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DESIGN OF DUAL-BAND MICROSTRIP REFLECTARRAY USING SINGLE LAYER MULTIRESONANCE DOUBLE CROSS ELEMENTS

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Abstract—A multiresonance double cross element is used to design a dual-band reflectarray with dual linear polarization. The proposed element has a single conductive layer structure which makes it easy to manufacture. The results presented in this paper show that the mutual effect between the elements of the two bands is negligible. Hence, it is easy to achieve the phase compensation for each band separately. The simulated and measured results for an element designed to cover the X- and K-bands have confirmed the suitability of the proposed element to build a dual-band reflectarray.

1. INTRODUCTION

The microstrip reflectarray is an antenna that consists of a flat reflecting surface with many microstrip elements and a feed antenna. It uses a suitable phasing scheme to convert a spherical wave produced by its feed into a plane wave [1–6]. The microtsrip reflectarray is a high gain antenna which evolved as an efficient and cost-effective replacement of the parabolic reflectors and phased arrays: The parabolic reflector lacks the ability to achieve wide angle beam scanning, whereas the high gain phased array with electronic scanning is very expensive due to its complicated beamforming network and amplifier modules [1].

Some applications have emerged recently; where it is required to design a reflectarray within a limited certain space to cover two widely separated bands, such as the X- and K-bands for NASA space systems [1]. The conventional design of the reflectarray cannot

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accomplish the requirements of such dual-band applications. Hence, new methods have been proposed by many authors to design a reflectarray which covers the two bands with a high gain and wide scanning angle capability. A stacked structure which is formed from multiple small square loops at the top layer and a large square loop at the bottom layer were proposed in [7] to achieve a dual band performance with dual linear polarisation; whereas variable size crossed dipoles were presented in [8]. For the case of a closely spaced dual band operation, square loop elements were suggested in [9]. The phase compensation in this case was achieved by using a variable angle rotation technique. For linear polarisation, variable size pairs of dipoles were used for the case of widely or closely separated dual bands [1].

In another important development, the stacked approach was used as a suitable solution to the requirement of dual band operation accompanied by a compact size [10]. Two stacked patches with variable size were used independently for the phase compensation at the two bands. In another multi-layer configuration, perforated patches loaded by slots at the ground plane are used as the radiating elements at C-band and rectangular patches directly loaded by slots are used at K-band [11]. In a recent design [12], a single-layer dual closely separated bands (12 GHz and 14 GHz) orthogonal polarisation reflectarray antenna composed of a combination of split cross and rectangle rings for one band and double split square rings for the other band was proposed. A similar combination was also proposed for a broadband single band operation [13].

In this paper, a single-layer mulitresonance double cross reflectarray element, which was presented in [14], is modified to achieve the dual band operation with a dual linear polarisation. The curved multiresonance cross structure utilized in this paper has a broad bandwidth compared with the single-resonance elements, such as the printed dipoles or patches [15], and it is easy to manufacture compared with the stacked elements. In the presented results, it is shown that the proposed element can operate efficiently at the dual bands 10 GHz and 18 GHz with negligible mutual effect between them.

2. DESIGN

To design a dual band reflectarray, a multiresonance double cross-element shown in Fig. 1 is considered [8]. The microstrip reflectarray was designed to operate in the X- and K-bands. The reflectarray is assumed to be formed by many of the elements shown in Fig. 1 arranged in a square lattice with periodicity of 15 mm, which is equivalent to half a wavelength at centre of the lower band (X-band), i.e., 10 GHz. They

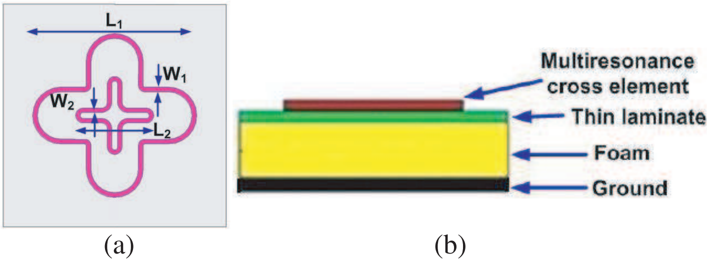

Figure 1. Configuration of the multiresonance double cross element. (a) Top view, and (b) side view.

are assumed to have a double symmetry as required in dual polarised applications. It is to be noted that the chosen value for the cell size prevents the appearance of grating lobes at the higher band, which is 18 GHz in this case, as the inter-element separation is less than one free space wavelength.

The configuration of the chosen element and substrate is shown in Fig. 1. Lengths of the dual cross elements (L_1, L_2) were changed to show their effect on the phase performance at the two assigned bands, while their widths (W_1, W_2) were fixed at 0.3 mm. As a general rule, values of the lengths L_1 (and L_2) should vary between quarter and half of the effective wavelength at the lower (and higher) bands in order to achieve the required 360° phase variation across each of the two bands.

