Analysis of Concentric Split Ring Square Reflectarray Element for Bandwidth Enhancement

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Abstract? An analysis of phase variation and phase range of concentric split ring square element for broadband reflectarray antenna is presented in this paper. This element is the combination of a single square element and a ring element where the square element is the modification of the conventional annular ring element which instead of using annul as the hole, this new idea presents a square as the hole in the ring. This will varies the current distribution in the element which will then improves the performance of the bandwidth. The analysis and the design of this reflectarray element is presented based on variable size which operates at the first resonant frequency of 13.44 GHz and at the second resonant frequency of 18.36 GHz. The design procedure and critical parameters consist of phase range and phase slope (or variation) are also discussed. Modifying the current distribution of square ring element, leads to a less steep phase variation and also enhancement on the bandwidth performance (up to 67.6%). The practical phase range is achieved through the use of RF35 as the substrate with the dielectric constant of 3.54 and the thickness of 1.524 mm. CST Microstripes is used as the software tool to get the simulation results.

Keywords: reflectarray antenna; dual frequency; broader bandwidth
Reflectarray antennas have been proposed as a possible replacement to the conventional parabolic reflector antennas [3], [4]. The development of microstrip technology and the need for low-cost, easy to install, light weight, high gain and aesthetically pleasing antennas for commercial applications has given additional impetus to the study. The basic ring element has been modified to allow the broadening bandwidth. This paper outlines the procedure for the analysis of concentric split ring square element using variable size.

In its basic form, a microstrip reflectarray consists of a flat array of microstrip patches or dipoles printed on a thin dielectric substrate. A feed antenna illuminates the array whose individual elements are designed to scatter the incident field with the proper phase required to form a planar phase surface in front of the aperture.

The basic design procedure entails the use of phase-design curves. Various approaches have been proposed in the past which include the use of variable size patches and identical patches with variable size stubs for obtaining the required phase shift [1], [5].

**ANTENNA STRUCTURE AND DESIGN**

This paper discusses two types of single element namely ring element and square ring element and one combination element of split ring and split square ring. Substrate RF35 is used for all designs with the dielectric constant of 3.54 and the loss tangent of 0.0018 at 1.9 GHz. The unit cell size is 10 mm x 10 mm. MicroStripes software is used as the tool to analyze the phase variation graph. In MicroStripes model, 0° phase reflection is used to define the resonance, whereas for a perfect conductor this is 180° relative to the incident wave.

**(A) Single Ring Element Behaviour**

The conductive ring is a simple symmetrical element, which can be nested and optimised for dual frequency and/or broadband operation. The resonant behaviour of periodic arrays of rings is determined by the element size, periodicity and the electrical properties of the substrate materials. In the absence of mutual coupling, when $\lambda_{eff} = pd$ (where $\lambda_{eff}$ is the efficient wavelength and $d$ is the ring element diameter), the rings resonate giving 180° reflection phase. The phase can therefore easily be controlled by varying the ring element diameter, and it is this method which is used to provide the required phase correction across the reflectarray antenna aperture.

**(B) Single Square Ring Element Design and Behaviour**

The new proposed element in this paper is a single square ring element which can give a bigger reflection phase range and less steep phase variation curve compared to the single ring element. This element has been modified to give a new physical view of the conventional ring element which the square annul is used instead of the basic circular annular ring.
The 3-D geometrical views of the single square element is shown in Fig. 1, where $a$ is the square length and $R$ is the ring radius from the end edge of the conductor. For investigation of square element structure performance and behaviour, the ratio of the square length and ring radius ($a/R$) was selected to be 0.7, 0.86, 1 (square length and ring radius is the same), 1.2 and 1.4.

![Figure 1: The 3-D geometrical view of a single square reflectarray element](image)

The resonant behaviour of a periodic square element is determined by the element size, periodicity and the electrical properties of the substrate materials. The phase is controlled by varying the square length, $a$ and the ring radius, $R$.

