Design Study of Microstrip Reflectarray Antenna Using Different Lengths of the patches

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Abstract

A microstrip reflectarray is a flat reflector antenna that can be mounted conformally on to a spacecraft's outside structure. The antenna's reflecting surface, being flat, can be more easily and reliably deployed than a curved parabolic reflector. This paper presents the design study of microstrip reflectarray, theoretical analysis of the antenna performance parameters, such as radiation pattern, gain, and bandwidth are also presented. A comparison between microstrip reflector array and parabolic reflector are presented.

الخلاصة:

مصفوفة العاكس ذات الهوائيات الشريطية هي هوائي عاكس مسطح يمكن أن يركب بشكل متماثل على السطح الخارجي للمركبة الفضائية . عندما يكون سطح هوائي العاكس مسطح يمكن أن يصبح أكثر سهولة و وثوقية و يكون أكثر انتشارا من العاكس ذو القطع المكافيء . في هذا البحث يمثل دراسة تصميمية لمصفوفة العاكس ذات الهوائيات الشريطية ، قدم التحليل النظري لأدائية متغيرات الهوائي ، مثل شكل الإشعاع و الربح و عرض الحزمة . قدمت مقارنة بين مصفوفة العاكس ذات الهوائيات الشريطية و العاكس ذو القطع المكافيء.

1-Introduction

The microstrip reflectarray, being one of the printed low-profile antenna technologies, consists of very thin, flat reflecting surface and an illuminating feed as shown in figure (1) [1]. On the reflecting surface, there are many isolated microstrip patch elements without any power division network.

Printed reflectarray is an antenna similar to a parabolic reflector. But with its reflecting surface capable of being designed either flat or slightly curved for conformal mounting onto an existing structure without adding significant amount of mass and volume to the structure [2].

The printed reflectarray combines some of the best features of microstrip array antenna and the traditional parabolic reflector antenna. It can be designed to have very high gain with relatively good efficiency, as well as to have its main beam tilted/scanned to large angles from its broadside direction. One significant advantage is that, when a large aperture (e.g. 9-meter size) antenna requires a deployment mechanism, the flat structure of the reflectarray will allow a much simpler and more reliable folding or inflation mechanism than the curved surface of a parabolic reflector. With all its salient features and capabilities, there is one distinct disadvantage associated with the reflectarray antenna. This is its inherent narrow bandwidth due to different path lengths or the so-called differential spatial phase delays from the feed to the reflecting elements, and the resonant nature of the patch elements. This narrow bandwidth generally cannot extend much beyond fifteen percent depending on its element design, aperture size, focal length, etc. In general, the larger the aperture, the smaller bandwidth it gets[2,3].

There are several methods for reflectarray elements to achieve a planar phase front. One is to use identical microstrip patches with variable -length phase delay lines attached [4, 5] so that they can compensate for the phase delays over the different paths from the illuminating feed. Another is to use variable - size patches, dipoles, or rings [2,6,7] so that elements can have different scattering impedances and, thus, different phases to compensate for the different feed - path delays as shown in figure (2).

In this paper, it is used different lengths of microstrip patch antennas so that elements can have different scattering impedances and, thus, phase to compensate for the different feed path delays.

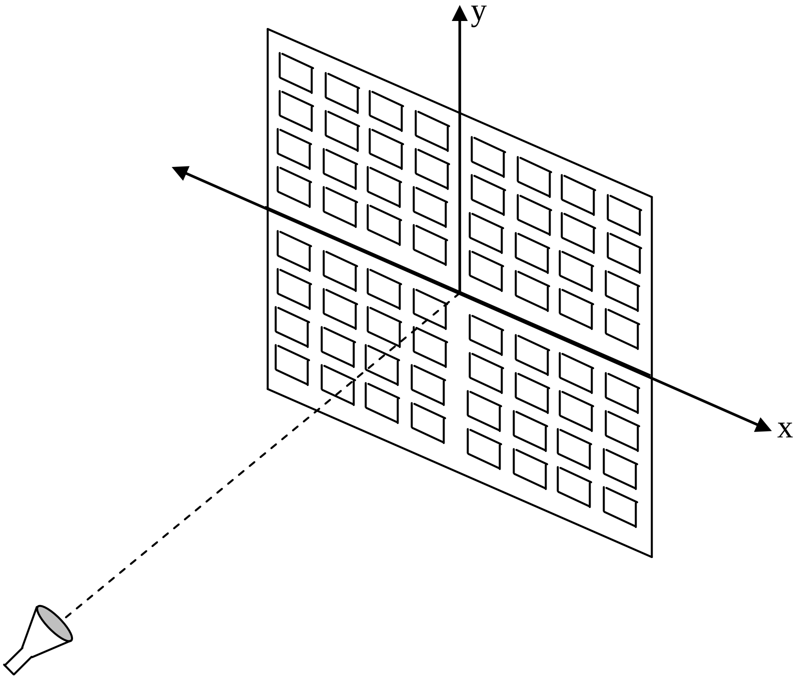


Figure (1) Rectangular Microstrip Reflectarray Array

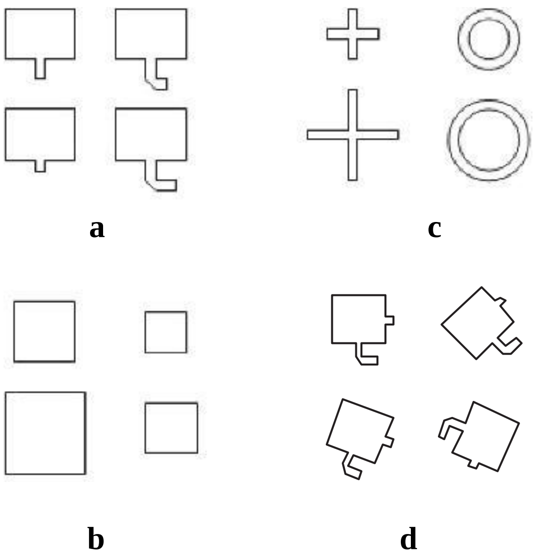


Figure (2) Various Reflectarray Elements:
(a) Identical Patches with variable -length phase delay
(b) Variable - size dipoles or loops,
(c) Variable - size patches and
(d) Variable angular rotations.

