fig. 2b. The design procedure starts by designing and characterizing the resonant patches and the

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coupling slot. The CPW resonator is simply a quarter-wave resonator (at the center frequency). Unlike the conventional methods, the inter-element spacing of the FSS is not arbitrary in the AFA approach, and must be chosen carefully. Each cell in the periodic grid must have an area equal to the effective aperture of the constituent antenna elements, given by [5]:

$$A_e = \frac{\lambda_0^2}{4\pi} D \,, \tag{1}$$

where λ_0 is the free-space wavelength at the center frequency, and D represents the directivity of the antenna in the boresight direction. For the AFA shown in Fig. 2, the simulated directivity of the hexagonal patch is D=5.07 at 35 GHz, which results in a cell area of 29.6 mm^2 (corresponding to an inter-element spacing of 5.44 mm in a square grid).

The three layer periodic structure is analyzed using a finite element method simulator [6]. For the case of normal incidence, the periodic boundary conditions reduce to perfect electric and magnetic walls, which results in a considerable simplification. Final tuning of the design is performed by minor adjustments in the length of the CPW resonator.

The simulated [6] frequency response of an FSS composed of such AFA cells for a polarization parallel to the CPW resonator (horizontal in the layout shown in Fig. 2) is given in Fig. 3, which presents a perfect 3-pole bandpass response with 2.24 GHz bandwidth centered at 34.9 GHz. The estimated in-band insertion loss is < 0.41 dB. This simulation ignores the metallic loss in the patches and the CPW resonator, and the estimated insertion loss is mainly due to the in-band ripple. As expected, the in-band phase delay varies almost linearly between the first and third peaks of the amplitude response. This FSS and the related AFA design, here-forth will be referred to as Type-I.

In some applications it is required to have a sharper roll-off in the upper or lower rejection bands. This may be achieved by using a higher order FSS, which generally requires more layers and results in higher insertion loss. An alternative approach is to introduce transmission zeros near the edges of the pass-band. The layout and circuit model of a second AFA design whit a transmission zero (Type II) are shown in Fig. 4. The receive and transmit patches are identical to those of the Type-I design, but are displaced horizontally to form an anti-symmetric geometry with respect to the CPW layer. The resonant structure is a variant of a half-wave CPW resonator in this case, and couples to the top and bottom patches through different coupling slots in the two ends (the vertical slots in the layout).

Type-II FSS is formed by combining the Type-II AFA cells. The cell area is 29.6 mm^2 as in the previous case. The simulated frequency response for the horizontal polarization is presented in Fig. 5, and contains a transmission zero in the lower rejection band. The pass-band is 2.38 GHz wide and is centered at 35.2 GHz, with an estimated in-band insertion loss of < 0.43 dB. Although presence of this zero causes a phase jump of ~180 degrees in the transmission, it does not degrade the in-band phase linearity drastically.

Some feature performance data for the Type-I and Type-II FSS's are summarized in Table I. As the designed FSS's have a large inter-element spacing ($\cong 0.63\lambda_0$), their angular range of operation is limited by the first surface wave null [1] that must be kept outside the pass-band in all cases. The location of this null is given for the cases of normal incidence and incidence at 22.5 degrees.

AFA Element	Type I	Type II
Center Frequency (GHz)	34.9	35.2
1-dB Bandwidth (GHz)	2.24	2.38
Max. In-band Insertion Loss (dB)	0.41	0.43
Surface-Wave Null for Normal Incidence (GHz)	48.6	
Surface-Wave Null for θ_{inc} = 22.5 degrees (GHz)	38.1	

TABLE I
MEASURED PARAMETERS OF TYPE-I AND TYPE-II FSS'S

III- CONCLUSION

This work presents a new approach for designing frequency selective surfaces. In this approach the FSS is composed of AFA cells, which receive, filter, and transmit the signal. Two types of 3-pole bandpass FSS have been designed using the AFA approach, which demonstrate the application of this technique for synthesizing all-pole as well as more complicated bandpass FSS's. Finite element simulations predict an excellent performance for these designs at normal incidence. Prototypes of these FSS's are currently being fabricated, which will be used to verify the numerical results and determine the performance limitations such as insertion loss and angular sensitivity.

REFERENCES:

[1]. B. A. Munk, *Frequency Selective Surfaces*, John Wiley and Sons, New York, 2000.

[2]. R. Pous, D. M. Pozar, "A frequency-selective surface using aperture-coupled microstrip patches", *IEEE Trans. on Antenna And Propagation*, vol. 39, pp. 1763--1769, Dec. 1991.

[3]. C. J. Larson, "Modified center layer metallic biplanar radome design", Tech. Rept. AFAL-TR-78-28, Ohio State Univ. Electroscience Lab., Rept. 4346-2, Columbus, March 1978.

[4]. Abbaspour-Tamijani, J. Rizk, G. M. Rebeiz, "Integration of filters and microstrip antennas," *IEEE Antennas and Propagation Symp. Dig.*, San Antonio, Texas, pp. 874--877, June 2002.

[5]. W. L. Stutzman, G. A. Thiele, *Antenna Theory and Design*, 2nd Edition, John Wiley \& Sons, New York, 1997.

[6]. *High Frequency Structure Simulator*, Ansoft Corporation, Pittsburg, PA, 2002.

