Antenna Array Design using Hybrid Feed for High Frequency Application

Sumit Tyagi, Garima Saini

Abstract: The objective of this paper to design eight elements (4×2) antenna array with hybrid feed structure. A number of microstrip antenna arrays such as microstrip antenna with inset feed, 2×1 antenna array, 4×1 antenna array and 4×2 antenna array have been designed using Rogers RT/Duroid 5880 as dielectric materials are proposed to enhanced gain and bandwidth in practical measurement. The simulated gain is 14.917 dB obtained with hybrid feed structure and bandwidth of the design is 396.8 MHz and 523.5 MHZ at 9.4 GHz and 11.6 GHz resonating frequency. A prototype of the antenna is also constructed and tested, the tested results shows a bandwidth of 500 MHz. Loss increases due to long feed transmission line which reduce the gain of the antenna when we use thicker substrate. So hybrid feed structure is used in this design to reduce the length of transmission line. The application of this design is in radio location.

Keywords: Antenna array, Antenna feed, Bandwidth, Gain, Microstrip antennas, Mutual coupling.

I. INTRODUCTION

An antenna may be defined as the structure used for the transformation between a directed wave and a free space wave or vice versa. The definition of antenna according to IEEE standard: “The part of transmitting and receiving system that is designed to transmit or receive electromagnetic wave” [1]. Antenna is a metallic device which is designed for radiating and receiving electromagnetic energy. Antenna should adjust to increasing demands of more effective and increased data rate of communication system. Therefore, from past few decades enhancing the gain of antennas and bandwidth are the topic of interest for research purpose. For gain enhancement antenna arrays is the latest research area. An antenna cannot be able to meet the radiation characteristics for some applications. Thus, it requires combination of several single antennas forming an array structure. Spacing between the element, number of element, geometry of the element, and the feeding technique can also affect the antenna performance. But they are not more effective, due to presence of mutual coupling between the closely spaced antenna elements. Mutual coupling occurs due to discontinuities in the patch, imperfection in the dielectric material, impedance matching and feeding structure [2]. Mushroom is a technique used for reduce the mutual coupling between the nearly spaced element in the array system [3].

Microstrip line inset feed is also used for proper impedance matching. Due to which the effect of mutual coupling reduced. Superstrate layer placed away from the patch reduces the loading effect on the antenna. The substrate superstrate spacing, number of superstrate layers, the shape of the superstrate and geometry of superstrate layer can also affect the antenna performance [4]. EBG structures are also referred as high impedance surface due to their capacity for the surface wave suppression at certain operational frequencies [5]. There are many bandwidth enhancement techniques like stacking, aperture coupling, slot coupling and addition of parasitic elements provide additional resonance, use of different feed geometry, different shaped patches, slot embedded in patches etc. Different type of feed are used while design an antenna array. But in this design hybrid feed structure is used. Hybrid feed structure is the combination of corporate feed and series feed. In series feed equally power is not distributed in all the elements of array antenna but this type of feed is easy to design. In corporate feed when design large size antenna array the transmission line used in the design very large due to this transmission losses introduced in the design is much more when we use thick substrate. So overcome the drawback of corporate feed and series feed hybrid feed structure is used in the design [2, 6]. Some related literature work:

Muhammad Saqib Rabbani et al. [2] presented rectangular microstrip patch antenna array which consist 2 elements, 4 elements, 16 elements and 32 elements. In this author work on substrate thickness and number of elements which is used in the design of array antenna to improve the performance of the antenna. Antenna was designed on RT Duroid 5880 material.

A De et al. [6] presented an inset fed patch linearly polarized rectangular microstrip patch antenna array which consist 16 elements. In this author initially designed and analyzed 2×1 array then 2×2 array, 2×4 array, 4×2 array and 4×4 array for enhance the performance of antenna in terms of directivity, gain, and efficiency. The author used swarm optimization method which is based on IE3D to design an inset fed patch. For this design RT Duroid dielectric substrate is used.

Vasujadevi Mudasala et al. [7] proposed a 3×3 compact microstrip patch antenna. Probe feeding is used to excite the patch element in array antenna. To analyze the antenna design here finite element method is used. FR4 substrate is used for this design.