The substrate used to support the cross elements is assumed to consist of a thin laminate of Rogers RT5880 with $\varepsilon_r = 2.2$, and thickness $h = 0.13$ mm, in addition to a 6 mm of Foam with a dielectric constant equal to 1.07. The parametric analysis using the software CST Microwave Studio has proven that this combination gives a suitable balance between the required volume occupied by the structure and the phase performance concerning the slope and range.

3. RESULTS AND DISCUSSIONS

Variation of the return loss's phase was studied as a function of frequency. Only the case of a linearly polarised TEM plane wave, which is normally incident on an infinite periodic array of identical elements, is considered. In this case, the side walls of the equivalent TEM waveguide are formed by a perfect magnetic conductor, while its bottom and top walls are composed of a perfect electric conductor. Using the equivalent unit cell waveguide approach, phase of the reflected wave was calculated for the loaded waveguide. The structure

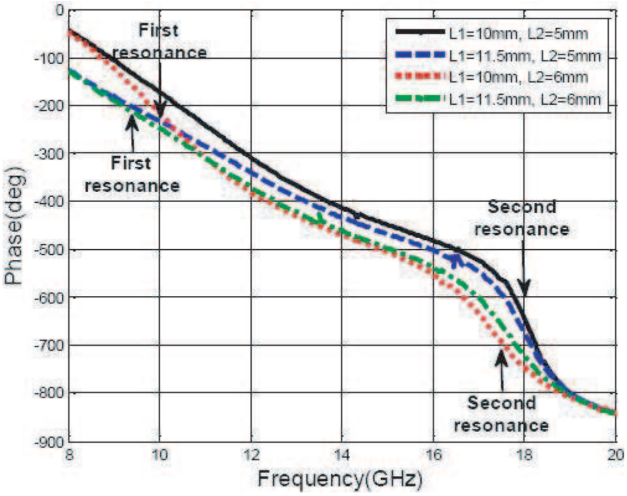

Figure 2. Variation of phase of the return loss with frequency for different lengths of the two cross elements.

was modelled using the software CST Microwave Studio.

Figure 2 shows variation of phase of the reflection coefficient with frequency for different lengths of the two cross elements. It is clear from this figure that the utilised structure has two resonant frequencies; one at around 10 GHz, while the other is around 18 GHz. Fig. 2 also reveals that the phase range for each of the two resonators exceeds the required 360°. Effect of varying length of each element on value of the resonant frequency is also shown in Fig. 2. Increasing length of the low-band element L_1 from 10 mm to 11.5 mm shifts the first resonant frequency from 10 GHz to 9.5 GHz, while changing length of the high-band element L_2 from 5 mm to 6 mm shifts the second resonant frequency from 18 GHz to 17.5 GHz. It is also clear from Fig. 2, that changing length of the high-band element has no effect on the low resonant frequency, and similarly changing length of the low-band element has no effect on the high resonant frequency. This means that it is possible to achieve the required phase compensation for each of the two bands independently by changing length of that band's element.

To make sure that the low-band element has a negligible effect on the phase performance at the high band, the simulation was carried out for two cases; the first case is when the low-band element has length = 10 mm, while the second case is when there is no low-band element, i.e., $L_1 = 0$. The result, which is depicted in Fig. 3, reveals that the phase performance and value of the high band resonant frequency is almost constant with or without the presence of the low-band element. Similarly, the simulation was also performed to make sure that the high-band element has negligible effect on the low-band performance. The result shown in Fig. 4 confirms the design

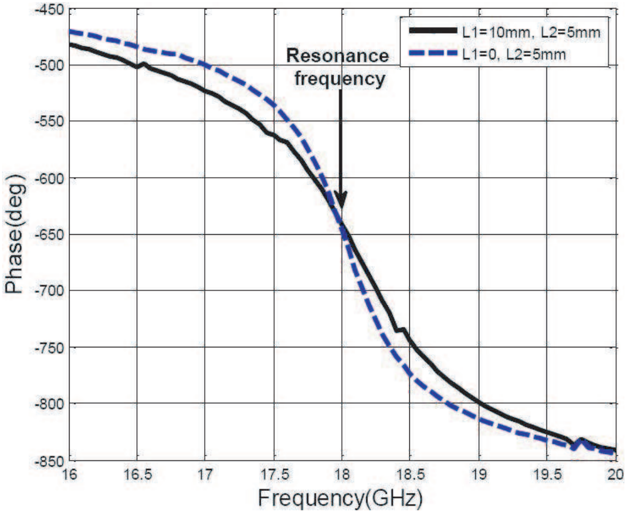

Figure 3. Effect of the low-band element on the phase performance of the high-band element.

