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A Compendium of Development in Analysis and Design of Microstrip Reflectarray Antenna

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Abstract In recent times, Microstrip Reflectarray antennas have become an alternative to conventional directive antennas. The reflectarray gives several benefits to reflector antennas such as easy deployment mechanism, cost effectiveness, portability, ease of beam steering and high throughput. Narrow bandwidth is the one distinct disadvantage of reflectarray antenna. Various techniques like aperture coupling, stacking and use of variable size patches is done to broadband the structure. Shaped beam, being one of the important features for satellite communication antennas can be easily achieved by using reflectarray antennas. This paper discusses different designs and analysis of such arrays along with the reflection mechanism.

Keywords — Microstrip, Shaped beam, Spatial Delay, Reflectarrays, Stacking, Illumination Efficiency

I. Introduction

Antennas are the core part for any wireless communication. Different types of antennas are used for different applications. Amongst all available antennas, Microstrip Reflectarrays are used in various fields such as remote sensing, radar and communications and in various applications of ground systems and spacecraft. These antennas are having very attractive features like portability, ease of manufacturing and installation mechanism. These antennas are also in tough competition with the antennas such as waveguide slot and reflectors arrays because of many exclusive features like beam steering and high power gain. This paper will provide an in depth knowledge on such antennas and various techniques to design and analyze such antennas will be discussed. One of the interesting applications of this antenna is satellite communication. Reflectarray can be mounted on a satellite and a desired shaped beam can be easily achieved through it.

II. Reflectarray Concept

The reflectarray can be termed as flat reflectors and the concept is identical to reflectors in which a feed horn is used to illuminate the reflector surface and in turn a planar wave front is generated. The printed reflectarray antenna consists of a feed which illuminates the reflector surface as shown in Figure 1. The reflector is made up of an array of patches, dipoles, rings or similar structures. A horn antenna can be used as a feeding element which illuminates the reflecting elements mounted on the reflector surface [1]. Different types like offset feed, inset feed or cassegrain feed can be used. The reflectarray has been popular since long but the main attention is gained by microstrip reflectarray because of its portable structure. The limitation of reflectarray is the narrow bandwidth and so major literature is found on improving the bandwidth by using the broadband radiating structure.

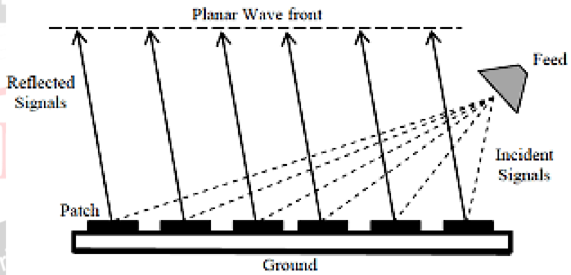

Figure 1: Reflectarray Concept

Bandwidth analysis can be done in many different ways according to the applications. If circular polarization is used, the bandwidth calculated will be in terms of Axial Ratio (AR) and the stable shaped pattern bandwidth is used for shaped beam antennas.

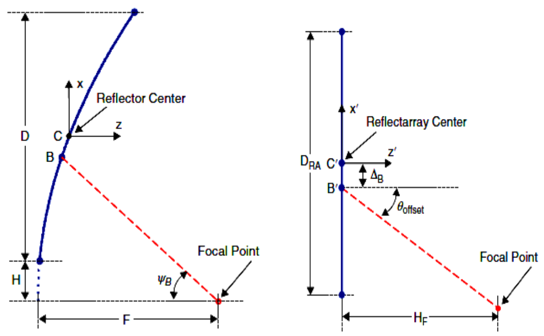

Figure 2: Reflector and Reflectarray Feed Configuration

The radiating elements decide the type of polarization. The

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radiating elements can also be designed to work for dual frequency. Reflectarray concept has been derived from the reflectors. Both the antennas share almost similar type of designing parameters as shown in Figure 2. The design parameters of the reflector antenna are diameter, focal length and offset height. The reflectarray antenna has diameter, focal length and tilt angle as design parameters. For reflectarray, the offset height has to be changed to offset diameter from the reflectarray centre. This is because the reflectarray has flat geometry whereas the reflectors have curved geometry.