2-Parabolic Reflector Antenna

Parabolic reflector antenna used in long-distance and high resolution radar applications, has high gain and wide bandwidth. The parabolic shaped reflector has a unique feature: all path lengths from the focal point to the reflector and on the aperture plane are the same as shown in figure (3), then the focal length is

$$f = \frac{D}{4}\cot\frac{\theta_o}{2} \qquad \ldots(1)$$

Where:

f is the focal length

D diameter of the reflector. The gain is given by [8,9]

$$G \approx 6\left(\frac{D}{\lambda}\right)^2 \qquad \ldots(2)$$

And the half power beam width is given by

$$HP = \frac{70\lambda}{D} \quad \text{(degrees)} \qquad \ldots(3)$$

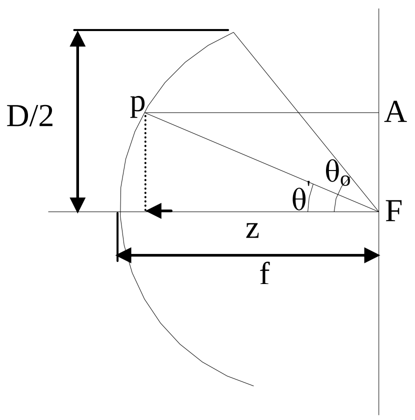


Figure (3) Parabolic Reflector Antenna Geometry

3- Mechanisms of Microstrip Reflectarray

The design and analysis of the reflectarray can be achieved through conventional array theory for arbitrarily located feed. When many microstrip antenna elements with different lengths are arranged in rectangular planar aperture and are illuminated by a feed antenna as shown in figure (4-a) these elements will reradiate their illuminated energy into space. The total reradiated energy will be non-cophasal if all elements and their terminations are identical. This is because the fields that propagate to the elements from the feed have different path lengths $s_1, s_2, \ldots, s_n$ as shown in figure (4-a).

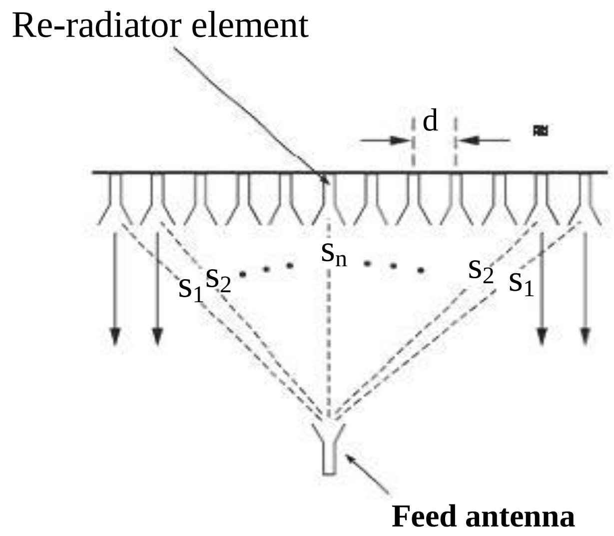


Figure (4-a) Side View for Rectangular Microstrip Reflectarray Array

The following derivative gives very simple method to calculate the compensating phase delay needed for each element of the reflectarray with a broadside directed beam. The differential path length for each element is given in x and y- directions. Then the phase for x –direction from figure (4-b):

$$(f+\delta_x)^2 = f^2 + x^2 \qquad \ldots(4)$$

Where

f is the focal length

x is the deviation from the center of planar array in x-direction

δ_x is the phase in x-direction

$$f+\delta_x = \sqrt{f^2 + x^2} \qquad \ldots(5)$$

$$\delta_x = \sqrt{f^2 + x^2} - f \qquad \ldots(6)$$

In the same manner the phase in y- direction

$$\delta_y = \sqrt{f^2 + y^2} - f \qquad \ldots(7)$$

Where:

y is the deviation from the center of planar array in y-direction

δ_y is the phase in y-direction

Then total phase:

$$\delta(x,y) = \delta_x + \delta_y \qquad \ldots(8)$$

Substitute equations (6) and (7) in equation (8) yields:

$$\delta(x,y) = \sqrt{f^2 + x^2} - f + \sqrt{f^2 + y^2} - f$$
$$= \sqrt{f^2 + x^2} + \sqrt{f^2 + y^2} - 2f \quad \ldots(9)$$

Where

δ(x,y) is the total phase in x & y -directions

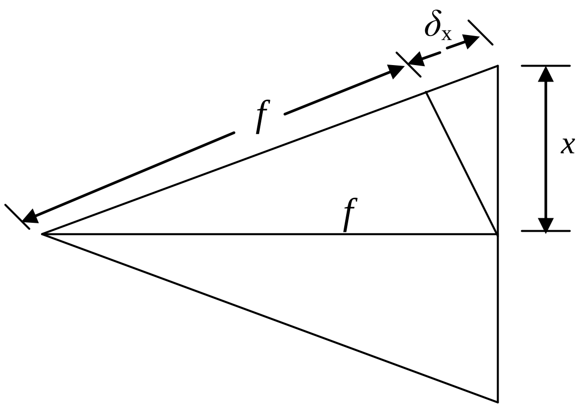


Figure (4-b) Side View for Rectangular Microstrip Reflectarray Array Show The Path Different for Feed Antenna.

The required path delay- compensating phase from the elements achieved primarily via the different length of microstrip element. Different lengths yield different input impedances (complex quantity) at a particular frequency, which in turn give different phase .

4. Rectangular Microstrip Antennas

A microstrip patch antenna consists of a very thin metallic patch placed a small fraction of a wavelength above a conducting ground-plane. The patch and ground-plane are separated by a dielectric. The patch conductor is normally copper and can assume any shape, but simple geometries generally are used, and this simplifies the analysis and performance prediction. The patches are usually photoetched on the dielectric substrate. The substrate is usually non-magnetic. The relative permittivity (ε_r) of the substrate is normally in the region between 1 and 10, which enhances the fringing fields that account for radiation, but higher values may be used in special circumstances. Due to its simple geometry, the half-wave rectangular patch is the most commonly used microstrip antenna. It is characterized by its length *L*, width *w* and thickness *h*, as shown in figure (5) [7,9].

