Int. J. Electron. Commun. (AEÜ) 70 (2016) 151–161

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Novel single layer reconfigurable frequency selective surface with UWB and multi-band modes of operation

Maryam Majidzadeh*, Changiz Ghobadi, Javad Nourinia

Electrical Engineering Department, Urmia University, Urmia, Iran

ARTICLE INFO

Article history:
Received 31 May 2015
Accepted 30 October 2015

Keywords:
Frequency selective surfaces (FSS)
Multi-band operation
Shielding effectiveness
Reconfiguration
Ultra-wide band operation

ABSTRACT

This paper proposes a novel reconfigurable frequency selective surface (FSS) structure for ultra-wide band (UWB) and multi-band applications. The proposed structure is a simple single layer FSS printed on 10 mm × 10 mm × 1.6 mm FR4 substrate. This structure embraces a simple square loop on the front side of the substrate whereas; another one along with two vertical arms is incorporated on the backside. Innovatively, a wise combination of diodes is embedded on the substrate's backside which are handled through a DC feed line circuit. By an effective diodes switching, three operating modes are attained. In the context of UWB filtering, the proposed FSS contributes in remarkable rejection of UWB frequencies through the "ON" state of all diodes. However, assigning a specific set of diodes in "ON" state provokes multi-band operating mode in which WiMAX, WLAN, and Ku bands are rejected. Moreover, setting all the diodes at "OFF" state extends the rejection capabilities by dismissing an additional frequency range. Furthermore, a remarkable notice relates to higher attenuation in shielding effectiveness (SE) acquired for rejection bands. Extensive numerical and experimental studies are devised to found a suitable comparison platform. The close agreements between the obtained results are acknowledging the suitable performance of the proposed FSS.

1. Introduction

The extensive deployment of modern telecommunication apparatus has raised serious concerns over the vicious effects of the radiated signals over the human health preserving and electrical interferences in operating devices. More specifically, a reduced apparatus lifetime, quality degradation as well as electrical disturbances are some of the potent depressing points caused by the radiation exposures. With the aim of suppressing such impressions, electromagnetic shielding (EMS) structures are proposed as protective solutions against the external undesired fields. EMSs are in fact filtering structures which are deployed in the sensitive parts of the electrical devices to isolate them from the potent interferences due to the undesired radiation signals. This task ends in a safe operation against disturbing external electromagnetic fields. In this way, there is a vast body of researches conducted on designing efficient EMS structures [1,2]. As an effective EMS category, frequency selective surfaces (FSSs) are well-recognized to demonstrate excellent shielding properties along with superior technical features. FSSs are defined as arrays of identical unit cells arranged in a specific configuration theme. The unit cell geometry, array type, and the elements spacing in each FSS foundation directly influence its filtering and technical performance [3]. At the moment, a broad range of applications is realized based on FSSs deployment say as antenna radome [4,5], antenna gain enhancement [6,7], absorbers [8,9], polarizers [10,11], RCS reduction [12,13], beam switching [14,15] and electromagnetic shielding [16]. Moreover, the design process of FSSs based on metamaterials is surveyed to extend the capabilities of these screens [17–19]. However, this specific sort of FSSs is not the main interest of the ongoing study. Based on a comprehensive literature review, FSSs are divided in two single layer and multilayer categories. Single layer FSSs consist of a single layer substrate on which conductive elements are printed. These types of FSSs usually exhibit narrow band operation; that is passing or rejecting a single and limited frequency band [20–22]. However, in some particular applications, wider stop band with flat top absorption curves are desired. In these cases, to extend the pass or stop bandwidth, FSS layers are cascaded which in turn, increases the size and cost of implementation [23,24]. On the other hand, due to the ceaseless technological advances in telecommunication systems, there is an emerging trend toward competent apparatus with reduced size and cost which simultaneously exhibit more than one operating

* Corresponding author. Tel.: +98 9144470776.
E-mail addresses: M.Majidzadeh@urmia.ac.ir (M. Majidzadeh), Ch.Ghobadi@urmia.ac.ir (C. Ghobadi), J.Nourinia@urmia.ac.ir (J. Nourinia).

http://dx.doi.org/10.1016/j.aeue.2015.10.011
1434-8411/

mode. This is while; to ensure a successful commercialization future, every communication device is faced with some impressive factors among which the fabrication cost, device overall weight and size could be named. Consequently, providing a reliable, secure, and cost-effective communication mission calls the need for design innovations in compact, small, and multifunctional devices. Paving the way to attain such features, the combination of reconfiguration technology with FSS structures seems to be a technically suitable therapy. Founding reconfigurable FSSs provokes indispensable joint functionalities through a simple structure leading to significant size and cost reductions. A thorough survey in the literature reveals that there have been some initial efforts in designing reconfigurable FSSs to obtain different functionalities. In a common sense, most of the proposed reconfigurable structures are based on the switching sequences of embedded diodes, in which turning the diodes on or off results in different applicable operating modes. In this context, authors in [25] have surveyed the contribution of using varactor diodes in a reconfigurable miniaturized frequency selective surface. In the established plant, the switching contribution of varactor diodes rehabilitates two band-pass and band-stop operating modes in excess. A ring-based FSS configuration with two-state switching capability is organized in [26]. The FSS in two cases is either transparent or reflective against the interested frequency band. Similarly, another research spotlighting on the applications of reconfigurable building architectures is recounted in [27] where the proposed electronically switchable FSS affords either transparent or reflective modes. Considering pertinent tuning techniques, a controllable pressure enables the spring resonators to demonstrate an erratic height which facilitates different operating capabilities based on the original plan [28]. Moreover, Sanz-Izquierdo and Parker in [29] have endeavored in the context of polarization reconfigurable FSSs. Suitable placement of varactor diodes and surface resistances is shown to effectively modify the FSS response with respect to different wave polarizations. Meanwhile, some other researchers have concerned devising proficient analysis methodologies to go through the FSS parametrical analysis and reconfiguration merits [30,31].