III. Historical Developments

The reflectarray antenna concept was initially introduced in the 1960s in which use of short-ended waveguide elements with variable lengths was done. The waveguide gets illuminated by the feed, the electromagnetic waves travels through it and reflects back from the short end of the waveguide. But due to the bulky structure, this kind of antennas didn't get much attention. In 1970s, spiral reflectarray were introduced by Phelen as shown in Figure 3. The diodes attached to the spiral ends were used to reconfigure the beam. The aperture efficiency of Spiral phase reflectarray was very low because of the large dimensions.

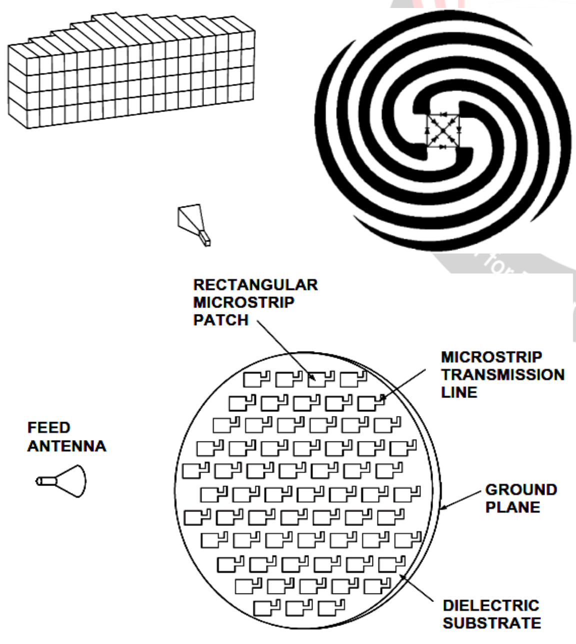

Figure 3: Various types of Reflectarray Antennas

The main research for reflectarray focuses on multibeam scanning for point to point communication and beam steering which can be useful for satellite communication. The latest amongst all the antennas is microstrip reflectarray which has gained much attention because of its light weight structure as shown in Figure 3. The printed reflectarrays came in various forms which had low mass reflecting surfaces.

IV. Reflectarray System Design

There are mainly two steps in the design of reflectarray antenna, the phasing element design and the system configuration design. The phasing element is the one which is used to radiate and the array of such elements in turn focuses to produce the desired beam. There are different methods of designing the phasing/radiating element. Elements with phase delay line can be used in which the phase is function as in equation (i):

$$\Phi_{delayline}=2kl \qquad \text{(i)}$$

Here, the term $\Phi_{delayline}$ represents the phase that should be given to the stub lines which is attached to each patch. l represents the length of the delay line. Thus the phase should be in proportion with the delay line length. Variable size patches can also be used because it is based on the fact that the patch with variable dimensions will give different reflections. The elements with variable rotational angles can also be used on the fact that rotating a Circularly Polarized (CP) antenna element about its origin by $\psi°$ will change the radiated phase by the same amount. A Figure 4 shows the arrangement of different elements in which subsection (a) describes patches with attached stubs, subsections (b) and (c) describes dipoles and patches of varying size, subsection (d) describes patches used for obtaining circular polarization. The second step in designing is the system configuration design in which the location and dimension of the feed is to be decided. The analysis of aperture efficiency can help to optimize the parameters of a system configuration, such as feed specifications, f/D ratio and aperture shape. The gain of the reflectarray antenna is directly proportional to antenna efficiency. Many factors influence the overall aperture efficiency of reflectarray antennas, and the dominant terms are spillover (ηs) and illumination (ηi) efficiencies.

$$\eta_{aperture} = \eta_i \, \eta_s \qquad \text{(ii)}$$

The equation (ii) shows that the reflectarray efficiency depends on the illumination efficiency which is based on the fact that the feed is not able to illuminate all the elements on the aperture uniformly. The spillover efficiency gives the information on the percentage of radiated power from the feed that is taken by the reflecting aperture relative to the total radiated power.