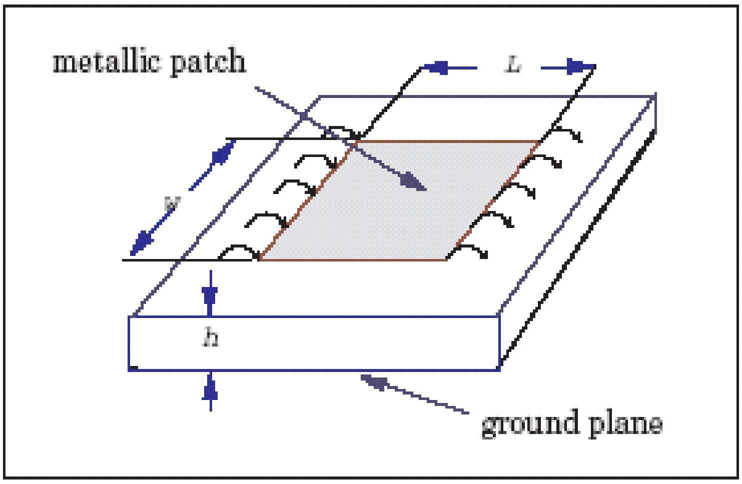


Figure (5) A square microstrip patch antenna showing fringing fields that account for radiation.

5. Improved Transmission Line Model for Rectanqular Patch Antenna

The circuit representation of the present model is shown in figure (6). In this network Y_s is the self admittance of the open-end terminations of the patch, and Y_m is their mutual (radiation) admittance. The mutual coupling is formally taken into account by voltage-dependent current source. The admittance matrix of this three-port model is given by [10]:

$$[Y]=\begin{bmatrix} Y_s+Y_c\cos(\gamma L_1)-Y_m & -Y_m & -Y_c\cosh(\gamma L_1) \\ -Y_m & Y_s+Y_c\coth(\gamma L_2) & -Y_c\coth(\gamma L_2) \\ -Y_c\csc h(\gamma L) & -Y_c\csc h(\gamma L_2) & Y_c\coth(\gamma L_1)+Y_c\coth(\gamma L_2) \end{bmatrix} \quad \ldots(10)$$

Where

$\gamma=\alpha+jB$ which is the propagation constant of the transmission line with aspect ratio W/h.

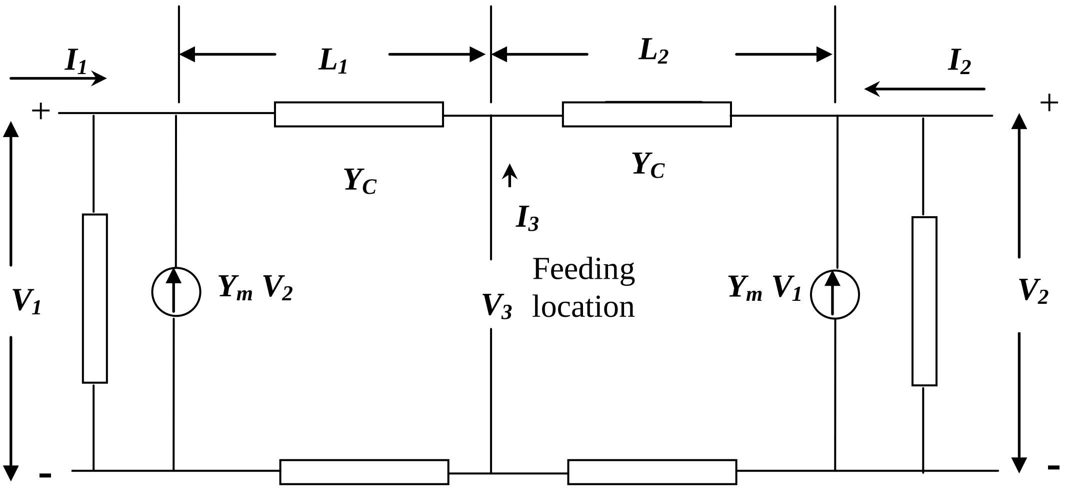
Y_c is the characteristic admittance of the transmission line with aspect ratio W/h.

In the case of a coaxial fed antenna, this corresponds to $I_2=I_1=0$, it follow from equation (10) that:

$$Y_{in}=\frac{Y_C+Y_S-Y_m^2+2Y_S\coth(\gamma L)-2Y_mY_C\csc h(\gamma L)}{(Y_C^2+Y_S^2-Y_m^2)\coth(\gamma L)+(Y_C^2-Y_S^2+Y_m^2)\coth(\gamma\Delta)\csc h(\gamma L)+2Y_SY_C} \quad \ldots(11)$$

Where:

$$\Delta=\frac{L}{2}-L_1$$



Figure(6) Improved Transmission Line Model Represented as Three Port

6.Radiation Pattern Analysis of the Microstrip Reflectarray

When a rectangular planar array with M*N microstrip patch elements is non-uniformly illuminated by a low-gain feed at f, as shown in figure (1), the reradiated Field from the patches in an arbitrary direction will be of the form [7,8,9]:

$$E(\theta,\phi)=\sum_{m=1}^{M}\sum_{n=1}^{N}F(\theta,\phi)\exp\left[j\left(m\beta d_x\sin\theta\cos\phi+\delta_x\right)\right]\exp\left[j\left(n\beta d_y\sin\theta\sin\phi+\delta_y\right)\right] \quad \ldots(12)$$

Where

F(θ,φ) is the pattern function of the microstrip patch given by:

$$F(\theta,\phi)=\frac{+jC\exp(-jK_o r)}{\pi r}\left\{\sin\theta\frac{\sin\left(\frac{K_oW}{2}\cos\phi\right)}{\cos\theta}\right\}\cos\left(\frac{K_oL}{2}\sin\theta\cos\phi\right) \quad \ldots(13)$$

d_x is the distance between elements in x-direction

d_y is the distance between elements in y-direction

and the directivity $D(\theta,\phi)$ of the reflectarray is given by:

$$D(\theta,\phi)=\frac{4\pi}{\Omega_a} \quad \ldots(14)$$

Where:

$$\Omega_a=\int_0^{2\pi}\int_0^{\pi}E^2(\theta,\phi)\sin\theta\, d\theta\, d\phi \quad \ldots(15)$$

7. Design Procedure

1- This project deals with the analysis of microstrip reflectarray that is included the derive of the phase delay needed for each element.