Although the investigated literatures have contributed a considerable share in FSS design, however some of the important running issues have been overlooked. As it is well-recognized, UWB rejection capability is generally required in key applications such as gain enhancement in UWB antennas as well as effective shielding of electrical devices from disturbing external electromagnetic fields. In spite of this, a brief review of the available documents clarifies a significant deficiency striking the field of UWB filters within which a wider frequency range is required to be rejected. As well, regarding the multi-band filtering mechanism, most of the available structures are merely apt to pass or reject some random frequency bands. However, less attention is dedicated on the applicability of FSSs operating bands such as accommodating WiMAX, WLAN, and other critical frequency ranges. Promisingly, suitable placement of conductive elements and appropriate tuning of their dimensions endow a unique opportunity to cover the desired frequency ranges in the pass or stop bands of the investigated screens. In this way, the multi-band FSS structures with more application characteristics are easily thought of.

Being biased based on the preceding survey, this study aims to present a novel simple single layer reconfigurable FSS to overwhelm some of the refined flaws. The proposed unit cell, printed on a $10\,\text{mm} \times 10\,\text{mm}$ FR4 substrate with thickness of 1.6 mm, founds a smaller size with respect to the most of available schemes [16]. Principally, two simple square loops are printed both on the front and backside of the substrate. As well, two vertical arms are adjoined in the backside's square loop to enhance the primary operational capabilities of the established screen. To realize the reconfiguration process, a set of diodes are embedded on the right and left sides of the integrated vertical arms. As well, two other diodes are suitably mounted on the main square loop's vertical arms. A DC feed line accompanied by a suitable combination of current-limiter resistor and isolating RF-chokes is deployed for fast and reliable switching of implanted diodes. Innovatively, setting all the diodes at "ON" state results in rejection of ultra-wide frequency band extending from 4.6 GHz to 16 GHz. Based on this notice, the proposed design sketch stands as one of the leading structures achieving this functionality. On the other hand, by deactivating only one specific pair of diodes, the multi-band operation feature is highlighted by the proposed FSS. In this process, the suitable switching strategy of the implanted diodes results in rejection of the three main and recognized frequency bands. The first frequency range is accompanied by the rejection of 2.5–3.4 GHz. This strip, which is called as frequency band 1, includes one of the main frequency bands namely WiMAX. An extra frequency band, extending from 3.9 GHz to 7.2 GHz, throws out the WLAN frequency range and is known as the frequency band 2. As the third rejecting capability, one other frequency band falling from 7.6 GHz to 17 GHz is dismissed effectively. This frequency range includes Ku band and is revealed as the frequency band 3. Moreover than the two preceding switching patterns, setting all the embedded diodes in "OFF" states declares the third functionality of the proposed screen. In partial, this frequency range refuses 4–7.3 GHz WLAN, 8–12.7 GHz X-band, and 13.7–16.7 GHz Ku band, respectively. To make it brief, changing the diodes "ON" or "OFF" states transfers the overall performance of the FSS from ultra-wide band dismissal to three-band rejection functionality. Based on an effective sizing of elements, the presented FSS is recognized as resilient enough to be utilized both in ultra-wide band and multi-band filters such as shielding applications without over sizing issues. What is more, the superimposed DC feed line circuit deployed for diodes switching mission is thoroughly investigated to concern its plausible effects on frequency response of the FSS. Based on an exact simulation approach, it is shown that a wise design procedure is apt to greatly diminish the effects of DC feed line presence on the expected overall performance of the proposed FSS. Contemplating the operational and technical features, the followings could be listed as the main contributions of the proposed FSS screen:

- Proposing a switching-based multi-functional single layer FSS;
- Providing enhanced ultra wide stop-band operation with smaller unit size;
- Achieving multi-band rejection capability based on diodes switching regime modification;
- Devising an improved easy-implementation DC feed line circuit for diodes reconfiguration task.

The remainder of this paper is organized as follows. Section 2 addresses the unit cell design process, reconfiguration realization, and also the performance analysis of the FSS based on the surface current distribution. A comprehensive parametric study is performed in Section 3 to scrutinize the effect of different incidence angles and wave polarizations in FSS performance. Experimental and simulation results are well-regarded in Section 4 to thoroughly assess the real-world and simulated performance of the screen. Eventually, Section 5 states the concluding remarks along with the possible future works.

2. Design approach and performance analysis of FSS unit cells

Fig. 1 illustrates the unit cell schematic structure. As it is depicted, a simple square loop is located on the front side of the unit cell. On the backside of the substrate, there is another square