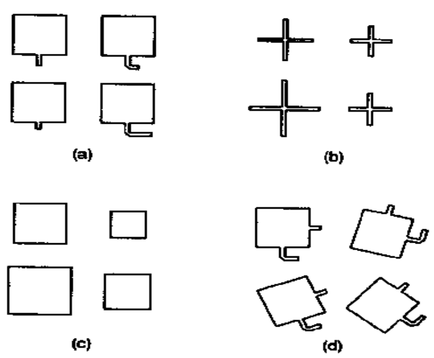

Figure 4: Various arrangements of patches

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Microstrip Reflectarray has a disadvantage of narrow bandwidth. The limitations in bandwidth are because of following reasons:

A) *Bandwidth limitation by the radiating element:*

The microstrip patch element has very narrow bandwidth of about 3 to 5 percent. This element when used as a radiating element in the array structure gives very narrow bandwidth of the whole structure.

B) *Bandwidth limitation by differential spatial phase delay:*

This limiting factor is illustrated in Figure 5 where ΔS is the differential spatial phase delay. This phase difference is created between the two paths S1 and S2 from the feed to reflectarray elements. As the frequency changes, the required phase in the array will change, and the reflectarray element phase will also change. Generally, these two phase changes do not match with each other and so phase errors are introduced resulting in gain and bandwidth reduction with degradation in pattern.

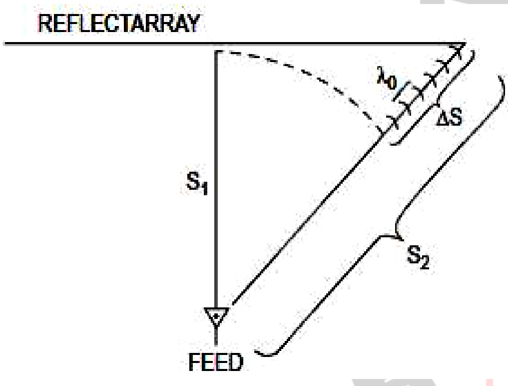

Figure 5: Spatial Delay

The above diagrammatic representation can be well explained using following equations [2]. The elements should satisfy the following equations (iii) and (iv).

$$\psi_2(f) - \psi_1(f) = k(R_2 - R_1) \quad \text{(iii)}$$

$$\psi_2(f_0) - \psi_1(f_0) = k_0(R_2 - R_1) \quad \text{(iv)}$$

$$PhaseError(f) = \psi_2(f) - \psi_1(f) - k(R_2 - R_1) \quad \text{(v)}$$

Equation (iii) gives the information on the phases which are function of frequency on elements 1 and 2. As both will experience some path difference it is equated to $\mathbf{k(R_2 - R_1)}$. In equation (iv), as the frequency has changed the phase on both the elements has to change being a function of frequency. The phase error occurs when both the equations (iii) and (iv) do not satisfy the equivalency as shown in equation (v).

V. Bandwidth Enhancement Techniques

Bandwidth can be improved if the phase curves are parallel and smooth for different frequency changes as shown in Figure 6. The phase curve gives the variation of reflection phase in accordance with the change in the element dimensions. If the curves are smooth and parallel it resembles that the radiating elements satisfies the conditions mentioned in equations (i) and (ii).

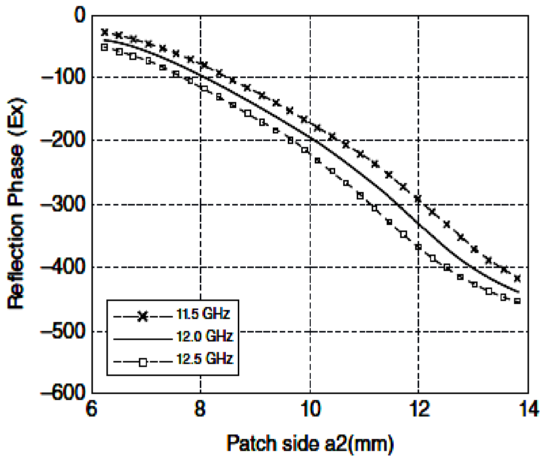

Figure 6: Phase curves for different frequencies

Many techniques for enhancement of the bandwidth have been proposed in the literature such as: stacking of arrays, using printed ridged shaped patches, or using multi-resonant elements as shown in Figure 7.