H. Errifi et al. [8] proposed a rectangular microstrip patch antenna array and compare the performance of single patch antenna with 2 elements, 4 elements, 8 elements and 16 elements patch antenna array. Results and performance of the antenna is compared on the basis of feed. Here proposed antenna design used three different type
of feed network which is Series, corporate and series-corporate feed network.

Shengjian Jammy Chen et al. [9] proposed a circular travelling wave series fed microstrip patch antenna array which consist 7 elements. Dual port feeding is used in the antenna design. Microstrip line is used to excite the patch with the help of coplanar proximity coupling. Rogers RT/Duroid 5880 substrate is used in this design. The proposed antenna design finds its application for polarimetry.

Xiaoshuai Wei et al. [10] proposed a printed log periodic monopole antenna array which consist 12 elements and result is compared with printed log periodic dipole antenna array. Simple feed structure is used for feed the patch element in antenna array. Antenna design is fabricated with the help of printed circuit board process. Author used forward firing feeding structure for feeding.

II. DESIGN PROCEDURE

The proposed antenna design consists of eight elements (4×2) antenna array. Initially inset feed microstrip antenna is designed then 3 MPAAs i.e 2×1(2 elements), 4×1(4 elements), 4×2(8 elements) patches, area designed on RT/Duroid 5880 material with 1.59mm thickness. The geometry of microstrip antenna, 2 element, 4 element and 8 element antenna arrays are shown in figure 1(a), (b), (c) and (d). The length ‘L’ and width ‘W’ of the patch element is calculated using equation (1) and (2) to improve the tolerance in fabrication [2]

\[
W = \frac{(2P + 1)}{\sqrt{\varepsilon_r + 1}} \times \left(\frac{\lambda}{2}\right)\]  
\[
L = \frac{(2Q + 1)}{\sqrt{\varepsilon_{eff}}} \times \left(\frac{\lambda}{2}\right) - 2 \Delta L
\]

Where P,Q are integers and in the design the value of P=1 and Q=0, \(\lambda\)  and \(\lambda\)  are free space wavelength and operating wavelength, \(\varepsilon\)  and \(\varepsilon_{eff}\)  are relative dielectric constant and effective dielectric constant calculated using equation (3)[8] and \(\Delta L\)  is the extension in patch length due to fringing field calculated using equation (4)[11].

\[
\varepsilon_{eff} = \frac{\frac{1}{2} + \frac{1}{2} \left[1 + 12 \left(\frac{h}{W}\right)^{-1}\right]}{\frac{h}{h^2 + 1}}
\]

\[
\Delta L = 0.412h \left(\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\right) \left(\frac{W}{h} + 0.264\right) - 0.8
\]

While designing inset feed microstrip antenna the inset depth and inset gap are calculated using equation (5) and (6) [11].

\[
Z_0 = Z_{in} \cos^2\left(\frac{nd}{L}\right)
\]

\[
g = \frac{v_b}{\sqrt{2\varepsilon_{eff}}} \times 4.65 \times 10^{-12}
\]

Inter separation, transmission line length, width between the elements in an array is calculate using following equation (7), (8), (9) and (10) [2].

\[
S = (2Q + 1) \times \frac{\lambda}{2}
\]

\[
L_{T_1} = (2P + 1) \times \frac{\lambda}{2} + 2 \Delta L
\]

\[
L_{T_2} = (2K + 1) \times \frac{\lambda}{4}
\]

\[
W_T = \frac{7.475 h}{\varepsilon_{eff}} - 1.25 t
\]

Where

P, Q, K are nonnegative integer. The value of K in our design is one. h, t and \(Z_c\)  is the substrate thickness, copper cladding and characteristic impedance.

The antenna design dimensions are calculated using above equation. Then high gain and large bandwidth can be achieved by optimizing the various parameters and dimensions of the hybrid feed antenna array design and also of the feeding structure. Better gain and bandwidth performance can be obtained by using inset feed for proper impedance matching and hybrid feed structure is used in

![Fig. 1 (a) Geometry of inset feed microstrip antenna](image-url)
this design to reduce the transmission line losses. Fig. 1(a), Fig. 1(b), Fig. 1(c), Fig. 1(d), Fig. 1(e), and Fig. 1(f) shows the geometry of inset feed microstrip antenna, two element array, four element array, eight element array, radiating side and ground side of a fabricated antenna. Inset gap and inset depth for all design is 3.408 mm and 2.5 mm. Table 1 shows the optimized dimensions of the antenna and antenna array.

