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Improving Directional Properties of Circularly Polarized Dish Parabolic Antennas through Knife-Edge Metallic Scatters

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Abstract: Circularly polarized dish parabolic antennas are highly valuable due to their superior resistance to external noise compared to linearly polarized antennas. Dish parabolic antennas equipped with end-fire helical feeds offer circular polarization, high directivity, and relatively low levels of side lobes. However, the presence of a conducting ground plane in the helical feed obstructs the reflected rays from the dish, resulting in a detrimental impact on the antenna's directional characteristics. This research focuses on optimizing the ground plane through a series of FEKO simulations, leading to a significant reduction of side lobes and an overall enhancement of the antenna's performance. Moreover, the introduction of knife – edge metallic scatters at specific positions and dimensions in the antenna configuration effectively decreases the sidelobe level within a range of 8 to 12 dB.

Keywords: Circurlarly polarized, metallic scatters and FEKO.

1 Introduction

The number of different types of antennas that currently exist in the telecommunication market is bewildering, but most are designed specifically to fit a pre-specified application. In this paper, the discussion is confined to one of the mostly used antenna which is the parabolic dish antenna. Parabolic antennas are known and widely used because they may provide extremely high directional characteristics in addition to other electrical and mechanical characteristics [1]. However, such antennas suffer from significant sidelobes especially the nearby sidelobes which are considered as a subject of interference [2]. Parabolic antennas are designed to have different types of feed elements such as horn feeds, end-fire helical feeds, and so on, depending on the application under consideration. Each of these feed elements would produce significant sidelobes due to the finite shape of the reflecting parabolic surface. Reducing sidelobes is required because they make the antenna much more exposed to noise from any other signal coming from any other source. For transmitting antennas sidelobes represent a security weakness, as an unintended receiver may pick up the classified communication. One major difficulty is that the higher the sidelobe level, the more likely an antenna is to interfere with or be interfered with by a receiver in the direction of the largest sidelobe. In addition, the increase of sidelobes means that the power is being lost and spread in undesired directions as waste. This paper provides a comparative estimation between different feed elements in a way to optimize the performance of such antennas. Analysis of parabolic antennas is based on the method of moments (MOM), in which integral equations involved in Maxwell's equations are solved [3]. In this paper a comparison between linearly and circularly polarized feed elements is presented since circularly polarized waves have much better immunity to weather conditions compared to linear, and which consequently provide further propagation of

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the electromagnetic waves radiated from such antennas [4]. So, a parabolic antenna with either a rectangular horn feed or an end-fire helical feed is analyzed and optimized using FEKO simulations at an operating frequency of 2.4GHz. Furthermore, for more improvement of the parabolic antenna performance, metallic scatters have been added to the antenna which led to minimizing the nearby sidelobes and consequently reducing interference without negatively affecting the main lobe in the radiation pattern. Several positions and dimensions have been simulated and have shown a great positive influence on the antenna's directional characteristics. Four metallic rectangular thin strips may reduce the sidelobe level for about 10dB. This paper is organized as follows. In Section II, we formulate the sidelobe reduction problem. The method used and various considerations are given in Section III. In Section IV, numerical results and discussion are presented. Concluding remarks are given in Section V.

2 DESCRIPTION OF THE PROBLEM

The main purpose of this study is to select the best primary source that provides a minimum sidelobes and minimum spillover for directivity improvement. The first step is to simulate the antenna with rectangular horn and then evaluate the sidelobe level of this antenna to use it as a reference value. For the next step, a circularly polarized parabolic antenna with helical feed is studied and simulated. Results are to be compared to the reference value. Furthermore, an optimization of the antenna with helical feed is accomplished throughout a series of simulations to optimize the radiation efficiency. For more improvement, metallic scatters in the form of thin rectangular strips are added to the circularly polarized dish with helical feed. The dimensions, positions and number of strips are considered and to be modified in a way to provide the desired results. Feko simulations are based on the Method of moments described by the formulas listed below.