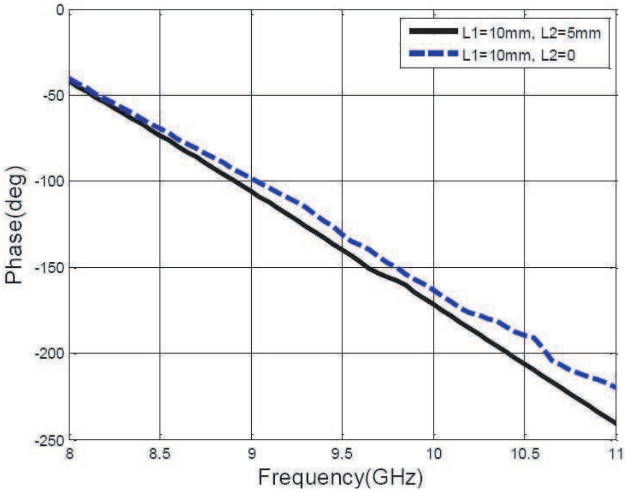

Figure 4. Effect of the high-band element on the phase performance of the low-band element.

expectation that there is no mutual effect between the two elements.

As a another step to test the coupling effect on the performance of the two elements that form the double cross cell, the phase performance at the two resonant frequencies 10 GHz and 18 GHz for different lengths of the two multiresonant elements is simulated. The result is shown in Fig. 5 for L_1 from 7 mm to 12.5 mm with $L_2 = 5$ mm, and for L_2 from 3 mm to 7 mm for $L_1 = 10$ mm. It is obvious from Fig. 5 that the two

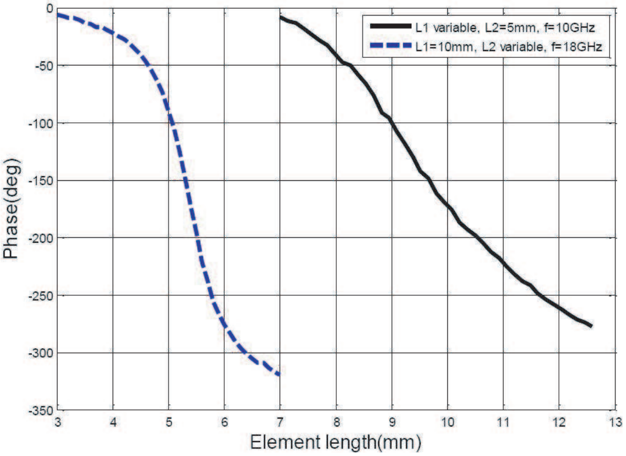

Figure 5. The phase performance of the proposed unit cell at 10 GHz and 18 GHz as a function of the element lengths (L_1 and L_2).

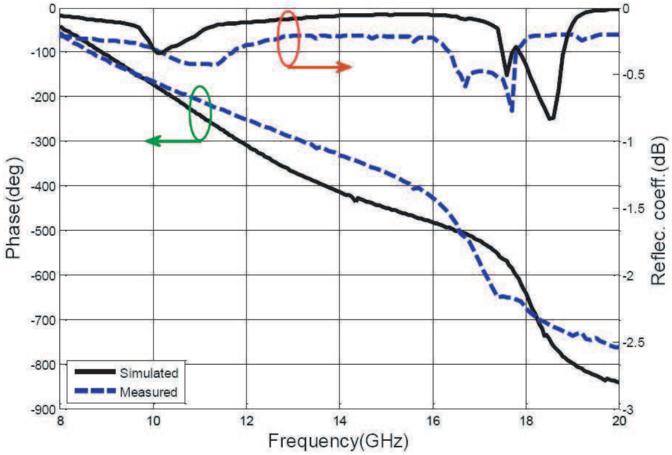

Figure 6. The measured and simulated performance of the proposed unit cell.

elements operate almost independently at 10 GHz and 18 GHz.

As a final step in checking performance of the proposed reflectarray, a unit cell with $L_1 = 10\,\mathrm{mm}$, and $L_2 = 5\,\mathrm{mm}$ and a double layer substrate (RT5880 with $h = 0.13\,\mathrm{mm}$, in addition to 6 mm of Foam) was manufactured, and tested using the waveguide approach [1]. Performance of the manufactured cell is shown in Fig. 6. It is clear that the developed cell has two resonant frequencies, which are 11 GHz and 17 GHz according to the measured results, and 10 GHz and 18 GHz according to the simulations. The total phase variation across the two bands is around 800°, which is more than the minimum value (720°) needed for a dual-band operation. Amplitude of the return loss across the band 8 GHz to 20 GHz was also simulated and measured. The measured results shown in Fig. 6 reveal that while the return loss is as low as 0.2 dB across most of the investigated band, it has higher values (more than 0.4 dB) at the resonant frequencies. This result is consistent with the simulated results shown in Fig. 6 and with the previously published findings, which show that the maximum return loss of the reflectarray occurs at its resonant frequencies [16].

4. CONCLUSION

A single-layer multiresonance curved double cross element, which can be used to build a dual-band reflectarray with dual linear polarization, has been presented. The results presented in this paper have shown that the mutual effect between the cross elements of the two bands is negligible, which makes it easy to achieve the phase compensation for each band separately. The simulated and measured results for an element designed to operate at the X- and K-bands have confirmed the suitability of the proposed multiresonance cross element for the design of a dual-band reflectarray.

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