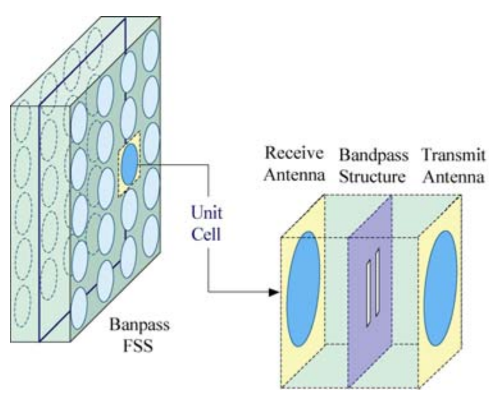

Fig. 1. Interpretation of the frequency-selective surface as an array of AFA cells.

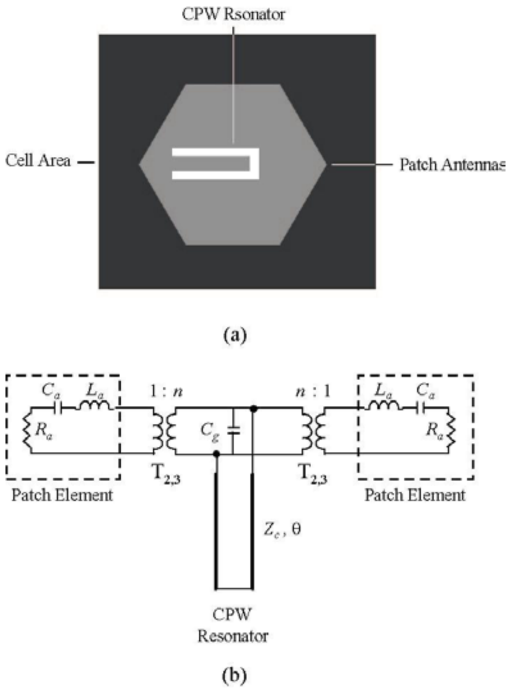

Fig. 2. Type-I AFA Cell; (a) layout, (b) circuit model.

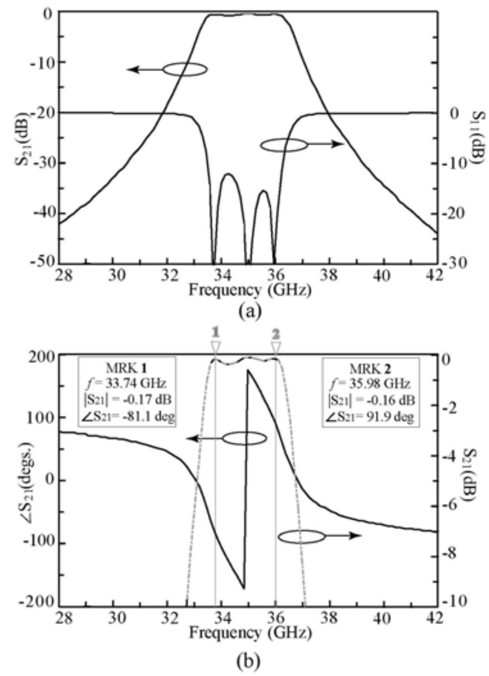

Fig. 3. Finite element simulation of the frequency response for Type-I FSS; (a) amplitude, (b) phase response.

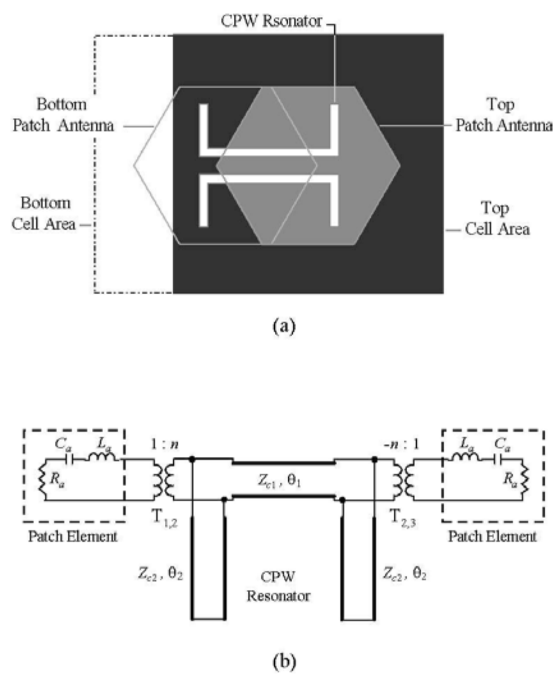

Fig. 4. Type-II AFA Cell; (a) layout, (b) circuit model.

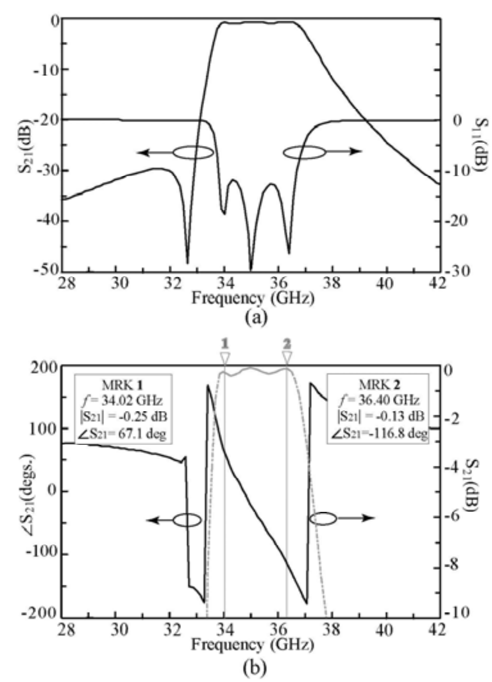

Fig. 5. Finite element simulation of the frequency response for Type-II FSS; (a) amplitude, (b) phase response.