$$\int_S u(r).(j_s(r')(g(r,r')+1/k^2 div'_s J_s(r') grad g(r,r'))dS' =$$

$$u(r).E_i(r)\,dx$$

$$g(r,r') = \frac{exp(-jk|r-r'|)}{4\pi|r-r'|}$$

$$nxE_1 = Z_m nxJ_s$$

FEKO is a suite of tools that is used for electromagnetic field analysis of 3D structures. FEKO simulations are based on the Method of Moments (MOM) solution to Maxwell's equations and features several extensions to the MOM for the solution of complex problems, including large structures and complex dielectrics or human tissue. Various output parameters can be computed and displayed in several formats to make FEKO a leading electromagnetic simulation software suite. It enables users to solve a wide range of electromagnetic problems.

3 DISH PARABOLIC ANTENNA WITH RECTANGULAR HORN

The parabolic reflector antenna consists of a feed horn placed at its focal point and a reflector shaped in such a way that all the rays being emitted by the feed are collimated and reach the aperture plane in phase. Feeds are responsible of providing the required pattern as well as the needed polarization. That's why different feed elements are used in dish parabolic reflectors especially the horn feed for linear polarization and the helical feed for circular polarization. As a start, we are going to simulate a dish parabolic reflector with rectangular horn placed at the focal point of the parabolic reflector at f = 2.4 GHz as shown in the figure below.

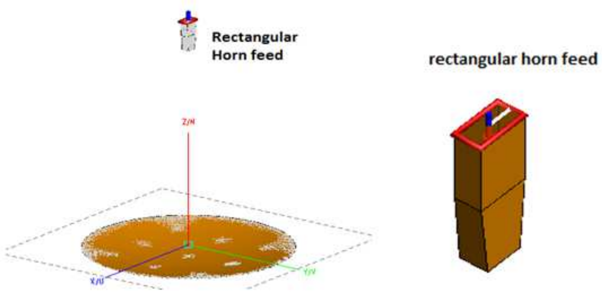

Fig. 1: Parabolic antenna with rectangular horn.

According to the figure shown about it is obviously shown that the pattern has a relatively narrow beamwidth, a significant sidelobe level of -15dB (nearest sidelobe) and -28dB (far sidelobes). The nearby sidelobes may be a subject of interference when using it in the vicinity of other antenna systems. So, we are aiming to decrease the sidelobe level by varying first the feed element dimension and type.

4 DISH PARABOLIC ANTENNA WITH A HELICAL FEED

In bad weather conditions, a circular polarization is needed since circularly polarized antennas are more immune to noise and provide better performance. Therefore, it would be convenient to use a helical feed (figure 3) as a primary source since it has high enough directivity in addition to

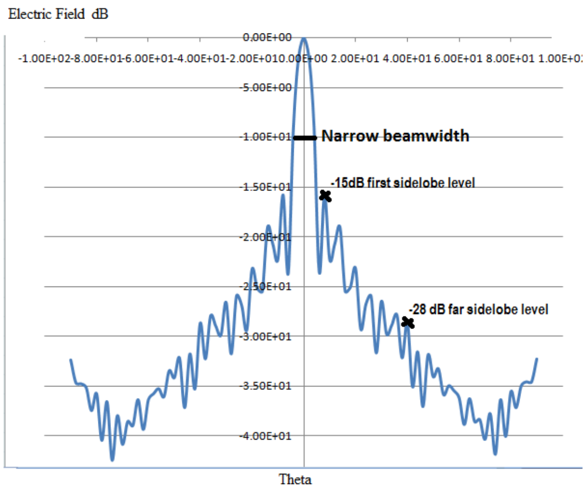

Fig. 2: E-plane pattern of the Parabola with horn feed.

the low sidelobe level. Simulation results on a parabolic reflector with axial helical feed are shown below in Figure 4.