2- Design of rectangular microstrip antenna that is included

- Input impedance for each element.
- Design of dimensions of rectangular microstrip antenna (width and length which that dependent on input impedance which, that give the needed phase delay).

The element used in this design is a rectangular microstrip antenna has the following specifications:

W=1.18 cm, L as shown in table (1,2 and 3), h=0.159 cm and ε_r=2.2

3- Design of microstrip reflectarray

It designed rectangular microstrip reflectarray operate at frequency 10 GHz (x-band) with 10*10 elements. The distance between elements is equal to 0.65λ in x and y-directions. The bandwidth of microstrip reflectarray is equal to (12%) (for 1dB gain variation as a standard value [8]) and the gain is equal to (30.733 dB) depending on equation (14). By depending on array theory, the radiation pattern analysis achieved. Figure(7) shows the relation between the phase needed and corresponding length for each element of microstrip antenna, it is noticed that when the choosing the focal length less than 0.9m, the phase needed becomes large and do not intersect with the curve of the figure(7). Consequent it is chosen three values (f=0.95, 1.25, and 1.5 for example) large than 0.9m. Figure (8) show the planar array geometry (reflactarry), the number shown for each element refers to the number corresponds in the tables (1, 2 and 3).

4-Calculation of radiation pattern of the microstrip reflectarray and the Directivity.

8. Results and Discussion

There are three cases for analysis of microstrip reflectarray at different value of focal length.

- First case for focal length (f =0.95m=31.667λ)

Table (1) shows the phase needed to compensate phase delay path for each element and corresponding length. Figure (9) shows the total E-plane radiation pattern of the microstrip reflectarray, and figure (10) shows the total H-plane radiation pattern of the microstrip reflectarray. The half-power beam width in E-plane equals to (4.67^o) and equals to (14.432^o) in H-plane.

- Second case for focal length (f =1.25m=41.667λ)

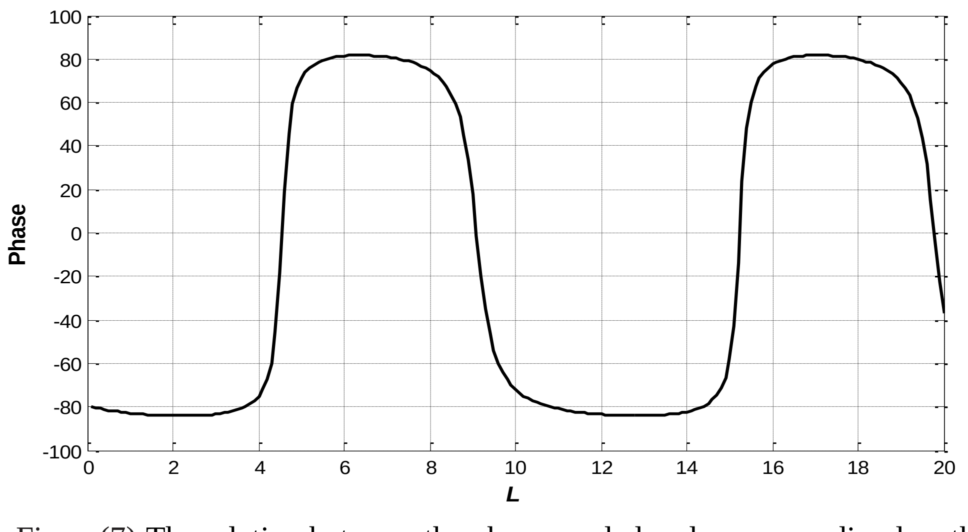
Table (2) shows the phase needed to compensate phase delay path for each element and corresponding length. Figure (11) shows the total E-plane radiation pattern of microstrip reflectarray, and figure (10) shows the total H-plane radiation pattern of microstrip reflectarray. The half-power beam width in E-plane equals to (4.714°) and equals to (14.432°) in H-plane.

- Third case for focal length (*f*=1.5m=50λ)

Table (1) shows the phase needed to compensate phase delay path for each element and corresponding length. Figure (12) shows the total E-plane radiation pattern of microstrip reflectarray, and figure (10) shows the total H-plane radiation pattern of microstrip reflectarray. The half-power beam width in E-plane equals to (4.71°) and equals to (14.432°) in H-plane.

This printed reflectarray combines some of the best features of microstrip array antenna and the traditional parabolic reflector antenna. Figure(13) shows a comparison between (10*10) reflectarray with (19.5cm*19.5cm) physical aperture and parabolic reflector antenna of the same aperture. The comparisons are listed in the table (4).

The bandwidth performance of the reflectarray is no match to the parabolic reflector, which has theoretically an infinite bandwidth. It is very important to study the bandwidth characteristics of the microstrip reflectarray and to optimize it for a given application. The bandwidth performance of a microstrip reflectarray can be limited by the bandwidth of the microstrip patch element and the array element spacing. The bandwidth of the microstrip patch element can be reduced to the impedance variation bandwidth and the field variation bandwidth. The impedance bandwidth is not transcend her because there is no feed network in the array arrangement while, the effect of the field variation and the array is studied, so that the bandwidth range is taken when the change in the directivity dose not exceed 1 dB as a standard value. Figure (14) shows the variation of the reflectarray gain with respect to frequency, the bandwidth is 12% for reflectarray gain variation within 1dB. MATLAB version 7 is used as software to perform the programs.



