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An Approach for Designing FSSs with Different Responses

***Abstract**. An approach to design an FSS (frequency selective surface) has been proposed. The approach can be used to design different types of filters including bandpass, multiband, band rejection or band-rejection. It is based on the study and analysis of periodic structures under plane wave illumination for finding equivalents of capacitor and inductor to design an FSS with the desired response. For instance, the FSS types designed her by using the proposed approach is a wide bandpass with very low insertion losses, band-rejection and multiband FSSs. Moreover, the size of the proposed unit cells is a lot less than the wavelength at the resonant frequency and the smallest size of the exhibited unit cells in this manuscript is 0.056λ x 0.056λ.*

***Streszczenie.** Zaproponowano podejście do projektowania FSS (powierzchni selektywnej częstotliwości). Podejście to można wykorzystać do zaprojektowania różnych typów filtrów, w tym filtrów pasmowoprzepustowych, wielopasmowych, odrzucania pasma lub odrzucania pasma. Opiera się na badaniu i analizie struktur okresowych w świetle fali płaskiej w celu znalezienia odpowiedników kondensatora i cewki indukcyjnej w celu zaprojektowania FSS o pożądanej odpowiedzi. Na przykład typy FSS zaprojektowane dla niej przy użyciu proponowanego podejścia to szerokie pasmo przepustowe z bardzo niskimi stratami wtrąceniowymi, odrzucaniem pasma i wielopasmowymi FSS. Co więcej, rozmiar proponowanych komórek elementarnych jest znacznie mniejszy niż długość fali przy częstotliwości rezonansowej, a najmniejszy rozmiar komórek elementarnych przedstawionych w tym manuskrypcie to 0,056λ x 0,056λ. (**Podejście do projektowania FSS z różnymi odpowiedziami**)*

Keywords: FSS, wireless, periodic structure.
Słowa kluczowe: FSS, bezprzewodowy, struktura okresowa.

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Introduction

A frequency selective surface (FSS) is periodic surfaces, namely unit cells, usually supported by an insulating substrate. Depending on the shape of the unit cell, it can reflect or transmit a certain frequency range [1]. With the improvement of communication devices and the development of radome performance, the requirements for multi-frequency band communication are becoming more and more important. For such applications, multiband FSSs have been used especially when multiple independent transmission bands are required. Therefore, multiband FSS designs have been subject to extensive work. Recently, many approaches have been used to design multiband FSSs such as multi-layer unit cells to obtain multiple resonant frequencies [2]. Single-layer FSS with fractal structures is also used to achieve multiple bands [3]. Combining two resonators into a single surface to obtain a dual-band frequency response was shown in [4]. In this paper, the unit cell elements with their interaction with each other will be studied and represented by their equivalent circuits. In addition, FSSs with different frequency responses will be designed.

Circuit analysis and design

An incident plane wave is transmitted or reflected at certain frequencies due to capacitors and inductors generated for any given FSS. FSSs are spatial filters, so their reflection and transmission coefficients are affected by the polarization and angle of the incident wave, as well as by the dimensions and shapes of the FSS surfaces. One of the challenges in achieving the desired frequency response of the antenna is a difficulty in predicting the behavior of the unit cell elements. This may be due to the difficulty in predicting the equivalent circuit of the unit cell elements and then the entire structure. For instance, although some consider that the equivalent circuit of the patch structure is a capacitor (C), and the equivalent circuit of the loop mesh is an inductor (*L*) [1, 5]. In fact, these equivalent circuits could be approximations or used to avoid the complexity. The patch acts as a band-rejection FSS (*LC* series) with a dominant *C* value. While the mesh loop acts as a wide bandpass FSS (parallel *LC*) with the dominant *L* value [6-11]. However, a method for designing unit cells based on the equivalent circuit shape to obtain the preferred responses will be presented here.

