Characterization of Capacitor-based Reconfigurable Frequency Selective Surfaces

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***Abstract*—In this paper, the characterization of reconfigurable frequency selective surfaces (FSS) based on capacitor is numerically investigated. The capacitor is applied to control the characteristic response, i.e. reflectivity, of FSS. A simple rectangular patch with the total length of 130mm and the width of 0.6mm which has 2 resonant frequencies at 2.4GHz and 4GHz is used as basis of reconfigurable FSS construction. The investigation is conducted by varying the patch shape and the capacitance value. The relationship of patch shape and the presence of capacitor to the characteristic response of FSS is analyzed, first, by proposing the initial construction which is divided into 2 identical parts. Secondly, the variation of up and bottom width of patch without modifying the center side, so the construction becomes a bow-tie shape, is carried out. In the last, a capacitor is applied in the middle of patch to obtain the variation of characteristic response. From the characterization result, it shows that the higher capacitance value affects to the reflectivity of lower frequency response.**

***Keywords*—bow-tie shape; capacitor based; reconfigurable frequency selective surfaces (FSS); rectangular patch.**

I. INTRODUCTION

In recent times, frequency selective surface (FSS) has been intensively investigated for a number of applications in communications systems. As per definition, FSS is a structure of planar periodic constitutes an array of metallic sheet on a surface or a conducting sheet pierced with apertures [1]. The structure shows different reflection and/or transmission characteristics as a response to the incident electromagnetic waves. There are many element geometries of FSS structure which have been analyzed numerically and experimentally ranging from dipole wire and square patch to circular loop [1]– [2]. However, for the most part applications using the structure require only passive printed conductors on a dielectric substrate.

Since the FSS structure has unique characteristics of reflection and/or transmission, it is sometimes applied to reject or to pass the incident waves at its resonance frequency and simultaneously to allow or to eliminate higher or lower frequency ranges [1], [3]– [4]. For a variety of applications it would be more attractive to have an electronically reconfigurable characteristic for the selection of frequency as well as FSS reflectivity and transmittivity characteristics. Along with the development of communication system, the structure has been extensively implemented to improve the performance of antennas that work in narrowband and broadband operations [5]– [6]. Moreover, in [7]– [8], the structure is employed to enhance the directivity of wide-band electromagnetic band gap (EBG) antenna which is applied for Ku-band communication.

The earlier investigation of FSS structure and its properties have been theoretically developed from a structure of phased array antenna [7]. Based on the theory of phased array antenna, then the derivative method is established to be specifically applied in the design of FSS structure [9]. In spite of derivative theories for designing FSS have been well-developed by many researchers recently, however the quantitative analysis of FSS structure is still remaining for the advanced exploration. The analysis is useful to characterize the properties of FSS structure in determining its characteristics related to the reflectivity and the transmittivity.

In this paper, double periodic arrays of passive rectangular strip loaded with capacitors are proposed as a structure of FSS which is suitable for establishing a reconfigurable FSS. In the characterization, it will demonstrate how the frequency response of the FSS structure can be tuned-in by varying the capacitance value of capacitor. At first, a brief description how to determine the dimension and the shape of patch required for reconfigurable FSS structure is explained. Then, the investigation to characterize relationship between the shape and the presence of capacitor to the characteristic response of FSS is is presented. Finally, the variation of capacitance value is conducted to obtain the desired characteristic response of reconfigurable FSS.

II. BASIC CONSTRUCTION OF RECONFIGURABLE FSS

To characterize the effect of dimension and shape of patch modification for reconfigurable FSS structure related to the reflection coefficient, the quantitative analysis discussed here is carried out by taking the consideration of resonance frequency and bandwidth. The characterization is carried out numerically to obtain the desired characteristics response of reconfigurable FSS structure. In general, the resonant frequency of FSS structure can be theoretically calculated using (1).

$$f_r = \left(2\pi\sqrt{LC}\right)^{-1} \tag{1}$$

It clearly shows that larger capacitance and/or inductance would raise up the resonant frequency of FSS structure. Then, by using (2) the bandwidth (BW) of FSS structure will be widened by increasing the inductance value and lowering the capacitance value. In the implementation, this is conducted by modified the dimension and shape of patch as the element of reconfigurable FSS structure. However, one thing that should be paid more attention is that lowering the capacitance value for obtaining wider bandwidth of FSS structure will affect to the increase of its resonant frequency. Therefore, there should be a trade-off and priority to be defined in the design process related to the capacitance value.

