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Dual resonance element for broadband reflectarray antenna

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ABSTRACT

A dual resonance reflectarray unit cell element has been proposed which evolved from a square patch element to enhance its bandwidth performance. A bend in the width of the element is used to modify its dimensions and surface currents for broadband operation. The results have been analyzed in the frequency band of 24 GHz to 28 GHz. Two different combinations of its dimensions are selected for the investigating of its various performance parameters. A maximum static phase range of 432° and 255° have been obtained with selected dimensions. The wide-band features of proposed unit cell element can be used particularly to design a broadband reflectarray antenna for future fast communication systems.

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1. INTRODUCTION

A microstrip reflectarray antenna consists of an array of patches printed on a flat grounded dielectric substrate [1]. It replaces the parabolic reflectors and phased arrays by its low profile design and beam scanning capabilities [2]. The design and arrangement of the patches on the reflectarray surface refer to provide desired results. A reflectarray layout has been shown in Figure 1 with an offset feed operation to reflect the incident signals with a planar wave-front. The planar wave-front is required for a high gain operation with low side lobe level [3]. Moreover, it also defines a wide operational range of frequency for selected reflectarray. An appropriate design of its unit cell element is solely responsible for its high performance operation [4]. However, reflectarray possesses drawbacks of limited bandwidth and low gain performance [5]. This issue is even more challenging at high frequencies such as millimeter waves due to shorter operational wavelengths [6]. The bandwidth of a reflectarray can be enhanced by a wide-band unit cell element with wide reflection phase range [7]. Its gain depends on the reflection losses conceded by its unit cell element. Most of the conventional and low loss unit cell reflectarray elements such as rectangular and square elements have limited reflection phase range with large phase errors [8]. Phase error is a phenomenon which restricts an element to acquire a full reflection phase swing of 360°, which is essential for a planar wave-front. This can be eliminated by selecting broadband elements such as rings and dipoles or a multi-resonance element. A multi-resonance element has the ability to extend its reflection phase swing beyond a single resonant frequency. However, elements with wide reflection phase range are usually restricted by high reflection loss performance.

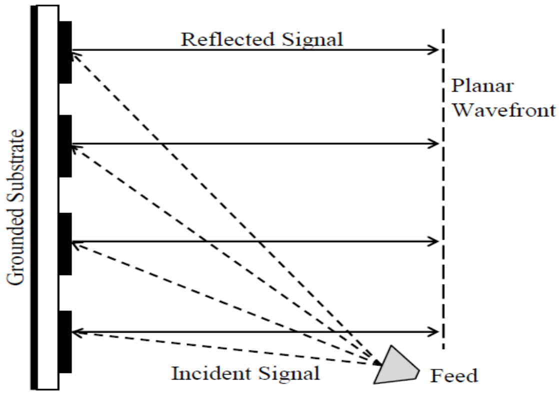


Figure 1. Reflectarray antenna design layout

Therefore in this work, a dual resonance reflectarray element has been designed with wide reflection phase range and optimized reflection loss performance. The element has evolved from a square patch operating in a frequency range of 24 GHz to 28 GHz proposed for future fast communication systems [9]. A detailed parametric study of the unit cell element is presented in [10]. However in this paper, two different combinations of lengths and widths of the element have been selected to analyze its reflection characteristics by Finite Integral Method (FIM). The concentration of electric currents on the surface of selected element has also been examined in relation with its resonance performance.

2. DESIGN CONSIDERATIONS

A square patch element offers a single frequency operation, in order to extend its operation for an extra resonance requires a change in its design configuration. Figure 2 depicts the design of the selected wide-band reflectarray element. It can be seen from Figure 2 that, a bend in the width of the square patch has been introduced at the upper right corner. This embedded bend is used to modify the surface currents of square patch element in extent to achieve an extra resonance for reflection phase modification. Table 1 summarizes the selected dimensions of the unit cell element with its resonant frequencies where “d” represents the bend depth (W2-W1). The first combination of dimension provides two resonances at 25.7 GHz and 26.5 GHz, whereas other combination is used to combine both resonances at a single frequency of 26 GHz.