Figure(7) The relation between the phase needed and corresponding length for microstrip antenna

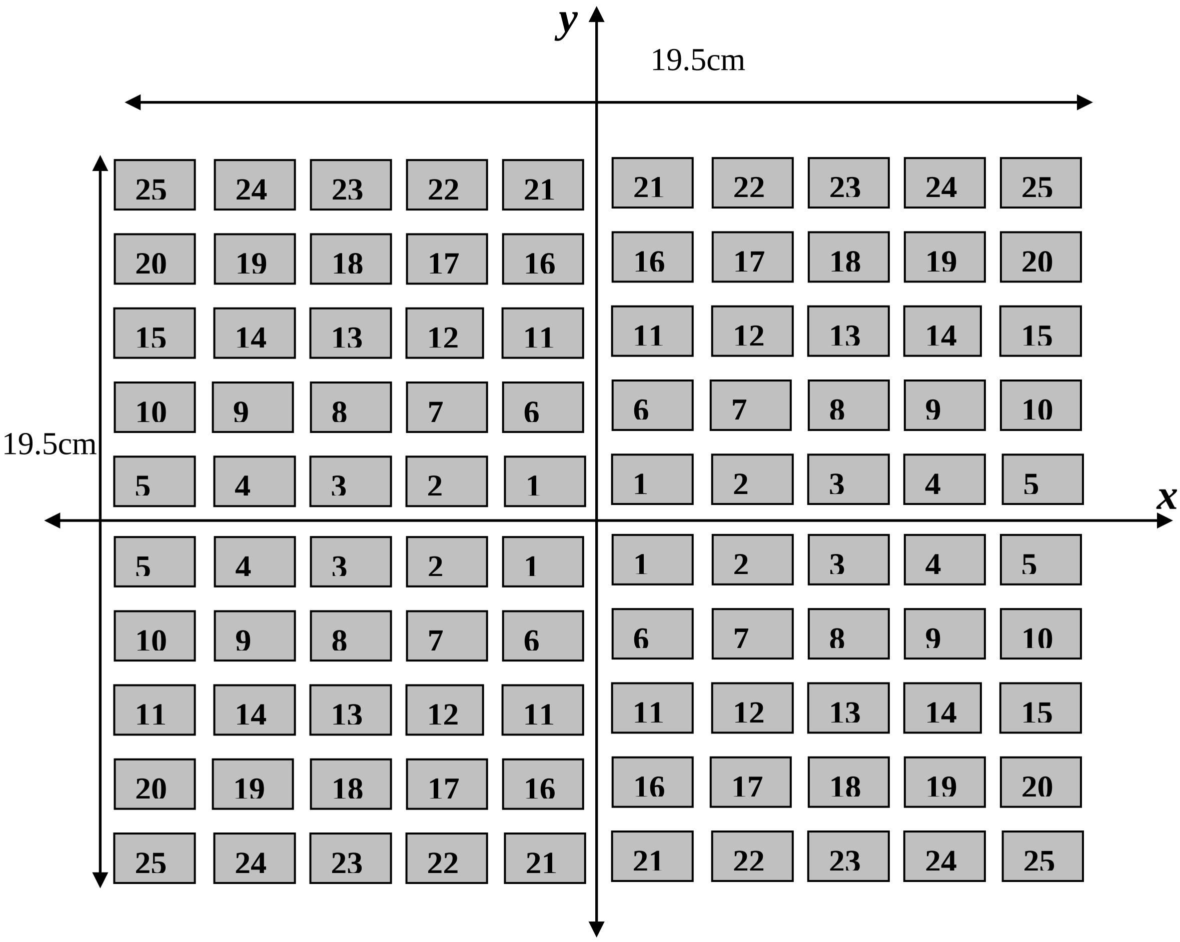


Figure (8) Planar Array Antenna Using Microstrip Antennas , the Numbers Refers to Number of Element as Indicates in the Tables Which Corresponds to Length

Table (1) shows the phase needed to compensate phase delay path for each element and corresponding length for focal length is equal to 0.95m

No. of elements In array	**Phase (degrees)**	**Length of elements (mm)**	**No. of elements In array**	**Phase (degrees)**	**Length of element(mm)**
1	81.7026	16.9336	14	44.9035	15.3830
2	77.6109	16.0016	15	28.5805	15.3156
3	69.4318	15.6465	16	57.1743	15.4675
4	57.1743	15.4675	17	53.0826	15.4338
5	40.8513	15.3632	18	44.9035	15.383
6	77.6109	16.0016	19	32.6460	15.3297
7	73.5191	15.7707	20	16.3230	15.2783
8	65.3401	15.5665	21	40.8513	15.3632
9	53.0826	15.4338	22	36.7596	15.3456
10	36.7596	15.3456	23	28.5805	15.3156
11	69.4318	15.6465	24	16.3230	15.2783
12	65.3401	15.5665	25	0	15.2354
13	57.1611	15.4674			