Fig. 2 shows the frequency response for variable-ratio of $a/R$ at the nominal size of ring radius, $R = 3.46$ mm, the periodicity = 10 mm, the dielectric constant for the substrate, $\varepsilon_r = 3.54$ and the thickness of the substrate, $t = 1.524$ mm.

It is clearly shown that in Fig. 2, the frequency resonant is shifted by modifying the physical geometry of both parameter square length, $a$ and ring radius, $R$. The phase slope is reduced for the smaller ratio of the square length and the ring radius ($a/R$). In other words, when $R$ is fixed to one value, the bandwidth performance is improved for smaller value of square element size, $a$. However, the linear phase range is also decreased, and therefore, a trade-off must be made between these two parameters.

Fig. 3 shows that a high current density is observed at area $x$, at the resonant frequency, 9.97 GHz. For a smaller area of copper size $x$ and $y$, the gradient is decreased and improved while the practical phase range is decreased and degrades the performance of the element. The element ratio of $a/R = 1$ therefore is selected to be the trade-off value for giving the optimum value of phase gradient and linear phase range.
Figure 2: Frequency response of a single square reflectarray element with different $a/R$ ratio.

Figure 3: Surface current distribution at 9.97 GHz for a grounded square reflectarray element with $a/R$ ratio = 1 ($a = 3.46$ mm, $R = 3.46$ mm, periodicity = 10 mm, $e_r = 3.54$ and $t = 1.524$ mm).
In Fig. 4, $g$ is the gap size for the split of the elements. The nominal inner radius of the outer split ring element is 3.56 mm and the radius of the split square ring is 3.06 mm which give the ratio of $I/O$ value = 0.86. In this work, the gap size is limited to 0.28 mm due to fabrication tolerances, but ideally it should be smaller [2], [6] so that the resonant frequency is not increased. The unit cell size is 10 mm x 10 mm. RF-35 with a dielectric constant of 3.54 and a loss tangent of 0.0018 at 1.9 GHz was used. Copper metal was used to simulate the designed element and the ground plane.

![Figure 4: The top-view of concentric split ring square reflectarray element.](image)

From studies in [2] and [6], the introduction of gap on a structure can affect the frequency response performance. In this work, gap is also introduced to improve the performance of both phase range and gradient for periodic reflectarray elements. In this work, we also compare the performance and behavior of three concentric square element and systematically introduced gap in the structure. Fig. 5 shows the frequency response for the three designed element which are concentric solid ring square element (without any gap), concentric ring square element with gap on the ring element, and concentric split ring square element (gaps are on both ring and square structure).

From Fig. 5, it is clearly shown that, for the first resonance, the gradient of the curve is largely decreased when gap is introduced in the design. The bandwidth performance is improved from 26.9% to 67.6%. While for the second resonance, the phase slope is slightly improved from 19.8% to 20.3% only, however the plateau region is largely improved for the element with gaps.

Fig. 6 shows the current distribution for concentric split ring square reflectarray element. It is evident that the outer ring is determining the first resonance, while the inner square ring determines the second resonance. For the first resonance, it is observed that the outer ring element is strongly excited, and for the second resonance, the inner square ring element is strongly excited.
Figure 5: Frequency response for three element designed.

Figure 6: Surface current distribution (a) at 13.44 GHz and (b) at 18.36 GHz for a grounded concentric split ring square reflectarray element with \( a/R = 1 \) and \( I/O = 0.86 \). (\( O = 3.56 \) mm, \( \sigma = 3.06 \) mm, \( R = 3.06 \) mm, periodicity = 10 mm, \( \varepsilon_r = 3.54 \) and \( t = 1.524 \) mm)
RESULTS AND DISCUSSION

With the designed structure dimension given in Section II, the simulated reflection phase versus ring radius of the proposed antenna is plotted and shown in Fig. 7.

