High gain steerable antenna with different substrate materials for satellite applications

M. Wady 1, 2, W. Swelam 1, 3 and Mohamed H. Adel Azeem 1, 4

1 Arab Academy for science and technology and maritime transport, Cairo, Egypt
2 mmwady@gmail.com, 3 wswelam@gmail.com, 4 mhabdazeem@aast.edu

Abstract – In our analysis in this paper we have improved the design of microstrip antenna array to be used in the non-geostationary satellite systems with electronically steerable beam which can trace the desired earth station on Earth without any need to change the angle of the cube satellite in space so we can save the batteries on the satellite board with low cost, easy to fabricate antenna. The array antenna consists of multiple patches and multi feeders with different phases to control the steerable beam electronically. The antenna array operates in Ka frequency bandwidth and consists of 6*6 elements with gain reaches 18.8dBi, each element in the array has the dimensions of (4.6mm * 2.6mm) with rounded edges and the total size of the antenna array is (5.43 cm * 3.33 cm), there are narrow strip fences applied between elements to reduce the effect of mutual coupling and in accordance reduce the sidelobe level of the antenna array.

1. INTRODUCTION

In these days the need for satellite communications increased for several reasons, the most important reason is the global availability of the satellites over earth so it can serve the areas which difficult to have infra structure like mountains [1].

In this paper we make analysis of microstrip antenna to use it in satellite systems instead of the traditional parabolic antennas specially in non-geostationary satellite systems which don’t need very high gain due to the low attitude of the satellite over earth which results low free space loss and in this case the micro strip antennas can be a very competitive alternative to parabolic antennas.

As we can use the micro strip antennas in satellite systems so we can take the advantages of low cost and the high reliability the array antennas, we can use the steerable beam instead of the traditional ways of rotating the whole satellite in its orbit. This microstrip antenna array can also be used in the earth stations of non-geostationary satellites.
One of the problems in the parabolic antennas that they need mechanical movement to trace the satellite in orbit during its visible time[2] and in some services like broadband services which the continuity of the service is very important we need two parabolic antennas to hand over between satellite series in the same orbit[3].

In our design we focused on the frequency range of 27-28.8 GHz which uses for METEOROLOGICAL AIDS [5] services according to ITU-RR [6].

The design consists of 6*6 patch elements, each element has its separate feed and the direction of the main beam can be controlled by changing the phase shift between each feed, all simulations done by using CST software [7].

2. SINGLE PATCH ANTENNA

The antenna consists of single layer with substrate from cheap FR-4 and full ground, The schematic of the single patch antenna fed by coaxial probe is shown in Fig. 1, the single patch antenna dimensions are given in table 1.

| Ws  | Ls  | Wp  | Lp  | Wf  |
|-----|-----|-----|-----|-----|
| 30 mm | 28 mm | 4.6 mm | 2.7 mm | 0.8 mm |

The results of calculated return loss for different patch widths (Wp) are shown in Fig. 2, We can notice that the center frequency increased as the increasing of patch width, We optimized the patch width as 4.65 to get the lowest return loss.

3. 5*5 ANTENNA ARRAY DESIGN

In this approach we used 25 patch elements, and the spacing between elements is 9 mm in X-direction and 5.3 mm in Y-direction and each one of them has its own feed port as shown in fig3.
The space between array elements in X direction has a great effect on the result gain depending on the frequency band and number of array elements as shown in figure-4 so we can notice that the maximum gain achieved is 14.1 dB using 9 mm spacing between elements in X-direction.

We have used two substrate materials to compare between them, the first one is FR-4 which are available and very cheap but has high loss compared to the Glass material which improved the gain but has high cost,

Figure-5 shows the different between gain pattern for both materials FR-4 and Glass, the increase of the maximum gain of the main beam is 18.2 dBi.
The gain of the 5*5 array antenna reaches 14.1dBi with the ability to point the main lobe direction by changing the phase shift between the feeders of elements according to [eq-1] described below.

The main beam angle shift $\Delta \delta (\theta_0)$ can be calculated using this eq-[1][8]:

$$\Delta \delta (\theta_0) = -K \cdot d \cdot \sin(\theta_0) \quad (1)$$

Where:

$K = 2 \cdot \pi / \gamma$

$\gamma$: wave length.

d: spacing between array elements.

$\theta_0$: phase shift between the adjacent antenna elements.

Table 2 shows the needed phase shift between the array elements to get the main lobe gain at different angles.

| Beam angle | 5   | 10  | 15  | 20  | 25  | 30  | 35  | 40  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|
| phase shift| -15 | -31 | -45 | -60 | -74 | -88 | -101| -113|

| Beam angle | 5   | 10  | 15  | 20  | 25  | 30  | 35  | 40  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|
| phase shift| 15.3| 31  | 45  | 60  | 74  | 88  | -101| 113 |

**Figure 6:** Steerable beam of the antenna array

The sidelobe level of 5*5 array antenna reaches 5 dBi for the substrate of FR-4 material which is very high, so we applied two techniques to decrease the levels of sidelobe gain and also to improve bandwidth,
First, we applied rounded edges at the four corners for each patch because one of the important reasons of the side lobes is the sharp edges in the antenna design, Figure-7 shows the elements of the antenna array after applying rounded edges.

![Figure 7: Antenna array elements with rounded edges](image)

Figure 7: Antenna array elements with rounded edges

Second, we applied narrow strip fences between elements of the array [9] to decrease the mutual coupling between elements as shown in Figure-8.