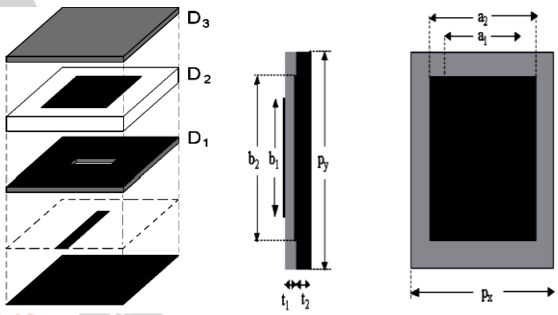

Figure 7: Broad banding Techniques

Each technique has its own disadvantage. The stacking of arrays can be used for enhancing the bandwidth but it leads to increase in cost as it requires more material and more number of elements. The use of ridged shape patches leads to cross polarization. In last few years operation of reflectarray on dual frequencies has been into research for broad banding the operation of the antenna. It can be obtained using techniques such as using two layers [4] in which each band is for different frequency operation, or using Frequency Selective Surface (FSS)-backed structures. Foam can be used to increase the height of the structure which leads to enhanced bandwidth. The multilayer structure undoubtedly leads to enhanced bandwidth but it has the disadvantage of fabrication error [3]. Because of the above said reason, single layer reflectarray antennas using thick substrate were designed in which the bandwidth reported was around 24%. In this approach for obtaining linear phase curves, thick substrate is to be used which may lead to increase in cost. Thick substrate leads to linear phase for small range. In order to overcome the small range problem, the dimensions of the elements have to be largely

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varied. In this approach the potential phase error occurs which is unavoidable. Large variations in the dimension of the elements also have the problem of the mutual couplings which leads to fabrication errors. This error can be resolved by using phase delay lines that provides large linear phase. Hence, from the above said technique, thick substrates and largely varying elements if optimized properly may contribute to broad bandwidth. One technique of aperture coupled feeding can be used for overcoming the disadvantage of microstrip reflectarray antenna. In aperture coupling, a slot controls the overall radiation of the structure. As aperture coupling is also a multilayer structure, it may lead to increase in height and ultimately increases bandwidth [5]. In today's date, this area has wide scope of research.

VI. Types of Reflectarray Antennas

A. Inflatable/Thin membrane Reflectarrays

Several deployable antenna concepts have been proposed over the past few years in order to achieve finer radar imaging resolution, longer distance communications, higher data rates, etc. Various inflatable antennas such as Ka-Band 3-m Inflatable Reflectarray, X-Band 1-m Inflatable Reflectarray have been developed.

B. Multibeam Reflectarrays

Many feeds can be used at times to feed reflectarrays. The designing comes out to be the same as that of multibeam reflectors. Multibeam reflectarrays can be used to achieve shaped beam as the elements used can be varied in phase and the required shift can be produced using the multiple horns as feeding.

C. Amplifying Reflectarray

Reflectarray can be used as a power combiner and amplifying array by using microstrip patch antenna elements and giving them some phase. Bialkowski has demonstrated both the reflectarray techniques which were designed from 9 GHz to 11 GHz.

D. Folded Compact Reflectarray

In reflectarrays, the feed is placed at certain distance as in reflectors but this contributes to the problem of low compactness. Folded reflectarrays are the other type of reflectarrays which can overcome the above mentioned problem and can give linear polarization.

E. Contoured beam Reflectarrays

Contoured beam can be achieved using reflectarrays by giving the reflecting elements an appropriate phase shift [6]. In reflectarrays, the feed excites the elements and the phase on each element is adjusted to obtain the beam. There are reflectarrays made up of many different phase shifter elements which can efficiently be used to obtain the beam. Ray tracing method can be used to determine necessary phases on the reflectarray elements to duplicate the same radiating aperture phase distribution as if it is in case of shaped reflector antenna. If in case the whole geometry is to be defined than, radiation pattern must be cosecant square in elevation and sectored in azimuth. This can be generated as per the specifications and location of the antenna. For shaped beam formation, the geometry should be analyzed for phase only synthesis method regardless of the types of elements used. Afterwards a smart algorithm called Particle Swarm Optimization is used which adjusts the optimized phase distribution obtained from phase only synthesis to obtain shaped beam with wide frequency bandwidth performance. In PSO, the parameters associated with reflection phase and frequencies are as considered as inputs. In addition to this, a method called Intersection approach is useful in getting 2-D phase distribution [7].