It is worth it to mention that when electric field lines are parallel to a microstrip, the microstrip will act as inductor and it can be call an *L*-element (*L*-shape surface). On the other hand, when the electric field lines are perpendicular to a two parallel microstrip, the two microstrips will act as a capacitor and can be called a *C*-element (*C*-shape surface). Accordingly, when designing the *C*-element type, it can be obtained using the two parallel microstrips that must be perpendicular to the direction of the electric field, as shown in Figure 1(a), while designing the *L*-element type can be obtained by a microstrip that should be in parallel with electric field direction as shown in Fig. 1(b). The proposed unit cells were simulated by computer tool of CST Microwave Studio, periodicity along x and y axes are provided by using unit cell boundary conditions. A plane wave is used to excite the proposed FSS.

First step the design procedure is by finding the equivalent circuit of the desired response.
For instance, bandpass response can be achieved by combining L in parallel with series LC. Therefore, bandpass FSS can be built by combining the L-element in parallel with series of C-element and L-element.

The proposed bandpass is simulated to obtain the transmitted coefficient with unit cell dimensions (length x width) is 8x8 mm2, and substrate of FR-4 with thickness of 1.2 and relative permittivity constant is 4.4. Figure 2(a) illustrate the 3×3 unit cell of the proposed bandpass FSS. Figure 2(b) shows the geometry dimensions of the unit cell of the proposed bandpass FSS. Figure 3 illustrates the result that obtained by simulating the transmission coefficient (S21). The resonant frequency is about 2.51 GHz and the overall unit cell size is 0.073λ × 0.073λ.

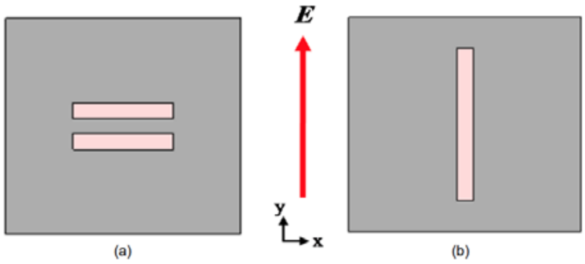

Fig.1. FSS unit cell, (a) Capacitive FSS unit cell (C-element), (b) Inductive FSS unit cell (*L*-element).

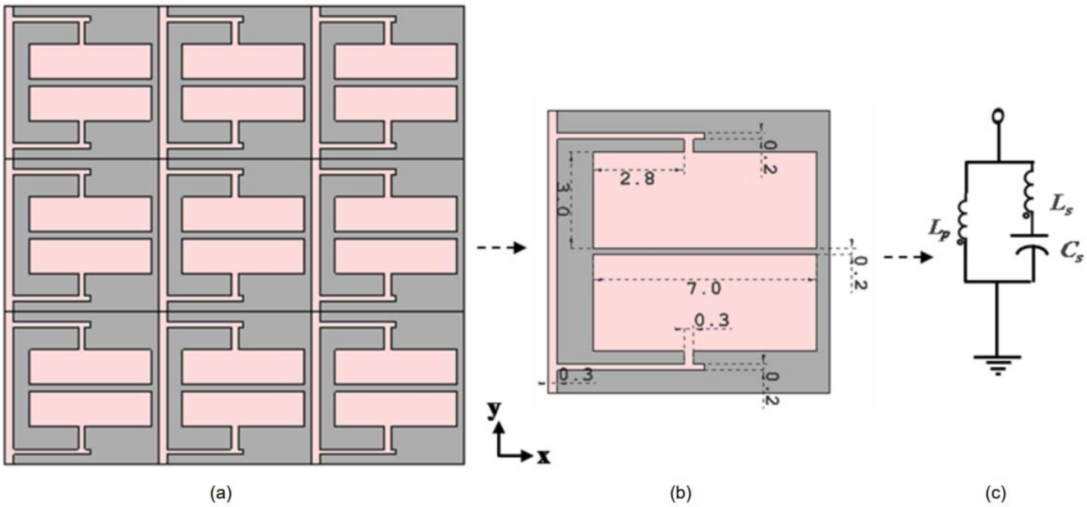

Fig. 2. The proposed bandpass FSS, (a) 3×3 unit cell, (b) unit cell with geometry dimensions, (c) The equivalent circuit of the proposed bandpass FSS.