Table 1. Selected Dimensions of Broadband Unit Cell Element

Parameter	Combination 1	Combination 2
d (mm)	0.41	0.24
L1 (mm)	3.59	3.58
L2 (mm)	3.61	3.59
W1 (mm)	3.36	3.46
W2 (mm)	3.77	3.7
Resonant Frequency (GHz)	25.7 26	26

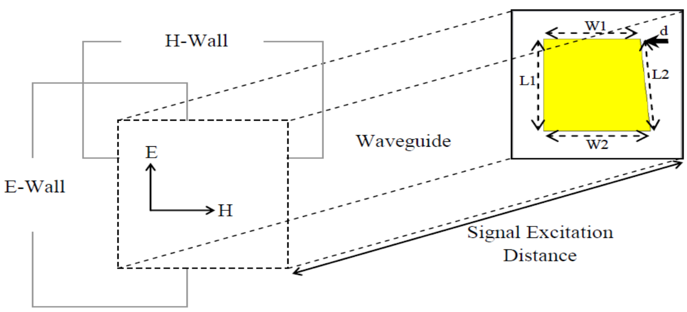


Figure 2. Infinite array approach for reflectarray unit cell element

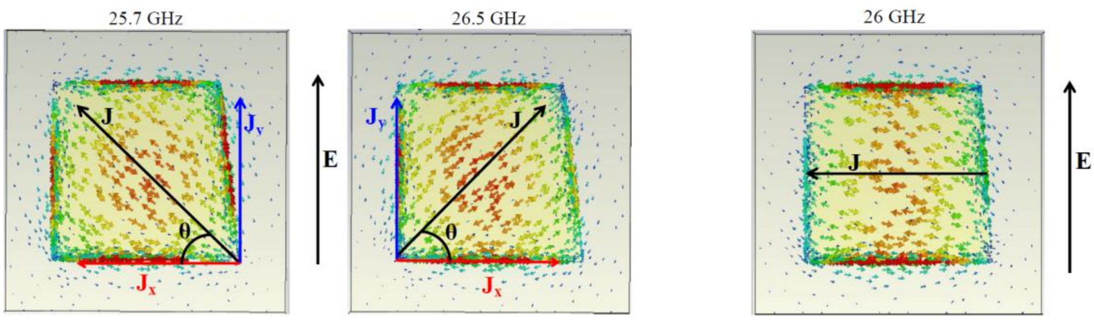
The modified unit cell element is then used as an infinite reflectarray element with proper boundary conditions for performance optimization. The H-wall waveguide simulator tactic as shown in Figure 2 is used to examine the series of results. The incident signal has been excited from a distance of a quarter guided wavelength to acquire maximum reflections. Rogers 5880 dielectric material with a thickness of 0.256 mm is selected as substrate due to its less dielectric losses. The selected substrate thickness provides a clear observation of reflectarray unit cell performance at the prescribed frequency range.

3. FORMATION OF TWO RESONANCES

The resonant behavior of a microstrip patch depends on its electrical dimensions and the flow of current on its surface. As aforementioned, the bend in the width of the square element has been embedded to form a broadband element. The width incorporated bend provides two different combinations of lengths and widths, where each combination is related with a single resonant frequency for the unit cell element. Similarly the change in the dimensions also modifies the surface currents (J) and changes their direction of flow. Figure 3 depicts the surface current flow for two selected combination of dimensions of dual resonance element. It can be observed from Figure 3(a) that, due to a bend in the width the surface current flows diagonally instead of a conventional vertical flow. Because of this reason it breaks into horizontal and vertical components called J_x and J_y respectively. Additionally, surface currents are also related with incident electric field (E) by the relation shown in (1) [11].

$$E = \frac{J}{\sigma} = \frac{J_x + J_y}{\sigma} = \frac{J\cos\theta + J\sin\theta}{\sigma} \tag{1}$$

Where: σ is conductivity of patch, and θ is angle of the flow of surface currents



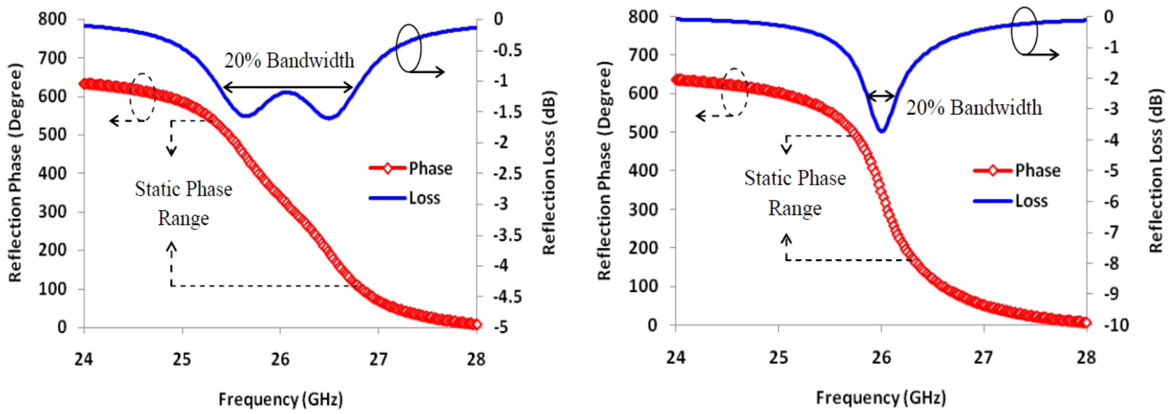
(a) Combination 1 (b) Combination 2

Figure 3. Flow of surface currents at resonant frequencies of dual resonance element

As shown is (1) shows that, the change in surface currents also modifies the electric field. Moreover, two components of surface currents are responsible to produce two different values for electric field which are related with two different resonances. A value of zero for θ represents J with a dominant Jx component, as shown in Figure 3(b). This single component of surface current combines two resonances closely together at a single frequency. The results related to each combination of dimensions of the broadband element have been discussed in the next section.