VII. Designing of Shaped Beam Reflectarrays

The thicker substrate gives better performance for obtaining shaped beam as mentioned in [8]. Variable size patches are better to control the phase. The substrate selection plays a very important in controlling the phase. In case if multilayer structure is used, the additional advantages are that as the delay line is used and it is on different layers than it gives more space and PIN diodes can be kept in order to achieve reconfigurable beam. In addition to this, Spatial Delay gets reduced because of the use of True Time Delay lines. The layers can be joined with plastic screw frame. This can avoid changes in electrical permittivity produced by glues. If the delay lines are used, they can be H or V polarized. It was proved that V-polarized delay lines produces less cross polarization and can be used for shaping the beam [9]. Single layer structure seems to be easy for the fabrication. If single substrate is to be used, foam can be used which is a low cost material with low loss tangent. Further, to achieve the required phase, rings along with patch can used which can be varied [10]. The shape of the reflectarray geometry also plays an equal role in getting desired beam. Concave, Convex and flat geometries can be used. A convex surface gives good results as to achieve pencil beam the elements at edges contribute less in comparison to elements at centre.

VIII. Conclusion

This paper presents information about reflectarray antenna. These antennas can prove to be a strong alternative to the expensive arrays and bulky reflectors which are usually used for space applications. Designing and analyzing procedures for such arrays are discussed. Narrow bandwidth being the only disadvantage of Reflectarray can be reduced using various techniques which are discussed. Historical reviews as well as current and future applications for reflectarrays are also presented. A depth study of shaped beam reflectarrays is also presented.

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REFERENCES

[1] John Huang, Jose A. Encinar, "Reflectarray Antennas", John Wiley & Sons, Inc., 2008

[2] Payam Nayeri, Fan Yang, Atef Z. Elsherbeni, “Reflectarray Antennas-Theory, Design and Applications”, Wiley IEEE press, 2018

[3] J. A. Encinar and J. Agustín Zornoza, “Broadband design of three-layer printed reflectarrays,” *IEEE Trans. Antennas Propag.*, vol. 51, no. 7, pp. 1662–1664, 2003.

[4] J. A. Encinar and J. A. Zornoza, “Three-layer printed reflectarrays for contoured beam space applications”, *IEEE Trans. Antennas Propag.*, vol. 52, no. 5, pp. 1138–1148, 2004.

[5] M. E. Bialkowski and H. J. Song, “Dual Linearly Polarized Reflectarray using Aperture Coupled Microstrip Patches*”, IEEE Antennas Propag. Soc. Int. Symp*. 2001, vol. 3, no. 1, pp. 486–489,

[6] M. Karimipour, A. Pirhadi, and N. Ebrahimi, “Accurate method for synthesis of shaped-beam non-uniform reflectarray antenna”, *Iet Microwaves Antennas Propag.*, vol. 7, no. 15, pp. 1247–1253, 2013

[7] O. M. Bucci, G. Franceschetti, G. Mazzarella, and G. Panariello, “Intersection approach to array pattern synthesis”, *Microwaves, Antennas Propagation, IEE Proc. H*, vol. 137, no. 6, pp. 349–357, 1990.

[8] D. M. Pozar, S. D. Targonski, and R. Pokuls, “A shaped-beam microstrip patch reflectarray”, *IEEE Trans. Antennas Propag*., vol. 47, no. 7, pp. 1167–1173, 1999

[9] E. Carrasco, M. Arrebola, J. A. Encinar, and M. Barba, “Demonstration of a shaped beam reflectarray using aperture-coupled delay lines for LMDS central station antenna”, *IEEE Trans. Antennas Propag.*, vol. 56, no. 10, pp. 3103–3111, 2008

[10] M. Karimipour and N. Komjani, “Bandwidth enhancement of electrically large shaped-beam reflectarray by modifying the shape and phase distribution of reflective surface”, *AEU - Int. J. Electron. Commun*. vol. 70, no. 5, pp. 530–538, 2016.

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