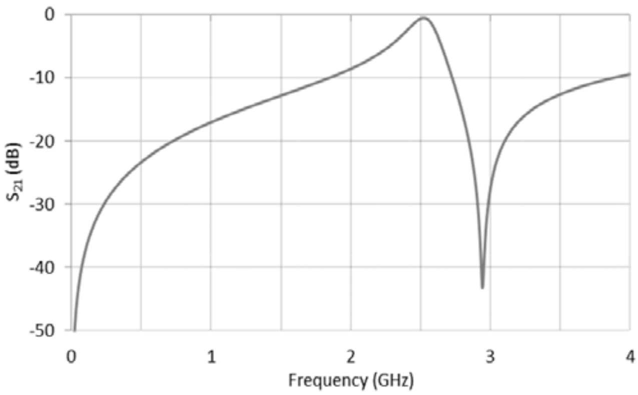

Fig. 3. The simulated S21 coefficient of the proposed bandpass FSS.

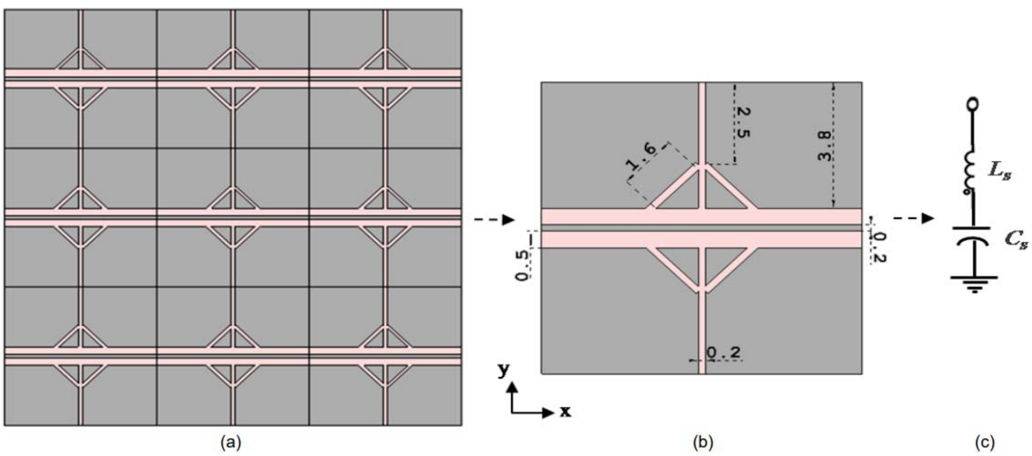

Fig. 4. The proposed band-rejection FSS, (a) 3×3 unit cell, (b) unit cell with geometry dimensions, (c) the equivalent circuit of the proposed band-rejection FSS

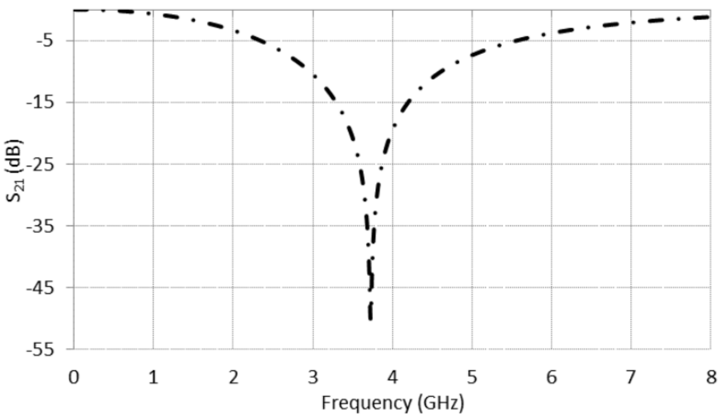

Fig. 5. The simulated Transmission coefficient (S_{21}) of the proposed band-rejection FSS.