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Fig. 1 (b) Geometry of two element antenna array

Fig. 1 (c) Geometry of four element antenna array

Fig. 1 (d) Radiating side of fabricated antenna

Fig. 1 (c) Geometry of eight element antenna array

Fig. 1 (d) Ground side of fabricated antenna
Table-I: Optimized values of the proposed antenna in mm

| Antenna Design | L  | W  | \(L_{T1}\) | \(W_{T1}\) | \(L_{T2}\) | \(W_{T2}\) | \(W_{T3}\) |
|----------------|----|----|-----------|-----------|-----------|-----------|-----------|
| One element    | 8.6| 27 | 12.0      | 4         | -         | -         | -         |
| Two element    | 8.5| 31 | 13.5      | 2         | 11        | 2.4       | 0.08      |
| Four element   | 8.5| 31.5| 15.5     | 2         | 11        | 2.4       | 0.08      |
| Eight element  | 8.5| 31.5| 15      | 4.40      | 8         | 2.4       | 0.08      |

III. RESULT AND DISCUSSION

A. Simulated Results

The proposed antenna designs using Rogers RT/duroid 5880 as dielectric materials are simulated and examined using (HFSS). The performance parameters such as length, width, inset gap, inset depth, and transmission line length and width of the design have been optimized by using parametric study of effect on bandwidth and gain of proposed antenna. Fig. 2, 3, 4 and 5 shows the experimental result of inset feed microstrip antenna, 2 element, 4 element and 8 element antenna array, where a and b shows the S11 response, gain and Fig. 5 (c), (d) shows VSWR and radiation pattern of the antenna. Table 2 shows the performance parameter of the various antenna designs. It can be notice that if double the patch element then then gain increases near about 2 dB and the maximum gain is achieved using 8 element antenna array is 14.917 dB.
The prototype of the FR4 proposed antenna is also fabricated and is tested on Anritsu MS46322A 20GHz Vector Network Analyzer (VNA). The antenna design using Rogers RT/duroid 5880 as substrate material is fabricated. The fabricated antenna is resonating at 9 GHz frequency. The bandwidth of the antenna is 500 MHz from 8.6 GHz to 9.1 GHz is obtained. The VSWR of the antenna is 1.3 at 9 GHz frequency. The measured result gives an approximate bandwidth as simulated with shift the band at lower side of the frequency. The deviation in fabricated and simulated results is because of the fabrication error that inculcates during the antenna fabrication and cable loss. When antenna is fabricated characteristics of antenna may change due to environment, stress, heat and due to human error. Fig.6 (a), 6 (b) shows the measured $S_{11}$ response and VSWR. Fig. 7 shows fabricated antenna testing through VNA. Table II shows the performance of designed antenna array, which shows if the element in the design doubles then the gain of the antenna increase near about 2 dB.
IV. CONCLUSION

In this the performance of antenna and antenna array has been studied by designing and tested several prototypes with various number of patch element on 1.59 mm substrate thickness. The bandwidth and gain of microstrip antenna is the major concern in wireless system when we deal with antenna. In this paper four designs have been proposed with different number of elements. The highest gain and the bandwidth is achieved with eight elements (4×2) antenna array resonates at 9.4 GHz and 11.6 GHz with minimum return loss -22.0751 at 9.4 GHz. The achieved bandwidth of the design is 396.8 MHz and 523.5 MHz at 9.4 GHz and 11.6 GHz and a gain of 14.917 dB using Rogers RT/Duroid 5880. The maximum gain and achieved bandwidth of the design is 14.917 dB and 523.5 MHz. There is a shift in the return loss parameter at around 9 GHz frequency due to which the fabricated antenna provides a bandwidth of 500 MHz from 8.6 GHz to 9 GHz. The decrement in the bandwidth is due to the fabrication error incorporated during the fabrication of the antenna.

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