$$\mathrm{BW} \propto \left(\frac{L}{C}\right)^{\frac{1}{2}} \tag{2}$$

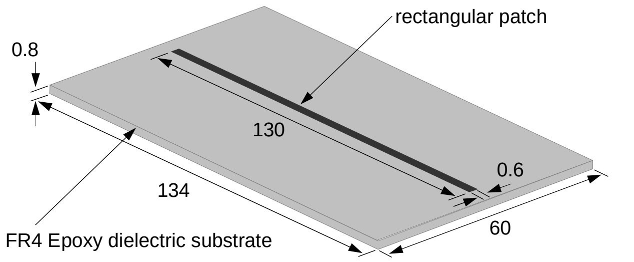

Fig. 1. Initial construction of FSS stucture of rectangular patch (unit in *mm*)

Since the FSS structure is intended to work at frequency about 2.4GHz, the size and dimension of patch is determined from the wavelength of working frequency band. In order to work on that frequency, the patch length is approximately equal to one-wavelength of the working frequency. The shape of patch is designed as simple as possible for the analysis, therefore a rectangular shape of patch is chosen as the initial investigation instead of other complicated shapes. In addition, a rectangular patch is deliberately applied due to its simplicity and easier in shape modification. In consideration for experimental characterization, the rectangular patch is placed on an FR4 Epoxy dielectric substrate with relative permittivity of 4.4. Fig. 1 illustrates the initial construction of FSS structure of rectangular patch and its dimensions.

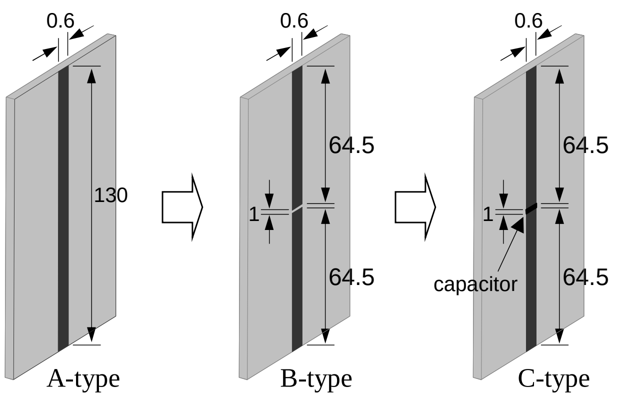

Fig. 2. Modification flow of FSS structure for investigating the dimension of rectangular patch (unit in *mm*)

Starting from the initial construction of FSS structure, some modifications are then implemented to the dimension of rectangular patch. Fig. 2 shows the flow of modification process made for the FSS structure to investigate its characteristics. The A-type is the initial construction of FSS stucture, whilst the size of dielectric substrate is allowed to remain for all modified structure. The 1st modification of initial construction is the B-type which is carried out by splitting the rectangular patch into 2 equal parts of patch. The C-type is the 2nd modification for investigation by putting a capacitor in the gap between 2 equal patches with the varied capacitance value of 1pF, 3pF, 5pF and 15pF. During the modification process, the change of characteristic response of FSS structure are observed to analyze the effects of each modification. Here, the resonant frequency, reflection coefficient, and bandwidth are used as key parameters for analyzing the effect of patch modification.

Furthermore, to characterize the different shape of patch to characteristic response of FSS structure, as indicated in Fig. 3 the edge-width on the long-side of initial construction of rectangular patch is enlarged without changing the width on the middle part of patch, therefore a bow-tie shaped of patch is formed, i.e. D-type. This is the 3rd modification for characterization. The edge-width termed as a is varied by 1.2mm, 2.4mm, and 3.2mm. Whilst the E-type is the 4th modification by splitting horizontally the D-type into 2 equal parts of half bow-tie patch. Last modification is the F-type where the capacitor is inserted in the gap connecting 2 half bow-tie patches. The same capacitance value as applied in the previous characterization is set for the capacitor.

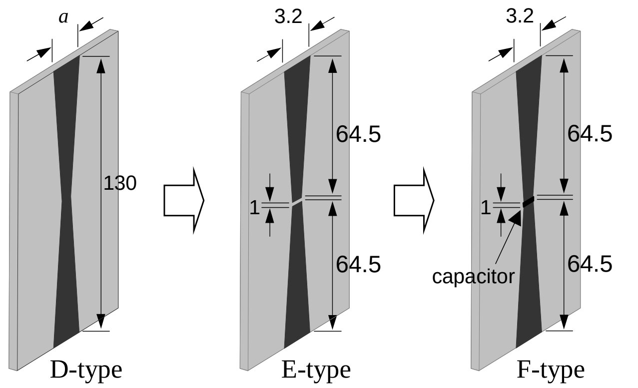

Fig. 3. Modification flow of FSS structure for investigating the shape of rectangular patch (unit in *mm*)