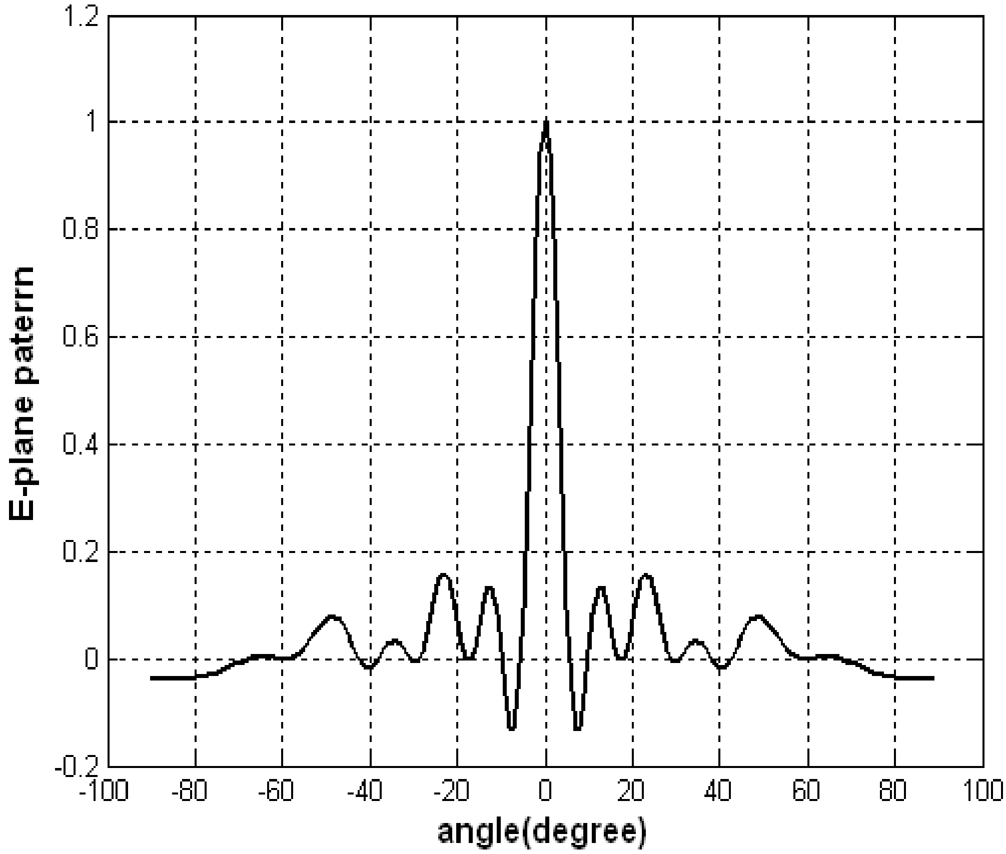


Figure (9) E-plane Pattern of Microstrip Reflectarray for Focal Length Equals to 0.95m

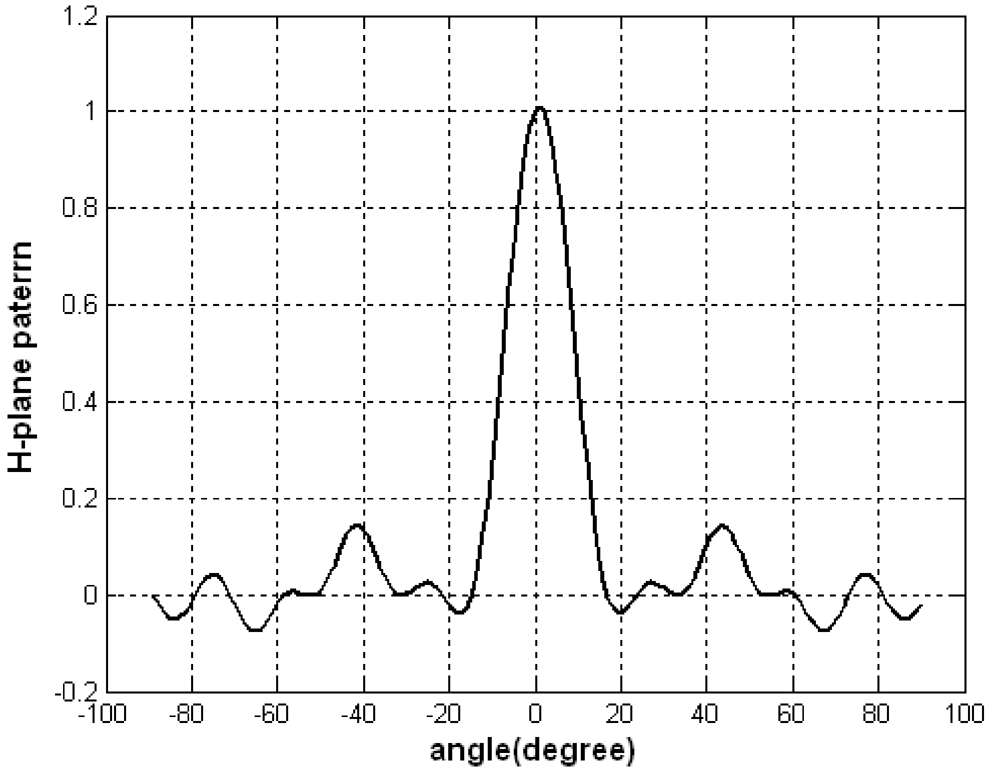


Figure (10) H-plane Pattern of Microstrip Reflectarray for Focal Length Equals to 0.95, 1.25, and 1.5m

Table (2) shows the phase needed to compensate phase delay path for each element and corresponding length for focal length is equal to 1.25m

No. of elements In array	Phase(degrees)	Length of elements (mm)	No. of elements In array	Phase(degrees)	Length of elements (mm)
1	62.142	15.5209	14	34.1636	15.3354
2	59.032	15.4855	15	21.743	15.294
3	52.814	15.4273	16	43.4917	15.3758
4	43.4917	15.3758	17	40.3817	15.3611
5	31.071	15.324	18	34.1636	15.3354
6	59.032	15.4855	19	24.8414	15.3034
7	55.922	15.4564	20	12.4207	15.2677
8	49.704	15.4106	21	31.0710	15.324
9	40.3817	15.3611	22	27.9610	15.3135
10	27.9610	15.3135	23	21.743	15.294
11	52.814	15.4273	24	12.42007	15.2677
12	49.704	15.4106	25	0	15.2354
13	43.4859	15.3758			