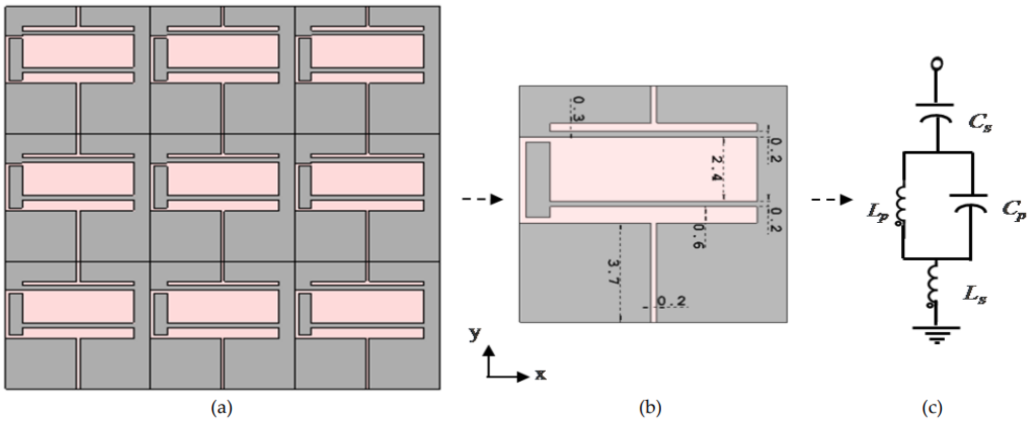

Fig. 6. Designed dual band-rejection FSS, (a) 3×3 unit cell, (b) unit cell with geometry dimensions, (c) The equivalent circuit of the designed dual band-rejection FSS

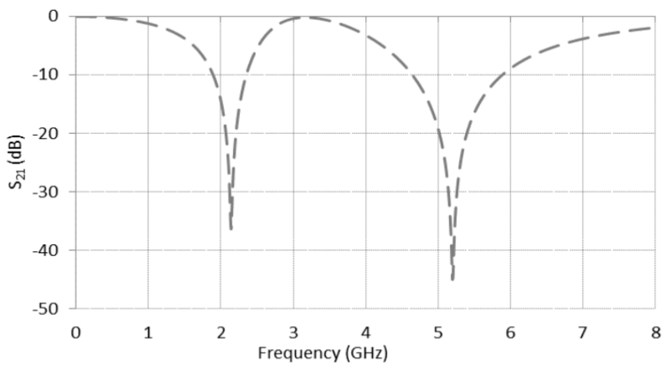

Fig. 7. The simulated S_{21} coefficient of the dual band-rejection FSS.

The FSS is designed with stop band response using the proposed approach. As it is known that the band-rejection filter can be built using an inductance in series with capacitance (one of several ways to obtain stop band response), thus a band-rejection FSS can be designed by an L-element in series with C-element on 1.2 mm thick of FR-4 substrate, as shown in Figure 4. Figure 4(a) shows the 3×3 unit cell of the proposed band-rejection FSS. The proposed band-rejection FSS unit cell with its geometric dimensions are illustrated in Figure 4(b). While Figure 4(c) illustrates the equivalent circuit of the band-rejection FSS.

The proposed band-rejection FSS is simulated to obtain the result of the S21 as illustrated in Figure 5. The FSS illustrates stop band response with resonant frequency at 3.8 GHz and the unit cell size of 0.102λ × 0.102λ with wide rejected band. The fractional rejected band (BW/fo) is 105%, where fo is the resonant frequency and BW is a 3 dB rejected band.

Thus, a dual band-rejection FSS is designed by using the proposed approach. First, the dual stop band response can be achieved by connecting a series LC with a parallel LC in series. It should be noted that the resonant frequencies of the series LC-circuit and parallel LC-circuit must be very close to each other to obtain the dual stop band response. Thus, a surface consisting of parallel LC elements connecting in series with series LC elements printed on 1.2 mm thick of FR-4 substrate is used to design dual band-rejection as illustrated in Figure 6. The 3×3 unit cell of the designed FSS structure is shown in Figure 6(a), while the dimensions of the unit cell elements of the dual band-rejection FSS are shown in Figure 6(b). The equivalent circuit of the designed dual band-rejection is illustrated in Figure 6(c).

Conclusion

This article used a simplified approach for studying the FSS, and this approach may give designers a greater ability to design the FSS with desired responses. The proposed unit cell and its elements were analyzed to find the equivalent circuits of the FSSs. The proposed FSSs by using the proposed approach were a wide bandpass with very low insertion losses, band-rejection and multiband. It is very obvious from the illustrated result that the size of the designed unit cell is a lot less than the wavelength at fo and the smallest size of the exhibited one is 0.056λ x 0.056λ.

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