4. RESULTS AND DISCUSSIONS

The selected broadband reflectarray resonant element has been analyzed using infinite array approach. Two different combinations of dimensions are tested for various reflection parameters. Reflection loss and reflection phase curves of selected combinations of dimensions has been depicted in Figure 4. The element bandwidth has been calculated moving 20% above the maximum loss value whereas the static phase range defines the linearity in the slop of reflection phase curve. It has been observed from Figure 4 that, selected element with both combination of dimensions attains a reflection phase range of more than 600°. This confirms the dual resonance response of the broadband element. Figure 4(a) depicts that, the two resonant frequencies extend the linearity in the reflection phase range.



(a) Combination 1 (b) Combination 2

Figure 4. Reflection loss and reflection phase curves of broadband element with selected combinations of dimensions

On the other hand, Figure 4(b) shows a comparatively narrower static phase range due to the super imposed resonances at a single frequency. Table 2 summarizes the performance parameters of broadband reflectarray element. It can be seen from Table 2 that, the first combination of dimensions acquires less reflection loss performance as compared to the second combination. The reason behind that is the higher surface current concentration of combination 2 which is 1961 A/m, as compared to combination 2. The high value of surface currents is responsible of dissipating more energy into the substrate region and escalating the loss performance. The high loss performance is also responsible of acquiring a steep reflection phase curve which reduces the element bandwidth by 0.22 GHz. On the other side, two separate resonances of first combination of dimensions provide comparatively wider bandwidth of 0.501 GHz and 0.487 GHz. Additionally, two resonances also smooth the slop of reflection phase curve and increase the static phase range up to 432°. Alternatively, the narrow bandwidth of second combination of dimensions also attains a narrow static phase range of 255°.

Table 2. Performance Analysis of Broadband Dual Resonance Element

Parameter	Combination 1		Combination 2
Resonant Frequency (GHz)	25.7	26.5	26
Reflection Loss (dB)	1.58	1.62	3.7
Surface Current (A/m)	1126	1240	1961
20% Bandwidth (GHz)	0.501	0.487	0.220
Static Phase Range (°)	432		255

5. CONCLUSION AND FUTURE CHALLENGES

Two different combinations of lengths and widths have been taken into account for a unit cell reflectarray element with bend in its width to analyze it reflection performance. It has been concluded that, a conventional square patch element can be extended to operate at two different resonances in order to enhance its bandwidth performance. The formation of two resonances is linked with the change in the dimensions and the surface current distributions of the element. The simple design of patch element can make it more feasible for the future fabrication and measurements. The broadband element discussed in this work can be used to eliminate the phase errors from a full reflectarray antenna for its broadband operation.

The change in the direction of surface currents of unit cell element can affect the reflected electric field orientation. The x and y components of surface currents are related to their respective reflection polarization. This effect can alter the polarization performance of reflectarray antenna. Moreover, the leakage currents can also be generated on the element due to a change in the current distributions for dual resonance. The leakage currents can affect a full reflectarray performance by producing high cross-polarization level with limited efficiency. These two major issues can be controlled by designing a reflectarray antenna with an optimized arrangement of elements on its surface. A thorough investigation on the design of reflectarray is required in this regard, which is under consideration as a potential future aspect.

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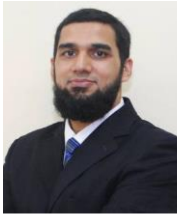	Muhammad Inam Abbasi received the B.Sc degree in Electrical Engineering with major in Telecommunication in 2008 from Centre for Advanced Studies in Engineering (CASE Islamabad), University of Engineering and Technology (UET, Taxilla), Pakistan. He joined Wireless and Radio Science Centre (WARAS), Universiti Tun Hussein Onn Malaysia (UTHM) as a Graduate Research Assistant in 2009 where he completed his Master by Research and Ph.D. in Electrical Engineering in 2011 and 2016 respectively. Currently, He is working as a Post-Doctoral research fellow at Wireless Communication Centre (WCC), Universiti Technologi Malaysia (UTM). His recent research interest lies in high performance planar and printed antenna design, passive and reconfigurable reflectarray and planar reflector antennas, novel materials for the design of enhanced performance antennas. Dr. Inam has published one book and more than 40 research papers in internationally indexed journals and conferences.
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