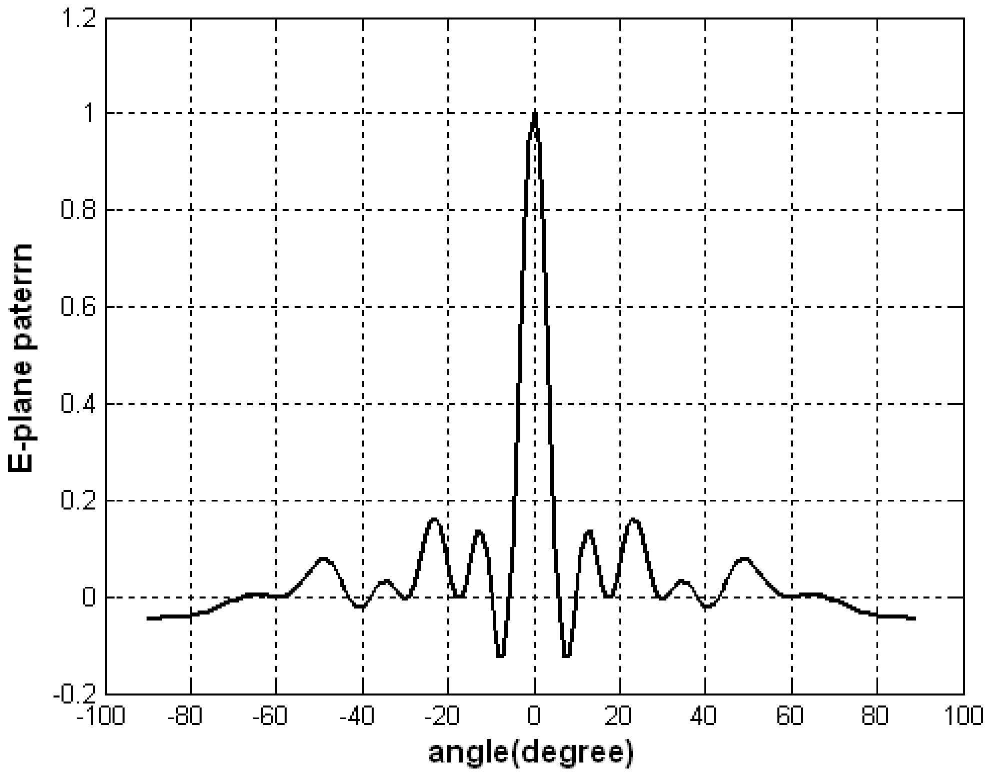


Figure (11) E-plane Pattern of Microstrip Reflectarray for Focal Length Equals to 1.25m

Table (3) shows the phase needed to compensate phase delay path for each element and corresponding length for focal length is equal to 1.5 m

No. of elements In array	Phase(degrees)	Length of elements (mm)	No. of elements In array	Phase(degrees)	Length of elements (mm)
1	51.8018	15.2354	14	28.4826	15.3659
2	49.2100	15.2622	15	18.1267	15.3785
3	44.0276	15.2834	16	36.2568	15.2987
4	36.2568	15.2987	17	33.6650	15.3336
5	25.9009	15.3068	18	28.4826	15.3659
6	49.2100	15.2622	19	20.7118	15.3923
7	46.6183	15.2909	20	10.3559	15.4076
8	41.4358	15.3152	21	25.9009	15.3068
9	33.6650	15.3336	22	23.3091	15.3436
10	23.3091	15.3436	23	18.1267	15.3785
11	44.0276	15.2834	24	10.3559	15.4076
12	41.4358	15.3152	25	0	15.4246
13	36.2534	15.3436			

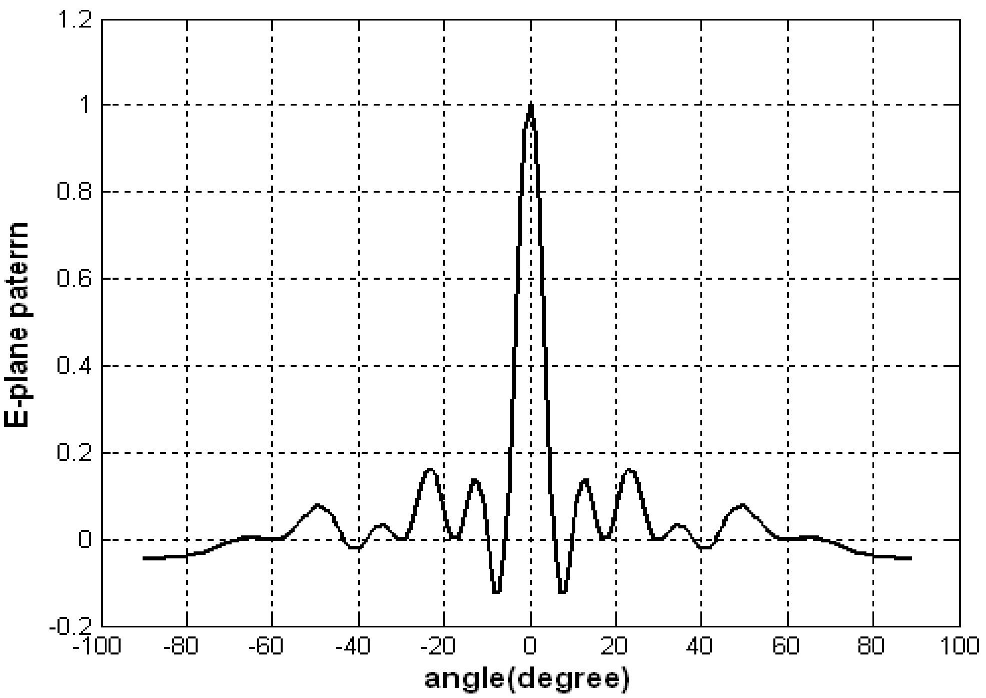
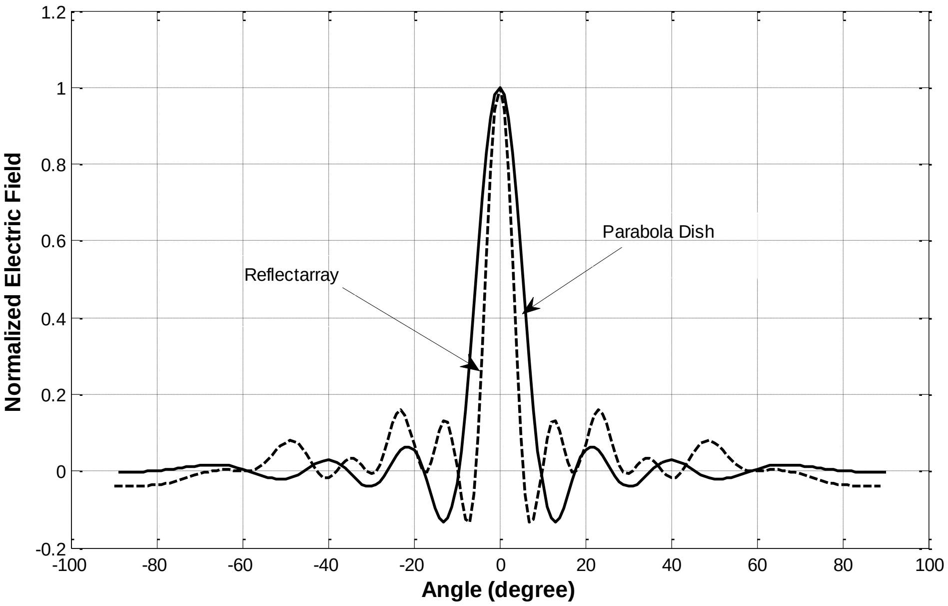
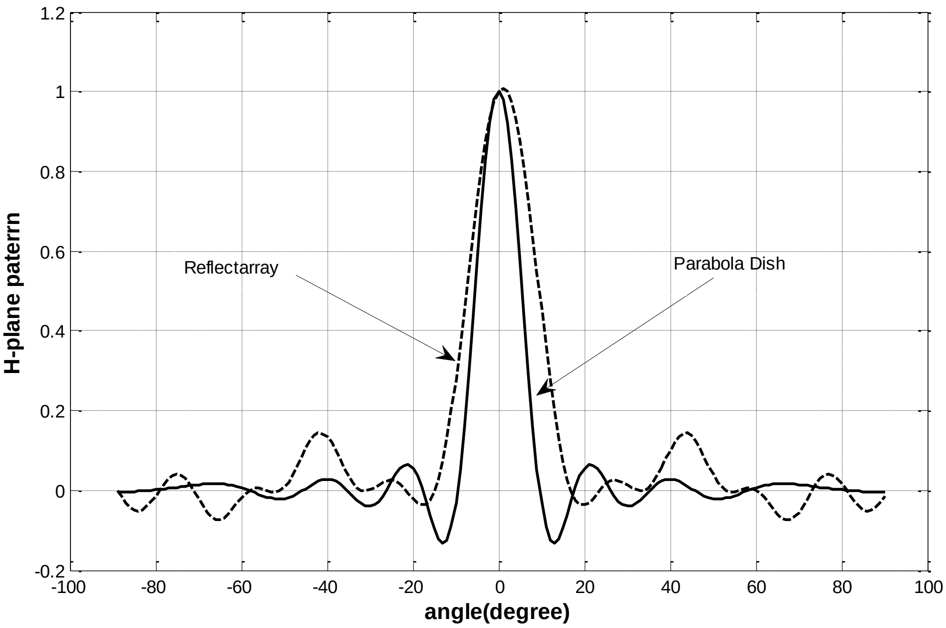