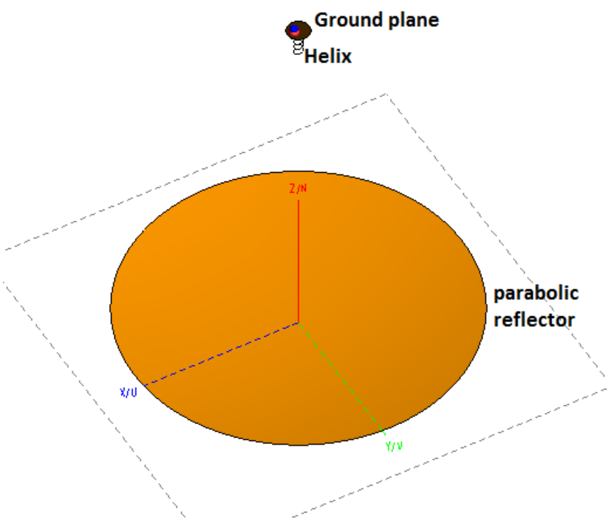

Fig. 3: Parabolic dish with helical feed.

So, an optimization process should be conducted in this project to obtain the maximum sidelobes reduction without affecting negatively the main lobe as well as the size and cost of the entire system. In the optimization process, the results of the antenna with rectangular feed will be used as a reference to compare other results to, so we will start the design process by modifying and optimizing the ground plane size of the helical feed since it is one of the major causes of sidelobes appearance.

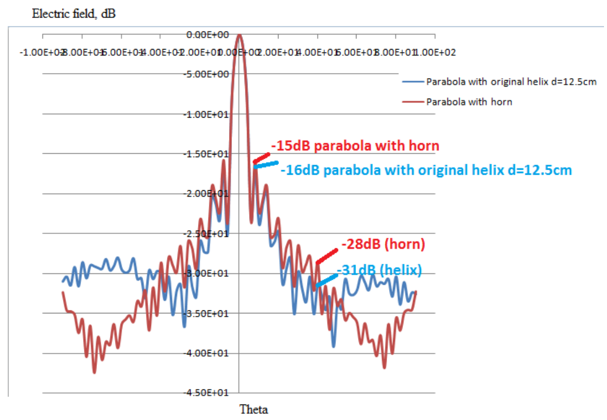

Fig. 4: Comparison between horn feed and helical feed (d=12.5cm).

Different ground plane diameters have been considered (d=5cm, 8cm, 10cm, ……, 27cm), so the results are shown below in Figure 5.

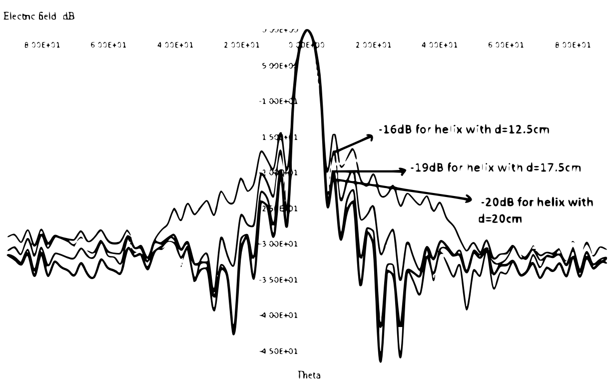

Fig. 5: Different values of the helical ground plane diameter.

According to the result shown in figure 5 we can notice that the sidelobes have been reduced from $-14dB(withd = 8cm)$ to $-20dB(withd = 20cm)$. However, if the diameter of the ground plane is to be increased above $20cm$, the sidelobes start to increase significantly, so we decided to stop on the value $d = 20cm$. So, we can conclude that the best sidelobe reduction was achieved when the ground plane diameter was around $20cm$ which is equivalent to about 1.6λ. The above obtained results have shown a sidelobe reduction of about 6dB by simply optimizing the helical ground plane. However, we are aiming more reduction and in the next step we are going to find out the optimum position of the helical feed i.e., optimizing the focal distance of the parabolic antenna.