III. Characterization Results and Discussion

The characterization for each modification is performed numerically with the initial construction, i.e. A-type, used as a reference. Fig. 4 shows the simulated result of reflection coefficient for B-type in comparison with the simulated result of A-type. It shows that the significant discrepancy between 2 types is on the resonant frequency along the frequency range of observation. The initial construction of FSS structure, i.e. A-type, has 2 resonant frequencies at 2.4GHz and 4GHz but with different magnitude of reflection coefficient. It is seen that the magnitude of reflection coefficient at 2nd resonant frequency, i.e. 4GHz, is greater 2 times than the magnitude at frequency of 2.4GHz. The existence of 2 resonant frequencies is affected by the periodic nature of FSS structure which resonates at its dimension of one-wavelength and at 1st harmonic frequency.

Furthermore, the simulated result for the B-type has only 1 resonant frequency at 4GHz in which the magnitude of reflection coefficient is stronger than magnitude of the A-type. It should be noted that by splitting the rectangular patch or putting a space into the rectangular patch has made the

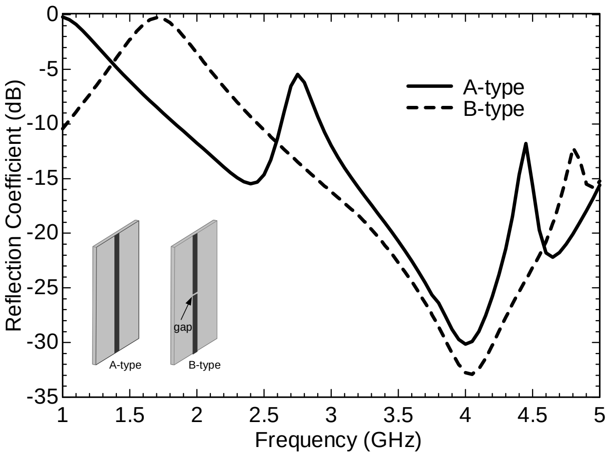

Fig. 4. Simulated result of reflection coefficient of A-type and B-type

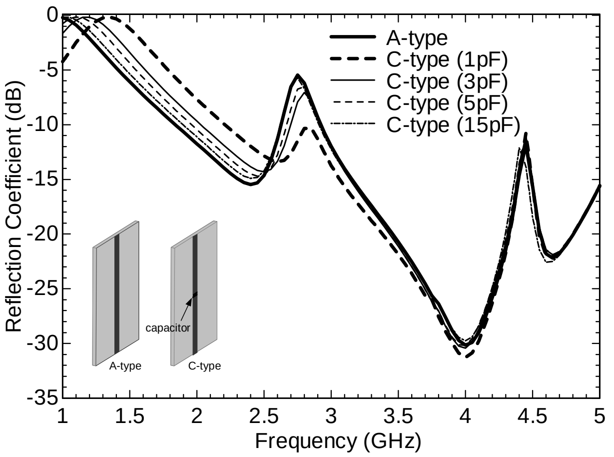

Fig. 5. Simulated result of reflection coefficient for rectangular patch with varied capacitance value put in middle of rectangular patch (C-type) and for rectangular patch without capacitor (A-type) as comparison

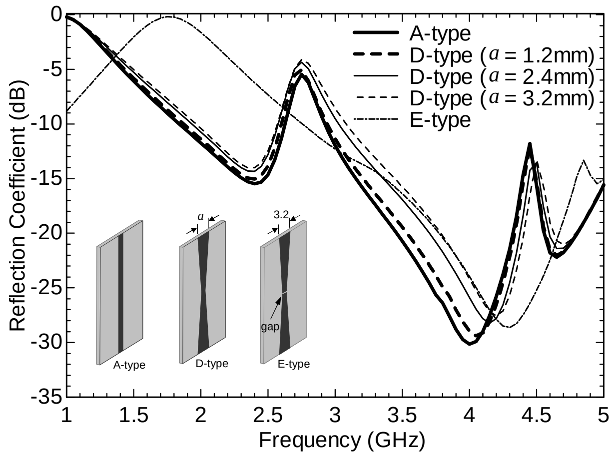

Fig. 6. Simulated result of reflection coefficient of D– and E-type with A-type as comparison

