Abstract

A new type of dielectric resonator reflectarray composed of 529 elements covering an area of 276 x 276 cm² is constructed. The unit cell consists of squared DRA supported on a strip with variable slot length, a dielectric layer and a conducting ground plane. The full phase of 360 degree of the array elements can be obtained by superposition two slot-strip sizes. Two types of feeding were analyzed, the first is center fed reflectarray while the second is offset feed to reduce the feeder blockage and as a result the antenna efficiency is improved. The antenna has 10% bandwidth for 1 dB gain variation is obviously wider than that of conventional reflectarray antenna while the offset fed reflectarray provide better far field pattern with back lobes reduction by -5 dB and side lobe by -2 dB. A rectangular X-band pyramidal horn was used in both reflectarrays which have 23 x 23 elements of with cells separation of 12 mm that less than 15 mm (lambda/2) for avoiding grating lobes. CST microwave studio© (finite integral technique) package is applied and compared with microstripes© package (transmission line technique) with good agreements between them. The mutual coupling between the feeding horn and the elements of the reflectarray are considered. At 10 GHz, the antenna provides a 3-dB beamwidth of 6 degree with a gain of 28 dB. The antenna bandwidth within 1dB gain variation is found to be 13% and aperture efficiency of 59%.

Keywords

DRA, Strip Loaded DRA, Reflectarray, Planar Array

1. Introduction

The conventional parabolic reflectors are generally bulky in size and large in mass due to the curved reflecting surfaces. Recently, microstrip reflectarrays are found to be very attractive aperture antennas because of their planar structure and simple feeding[1]. Its advantage over a conventional planar microstrip phased array is a low conduction loss, especially in a millimeter-wave region[2,3], because it uses a spatial-type beamforming network. However, its shortcoming is a narrow-band operation compared with the conventional parabolic reflector. Usually, the required phase value to compensate for the different paths of the wave from the feed horn to each array element is only achieved at the center frequency within a range of 360°. Each element phase can be adjusted to produce a required phase over the aperture and control the main beam orientation. Usually, the dynamic range of the phase shift in a single-layer reflectarray is less than 360°, and the complete compensation is only for central frequency, which restrict the application to the large-aperture and/or wideband reflectarray. The problem of narrow-band operation of single layer patch reflectarrays can be overcome by employing multi-layer variable size patches[4,5]. The use of stack patches improves the phasing range of the individual elements (to about 450° for two layers) by using dual patch sizes, the upper bigger patch is resonated for the lower frequency while the smaller patch for the upper frequency. That technique broaden the bandwidth by superposition the two bandwidths. That offers lower phase slopes and leads to an increased operational bandwidth of the entire array antenna. A new dual layer cell is designed with wide phase range than dual layer patch reflectarray[6]. Another way for extending the bandwidth of the reflectarray, a patch supported on variable slot length is employed as the element of reflectarray[7-11]. Overcoming the feed blockage that degrade the radiation efficiency of antennas as blocking by horn feeder some of reflected field, An offset reflectarray was designed using variable patch sizes[12]. The mutual coupling between microstrip elements printed on standard substrates becomes significant; in addition, the conductor and surface wave loss are severe. To overcome these limitations, other candidate, dielectric resonator antennas (DRA) have been introduced due to their low loss, relatively wide bandwidth, high radiation efficiency and low mutual coupling. These reflectarray antennas realized by rectangular
and crossed dielectric resonator for linear polarization[13]
which supported by strip for gain improvement while a
Ka-band variable DRA reflectarray lengths supported on
substrate of same dielectric constant of DRA was de-
dsigned[14]. A X-band rectangular DRA and circular polari-
zation at X-band[15] are investigated. Dual DRA sizes
supported on ground plane with variable slot lengths is il-
lustrated in[16] for getting full phase cycle using superposi-
tion. Apartment coupled DRA with variable strip line at
X-band was designed with good performance in radiation
patterns and total efficiency[17]. In this paper, slot-loading
of rectangular dielectric resonator elements reflectarray in
X-band is investigated. A reflectarray antenna consists of
elements of rectangular dielectric resonator (DRA) with slot
loading of different lengths is proposed for bandwidth en-
hancement. Fixed DRA size supported on strip conductor
with two slot widths are available to tune the phase of each
element in the reflectarray so that a full 360 degrees phase
shifts can be achieved by superposition. Two structures are
presented in that paper. The first is center fed reflectarray
while the second is offset feed for decreasing the feeder
blockage. The antenna has 10% bandwidth for 1 dB gain
variation is obviously wider than that of conventional re-
fectarray antenna while the offset fed reflectarray provide
better far field pattern with back lobes reduction by -5 dB
and side lobe by -2 dB. A rectangular X band pyramidal
horn was used in both reflectarrays which have 23 x 23
elements of with cells separation of 12 mm that less than 15
mm (lambda/2) for avoiding grating lobes. The analyses are
carried out using CST microwave studio(FIT)[19] and Mi-
crostripes package (TLM)[18] with good agreements be-
tween them.