5 EFFECTS OF METALLIC SCATTERS

For better enhancement of the directional characteristics of the overall antenna, a new approach is to be considered in this paper which is based on adding metallic scatters [5,6,7] on the parabolic reflector for them to diffract constructively the unwanted radiation of the helical feed and consequently reduces the sidelobes. However, it is so important to know their numbers, dimensions, forms and where these metallic scatters are to be placed (Fig.6).

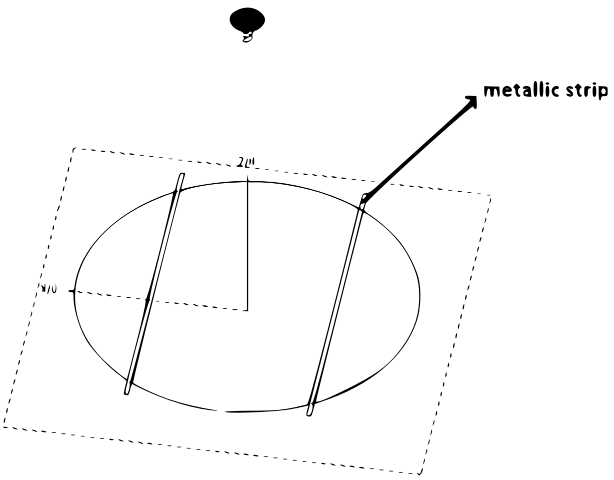

Fig. 6: Dish parabolic antenna with helical feed and 2 metallic strips.

In the next step, it is shown that adding metallic strips to the antenna would constructively scatter the incoming wave radiated by the primary source in the direction of the main reflector and consequently reduces the SLL significantly. The position of the strip on the main reflector is so critical, so the purpose of this thesis is to find out the optimum position of the strips with respect to the focal direction as well as to determine the best shape of strips and the effect of the numbers of scatters on the directional characteristics of such antennas. As a start, strips on the reflector may be considered as adding to the antenna some reactive elements such as capacitors or inductors. Two parallel metallic strips are like a two-wire line that has a circuit representation in the form of cascaded RLC elements. Thus, adding it to the antenna may cause a change in the impedance characteristics as well as an impact on the radiation pattern. Therefore, it would be reasonable to select properly the dimensions of these strips and attach them properly to the antenna for their impact to be beneficial.

For the first step, we are going to add two rectangular metallic strips of width $2cm(0.16\lambda)$ to the parabolic reflector with a helical feed having a planar ground plane of $d = 20cm(1.6\lambda)$ at different positions on the parabolic reflector starting at $x = 10cm(0.8\lambda)$ from the origin and ending at $x = 70cm(5.6\lambda)$ as shown in figure 6.

Simulations are made on FEKO and are showing a significant impact on the radiation pattern, so an extra 3 dB peak sidelobe reduction have been achieved when the position of the strips on either side of the central line of the reflector is $0.5m(4\lambda)$. This is shown in the figure below.

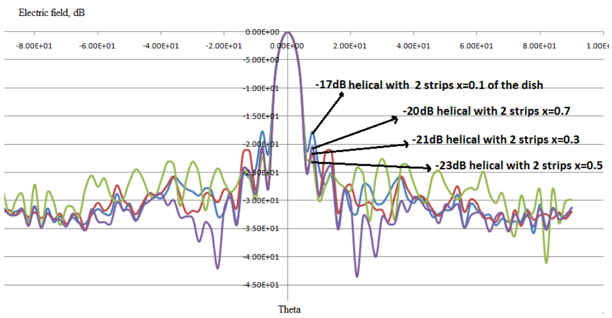

Fig. 7: Impact of strips position x on the radiation pattern.