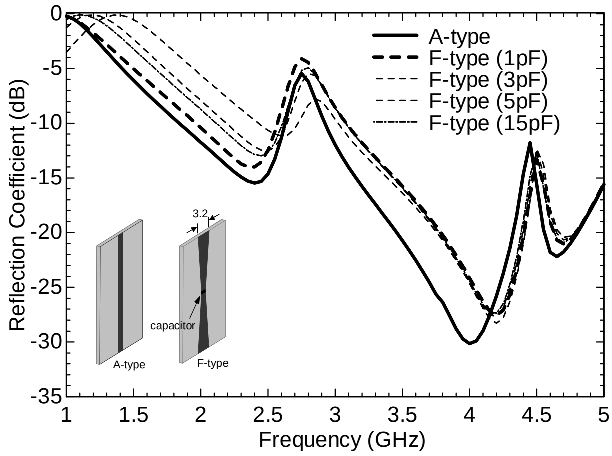

Fig. 7. Effects of varied capacitance for bow-tie shaped patch, F-type, with A-type as comparison

dimension of rectangular patch to be half of its wavelength thus it can eliminate low resonant frequency and, therefore, the FSS structure operates at higher resonant frequency. This is similar to the A-type which resonates at frequency of 4GHz in addition to the resonant frequency of 2.4GHz.

The characterization for the C-type is carried out by inserting a capacitor in the gap between 2 equal patches. The value of capacitor is varied by 1pF, 3pF, 5pF and 15pF to obtain the effect of capacitance value variation to the characteristic of FSS structure. Fig. 5 plots the result obtained through simulation for the C-type with the result of initial construction of FSS structure, i.e. A-type, as comparison. It should be noted that the capacitor in this investigation serves to reconnect 2 equal patches to have low frequency resonant. From the result, it shows that bigger capacitance values affect the resonant frequency shifts to the lower frequency region. It is noticeable that the capacitor has no effect to the reflection coefficient value at higher resonant frequency of 4GHz. The result also indicates that bigger capacitance values produce a similar result obtained by the initial construction of FSS structure.

The simulated result of reflection coefficient for the D– and E-type to characterize the effect of different shape of patch is depicted in Fig. 6 with the result of A-type plotted together as comparison. As mentioned in the previous section, the patches of D-type and E-type are referred as bow-tie shaped. From the result, it is found that the patch of E-type has the same characteristic as the B-type since it is halved as applied on initial construction of FSS structure. Whilst the result of D-type produces 2 resonant frequencies which are similar as the A-type but with worse reflection coefficient values. It is seen that by widening the edge-width on the long-side of rectangular patch, the higher resonance frequency is influenced. The high resonant frequency shifts to the higher frequency region but the low resonant frequency remains unchange. It shows that the bow tie design leads a shift to the higher resonant frequency as indicated by the E-type which produces resonant frequencies similar to the B-type.

Similar to the previous characterization for the C-type, a capacitor is inserted in the gap at the design of F-type. Here, the capacitor value is also varied to be 1pF, 3pF, 5pF and 15pF. The simulated result is shown in Fig. 7 which the result of A-type as comparison. It indicates that the capacitor affects to the lower resonant frequency. The result shows that the larger the capacitance, the frequency shifts to the lower frequency region and gets closer to the result of D-type. Moreover, the result also shows that the capacitor has no effect to the higher resonant frequency. Summarizing all the investigation results, Table I concludes the relationship of modifications which have been made to the characteristic response of reconfigurable FSS structure.

TABLE I. EFFECTS OF PATCH SHAPE AND CAPACITOR VALUE TO CHARACTERISTIC RESPONSES OF RECONFIGURABLE FSS STRUCTURE

Characteristics	**Modification**		
	Patch with gap	*Bow-tie shaped*	*Capacitor value*
Reflection coefficient	High	Low	Low
Bandwidth	Wide	Narrow	Narrow
Lower resonant frequency	No	Yes	Yes
Higher resonant frequency	Yes	Yes	Yes
Resonant frequency shift	No	Yes (low frequency)	Yes (high frequency)

IV. CONCLUSION

The characterizations of FSS structure to investigate the effect of patch dimension and shape as well as the capacitor value have been demonstrated by conducting various simulations to the modification made for initial construction. Splitting a rectangular patch into 2 equal patches or in other term by giving a gap in the middle part of rectangular patch has affected to the disappearance of low resonant frequency but given the stronger reflection coefficient to the high resonant frequency. It can be concluded that splitting patch into some parts has had no alteration to the resonant frequency. Whilst the shape of patch has significantly contributed to the bandwidth improvement. Moreover, a bow-tie shaped design has affected the higher resonant frequency but reducing the magnitude of reflection coefficient. By inserting capacitor in gap of 2 equal patches, the higher resonant frequency could be lowered, however, the bandwidth response of FSS structure has remained unchange. From the characterization results, it is expected to find out the relationship between the structure of reconfigurable FSS and its characteristics response which is available for simplification and optimization of the structure for some applications. In addition, the characterization of some modification has allowed the performance of the FSS structure to be quantitatively accessed.

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