![Reflection phase versus square ring radius for single square element with \( a/R = 1 \)
 at 23.70 GHz (periodicity = 10 mm, \( e_r = 3.54 \) and \( t = 1.524 \) mm)](image)

**Figure 7**: Reflection phase versus square ring radius for single square element with \( a/R = 1 \) at 23.70 GHz (periodicity = 10 mm, \( e_r = 3.54 \) and \( t = 1.524 \) mm)

As stated in Section II, \( a/R = 1 \) is used for further investigation on square element resonant behavior. The reflection phase versus square ring radius is plotted at the resonant frequency of 23.70 GHz. The linear phase range is 403° which is sufficient enough for practical design [2] while the gradient is 0.34°/μm. Bandwidth performance for this element is 40.8%. Fig. 7 also shows that the maximum radius, \( R \) for the square ring is 4.46 mm. This is because the phase given at the higher \( R \) is not an acceptable resonance because the edge of the ring almost touched the next periodic array and will cause a short-circuit phenomenon.

For concentric ring square element, \( I/O = 0.86 \) and \( a/R = 1 \) is used in reflection phase versus outer ring radius graph (Fig. 8) at the resonant frequencies of 7.48 GHz and 11.78 GHz. The linear phase range achieved at the first resonance is 249° with the gradient 0.54°/μm and the phase range at the second resonance is 230° with the gradient 0.50°/μm. Bandwidth performance for first resonance is 26.9% and 19.8% for the second resonance.

While for the concentric split ring square element performance as in Fig. 9, \( I/O \) and \( a/R \) ratio used is similar to the design (without gaps) at the resonant frequencies of 13.44 GHz and 18.36 GHz. The linear phase range achieved for the first resonance is 320°, which is acceptable for practical design [2] with the gradient 0.15°/μm and 464° (phase range) with gradient 0.33 °/μm at the second resonance. The bandwidth performance is 67.6% and 20.3 % for the first and second resonance respectively.

The performance for concentric split ring square element in Fig. 9 is improved from the design in Fig. 8 (without split). As shown in Fig. 9, the curve at the first resonance is largely improved where the plateau region is almost abolished and the curve is more linear.
The frequency is shifted from 7.48 GHz to 13.44 GHz which then give the bandwidth improvement of about 40.7%.

**Figure 8:** Reflection phase versus outer ring radius for concentric ring square element with $l/o = 0.86$ and $\alpha / R = 1$ at 7.48 GHz and 11.78 GHz. (periodicity = 10 mm, $\varepsilon_r = 3.54$ and $t = 1.524$ mm)

For the second resonance, the plateau region is again improved but with a slight change. This results the bandwidth improvement of about 0.5% only. However, the new concept of split is still giving the better performance compared to the previous design with no split introduced. The second resonant frequency shifted from 11.78 GHz to 18.36 GHz.

**Figure 9:** Reflection phase versus outer ring radius for concentric split ring square element with $l/o = 0.86$ and $\alpha / R = 1$ at 13.44 GHz and 18.36 GHz. (periodicity = 10 mm, $\varepsilon_r = 3.54$ and $t = 1.524$ mm)
The concentric element concept in the other hand is used to achieve a dual frequency operation compare to the single element performance which gives only one resonant frequency. The phase range performance in a single element is bigger compared to the first resonance of the concentric split ring square element. However, the phase gradient which leads to the bandwidth performance is improved from $0.34^\circ/\mu m$ to $0.15^\circ/\mu m$.

In concentric element design, the critical feature of mutual coupling should be taken care because the design consist two elements which use the copper metal material. In this work, the gap between the first and second element for concentric design is fixed at 0.5 mm.

CONCLUSION

A new design of reflectarray element for broadband dual frequency application is proposed in this work which is the concentric split ring square element. By modifying the current distribution of the physical geometry of the basic concentric ring square element leads to a better phase variation and bandwidth.

This new design gives the good performance in bandwidth which is up to 67.6 % and 20.3 % in dual frequency operations. The phase range for the element is also in a good practical region which gives the value of $320^\circ$ and $464^\circ$ at both frequencies respectively.

This antenna is easy to fabricate and low cost. These features are very useful for worldwide portability of communication applications.

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REFERENCES