Figure (12) E-plane Pattern of Microstrip Reflectarray for Focal Length Equals to 1.5m



(a)



(b)

Figure (13) Normalized Field Pattern of (10*10) Microstrip Reflectarray and Parabolic Reflector for Focal Length Equals to 0.95m

(a) E-plane

(b) H-plane

Table (4) Comparison between (10*10) reflectarray and parabolic reflector antenna

Type of Reflector	E-Plane HPBW	H-Plane HPBW	Gain (dB)
Reflectarray Antenna	4.67^{o}	14.43^{o}	30.733
Parabolic Reflector Antenna	9.54^{o}	9.54^{o}	25.0888

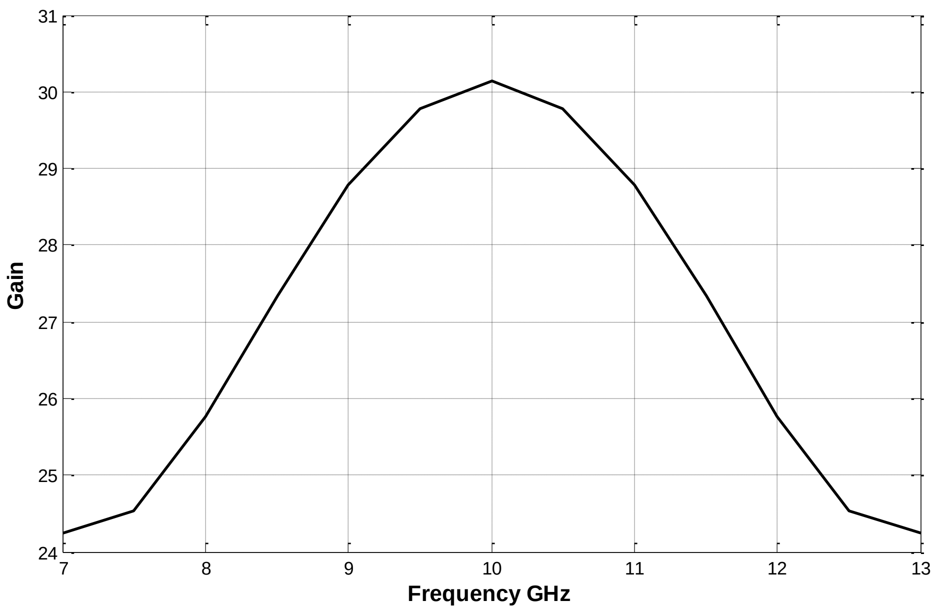


Figure (14) Directivity Variation w.r.t Frequency for Focal Length Equals to 0.95 m

9. Conclusions

1-Microstrip reflectarray at has been analyzed using conventional array theory. Antenna performance parameters, such as radiation pattern directivity (30.733dB),and bandwidth(12%) are calculated for 10GHz with 10*10 elements.

2- Drive the equation for required path delay compensating phases from the elements are achieved, primarily by the different lengths of microstrip patches. Different lengths yield different input impedances, which in turn give different phases.

3- A comparison between the reflectarray and parabolic antenna are achieved. It is found that the directivity for reflectarray is greater than parabolic, while the exact difference is in the bandwidth which is equals to 12% for the reflectarray, which can not been compared with infinite theoretical parabolic bandwidth.

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