2. Simulation Analysis

A DRA reflectarray with variable slot loading length
supported on dielectric substrate with conducting strip is
constructed as shown in Figure 1. The unit cell consists of
squared DRA, with length \( L \), width \( W \), height \( H \), strip con-
ductor of \( L_{strip} \) x \( W_{strip} \) with slot of length \( L_{slot} \) and width \( W_{slot} \),
a dielectric layer of thickness \( h \), and a conducting ground
plane. The bottom conducting plate is acting as a reflector to
reduce the back radiation and improve the front to back ratio
of the main beam. In order to determine the relation between
the reflected phase and the selected parameters, a unit cell in
an infinite periodic structure is considered with normal plane
wave incidence. The design center frequency is considered
10 GHz. Figure 2 shows the phase variations versus the
selected parameters. Two behaviours can be observed in
Figure 2a: for \( 0 < L_s < 5 \) mm with \( L = W = 5 \) mm and slot
width \( W_s = 0.6 \) mm, a 240° phase range can be obtained; for \( 5 < L_s < 8 \) mm with \( L = W = 10 \) mm, another 120° phase range is
reached. The complete phase 360° is obtained by superposi-
tion as shown in Figure 2b. FIT method (present method),
the transmission line (TLM) method and commercial HFSS
software[20] are used to investigate the performance of the
antenna for the variation of the phase of the reflection coeff-
ficient against the slot length. The phase of the reflection
coefficient for different frequencies as a function of DRA
length is computed and found to achieve 10 % bandwidth, which is corresponding to phase variation of ±
45° of the phase at 10 GHz for the middle size length as
shown in Figure 3. The phase of reflection coefficients as a
function of the plane wave angle of incidence is also pre-
dicted. The phase variation due to the angle of the incidence
plane wave between normal incidence and 30° is found to be
less than 90° as illustrated in Figure 4. Therefore; phases of
the reflection coefficient due to normal plane wave incidence
on a periodic infinite array are used to design the reflectarray
and found to be sufficient as will be seen later. Considering
the array on the x-y plane illuminated by a feed horn, the
required phase distribution, \( \Phi(x, y) \), at each element of the
array to collimate a beam in the \((\theta_o, \phi_o)\) direction is deter-
mined as:

\[
\phi(x_i, y_i) = k_o (d_i + \sin \theta_o \cos \phi_o q_i + \sin \phi_o p_i - \cos \theta_o \sin \phi_o q_i)
\]

where \( k_o \) is the propagation constant in vacuum, \( d_i \) is the
distance from the feed horn phase center to the element \( i \) of
the array and \((x_i, y_i)\) are the coordinates of the center of
element \( i \). Getting the full phase of 360°, two DRA elements
and two slot widths are used. First DRA has dimension of
square \((L = W = 7 \) mm\) and slot width \( W_s = 1.4 \) mm, while the
second has dimension of square \((L = W = 10 \) mm\), and slot
width \( W_s = 0.7 \) mm. The DRAs have height \( H = 3 \) mm with
relative dielectric constant \( \varepsilon_r = 10.2 \). The dielectric layer
thickness is 2 mm with \( \varepsilon_r = 1 \). Variable slot length \( l_s \) is used.

![Figure 1. DRA layout reflectarray a) Strip layer view b) Cell view](image)
Figure 2. Reflection coefficient phase versus DRA with variable slot length a) Super position b) Comparison

Figure 3. Variation of reflected phase versus length at different frequencies

Figure 4. Reflection coefficient phase versus variable length for different oblique angles

Figure 5. Reflected Field patterns of DRA reflectarray at 10 GHz with main beam at $\theta = 0^\circ$ a) YZ plane (E plane) b) XZ plane (H plane)
4. Offset Fed Reflectarray

According to the center fed reflectarray, the horn block some of reflected field and as a result, the total efficiency of reflectarray was degraded. An offset fed reflectarray was designed to minimize the feeding blockage. The feeder is at position of \(x_{fo} = 0\) mm, \(y_{fo} = 108\) mm, \(z_{fo} = 260\) mm that make \(22^\circ\) feeder tilting angle with respect to the reflectarray center. The array had 23 x 23 unit cells. The reflectarray size was 276 x 276 mm\(^2\) with elements spacing of 12 mm. The layout of the DRA elements and their relative sizes are shown in Figure 7. The radiation patterns of the designed reflectarray at 10 GHz are shown in Figure 8.

The gain verification figure is shown in Figure 9. The gain 1 dB bandwidth is about 9%.

The accuracy of the radiation patterns are verified by comparing the results of the two full wave package with good agreement.

3. Center Fed Reflectarray

The feed position is at \(x_{fo} = 0\) mm, \(y_{fo} = 0\) mm and \(z_{fo} = 345\) mm, with respect to the reflectarray center. The array is 23 x 23 unit cells. The reflectarray size was 276 x 276 mm\(^2\) with elements spacing of 12 mm and the focal length-to-diameter ratio F/D = 1. The layout of the DRA elements and their relative sizes are shown in Figure 1. Pyramidal horn of dimensions 60 x 30 mm\(^2\) is used. The radiation patterns of the designed reflectarray at 10 GHz are shown in Figure 5. The accuracy of the radiation patterns are verified by comparing the results of the present method with those from the TLM method.

The radiation patterns has a 3-dB beamwidth of \(8^\circ\) and a peak gain of 28 dB at \(\theta = 0^\circ\). The antenna gain versus frequency is shown in Figure 6 indicating 10% bandwidth with gain variations of 1 dB.
5. Conclusions

Slot-loading squared DRA elements reflectarray antenna was designed for linear polarization at X-band. The antenna was simulated by two feeding ways, one is center fed while the second is offset fed. Both arrays were fed by linearly polarized pyramidal horn. The cell reflection phase complete period was obtained by superposition of two strips sizes with variable slot lengths. The array cells were 23 x 23 elements reflectarray with area of 276 x 276 mm². The finite integration technique was used to compute the radiation patterns and the gain of the antenna. The method was verified by comparing the results with transmission line method and was found to be efficient and accurate for these analyses.

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Figure 9. Gain versus frequency