![Figure 8: Antenna array with strip fences between elements](image)

Figure 8: Antenna array with strip fences between elements

As a result of applying these two techniques on the antenna array design the sidelobe level for the FR-4 substrate decreased from 5dBi to 1.9dBi as shown in Figure-9 and the bandwidth increased from 1.3GHz as shown previously in Figure-2 to 1.8 GHz as shown in Figure-10.

When applying the same techniques on the antenna array design with glass substrate there wasn’t any reduction in the sidelobe level so it may be one of the disadvantages of this design in a trade of the high gain, the sidelobe levels are higher than the levels when we use FR-4 material as a substrate.

![Figure 9: 5*5 Antenna array gain for FR-4 after SLL reduction](image)

Figure 9: 5*5 Antenna array gain for FR-4 after SLL reduction
4. 6*6 ANTENNA ARRAY DESIGN

For the design of 6*6 the Spacing between elements need to be increased to maximize the gain, so the gain increased from 14.1 dBi (5*5 array) to 15.5 dBi (6*6 array) as shown in the figure-11.

As for 5*5 array the same comparison has been done for the 6*6 array and the gain greatly increased due to the material of substrate, the gain increased from 15.5 dBi for FR-4 to 18.8 dBi for Glass as shown in figure-12.

The sidelobe level for 6*6 antenna array (FR-4 substrate) is 4.5 dB so we applied the SLL reduction techniques as before and the SLL decreased to 3.6 dB as shown in figure-13.
Figure 12: 6*6 Antenna array gain for FR-4 after SLL reduction

5. CONCLUSION

The designed 6*6 array antenna can achieve maximum gain at main lobe 18.8dBi with Glass material for substrate which make it very competitive with the traditional parabolic antennas, each patch of the array has its own feeder from an electronical phase shifter to control the direction of main beam which also can be very competitive and alternative to the mechanical movable parabolic antennas used in satellite communications,

SLL reduction techniques have been applied and succeeded to decrease SLL from 5dBi to 1.9dBi for the antenna design with the FR-4 substrate but for the design with glass substrate the SLL didn’t change,

You can notice that the maximum gain decreases with the increase of elevation angle so we stop at the angles 40° < θ0 < -40° when the first side lobe power is half power of the main lobe.

6. REFERENCES

[1] https://www.telesat.com/about-us/why-satellite/advantages-satellites.

[2] A. Krauss, H. Bayer, R. Stephan, and M.A. Hein "Low-Profile Tracking Antenna for Ka-Band Satellite Communications”.

[3] VA-45-KA 4.5 Meter Ka-band Antenna.

[4] Naser Ojaroudiparchin, Student Member, IEEE, Ming Shen, Member, IEEE, and Gert Frølund Pedersen, Senior Member, IEEE, "Low-Cost Planar MM-Wave Phased Array Antenna for Use in Mobile Satellite (MSAT) Platforms”, Serbia, Belgrade, November 24-26, 2015.

[5] Earth Exploration-Satellite Service – Handbook - Radiocommunication Bureau - English Edition 2011

[6] ITU-RR ARTICLE 4: Assignment and use of frequencies.

[7] https://www.cst.com/academia.

[8] Vasujadevi Midasala, Dr. P. Siddaih "Microstrip Patch Antenna Array Design to Improve Better Gains" (International Conference on Computational Modeling and Security (CMS 2016)).
[9] N. Bayat, H.R. Hassani, S. Mohammad Ali Nezhad “Sidelobe Level Reduction In Microstrip Patch antenna array” 2011 Loughborough Antennas & Propagation Conference, 14-15 November 2011, Loughborough, UK.

[10] Nrusingha Charan Pradhan, Pravin Swami, Madhusmita Mohanty “Simulation and Design of Ka-Band Microstrip Array Antenna”, 2018 International Conference on Control, Power, Communication and Computing Technologies (ICCPCCCT).

[11] Yiwei Wu, Qi Zhu “Design of a Ka-band microstrip antenna array with sharpened-beam pattern and high gain” 2013 IEEE Antennas and Propagation Society International Symposium (APSURSI).

[12] Muhammad Kamran Ishfaq, Tharek Abd Rahman, Yoshihide Yamada, Kunio Sakakibara “8×8 Phased series fed patch antenna array at 28 GHz for 5G mobile base station antennas” 2017 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC).

[13] Andrew Chrysler and Cynthia Furse, Raine N. Simons and Félix A. Miranda “A Ka-Band (26 GHz) Circularly Polarized 2x2 Microstrip Patch Sub-Array with Compact Feed”, 2017 IEEE International Symposium on Antennas & Propagation; 9-14 Jul. 2017; San Diego, CA; United States

[14] M. Vasujadevi, Dr. P. Siddaiah and S Nagakishore Bhavanam "Rectangular Patch Antenna Array Design at 13GHz Frequency Using HFSS 14.0". (Springer India : Advancements of Medical Electronics, Chapter : 24, ISSN : 2195-2728, ISBN : 978-81-322-2255-2, ISBN : 978-81-322-2256-9 (eBook), Springer Book Publications, January 2015, pp.263-270).

[15] Ms. Varsharani Mokal, Prof S.R. Gagare, Dr. R.P. Labade "Analysis of Micro strip patch Antenna Using Coaxial feed and Micro strip line feed for Wireless Application" (IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) e-ISSN: 2278-2834,ISSN: 2278-8735.Volume 12, Issue 3, Ver. III (May - June 2017), pp 36-41

[16] V. Rabinovich and N. Alexandrov, Antenna Arrays and Automotive Applications,