Fig. 7 shows a sidelobe reduction ranging between -17dB to -23dB. This is a good reduction however we are aiming better results to our antenna more susceptible to interference. In fig.7 adding strips to the antenna results in a reduction in the nearby sidelobes which are the major factor of interference. However, this is accompanied by a little increase of the further sidelobes, but this is not so dangerous because their level is always below -25dB. So, our focus will be only on the near sidelobes. For more reduction, we further add extra strips to the parabolic reflector on either side of the center line (fig.8) to find out whether the number of strips would lead to more enhancements in the radiation efficiency. Results are shown below in figure 9. That's why we create two more scatters to see whether this idea is better for minimizing the sidelobes or not.

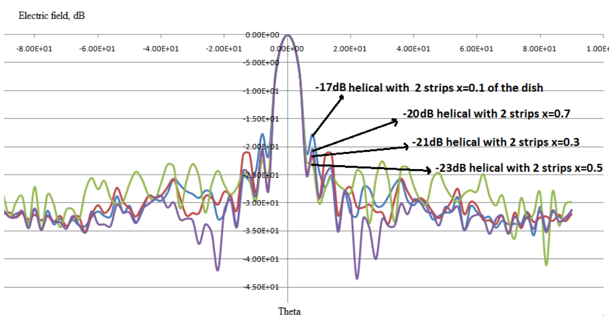

Fig. 8: Parabolic antenna with four metallic strips.

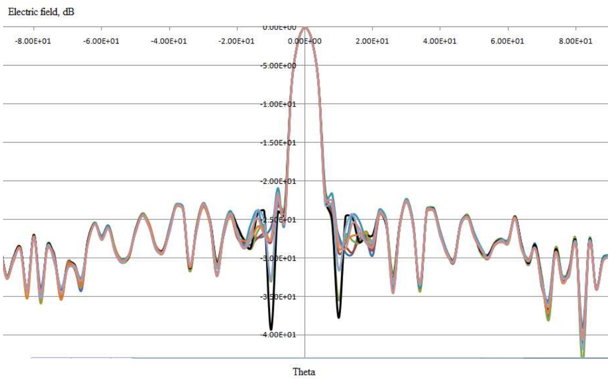

Fig. 9: Effect of strips quantity on the radiation pattern.

From the above figure, we can conclude that the number of strips has an impact on the nearby sidelobes but does not affect the far sidelobes. So, using 4 metallic strips spaced at different locations on the parabola as shown in (fig.8), a little sidelobe reduction may be detected especially in the region of nearby sidelobes of about 2dB. So, the already accomplished steps are shown in (fig.10) and summarized in table 1.

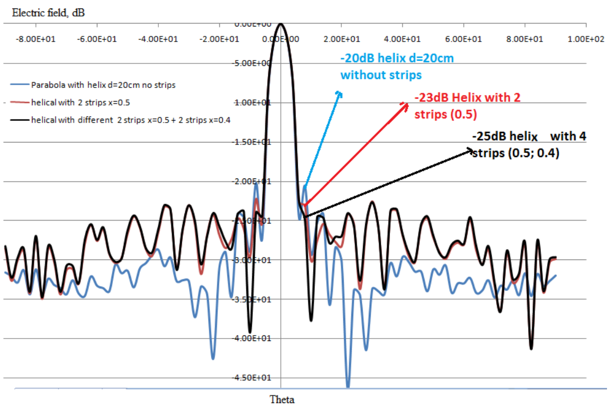

Fig. 10: A comparison between the antenna with no strips, 2 strips and 4 strips.

From the above table once can conclude that a 10 dB peak sidelobe reduction has been achieved so far in the region of near sidelobes which are the major factor of interference. This reduction is significant and helps the designed antenna be more vulnerable to noise and interference. In fig.11 results shown in the table are reflected in the form of radiation patterns. It is also so important to notify that the main lobe of the pattern has not been negatively affected when adding strips to the antenna which implies that the directivity is not interfered.

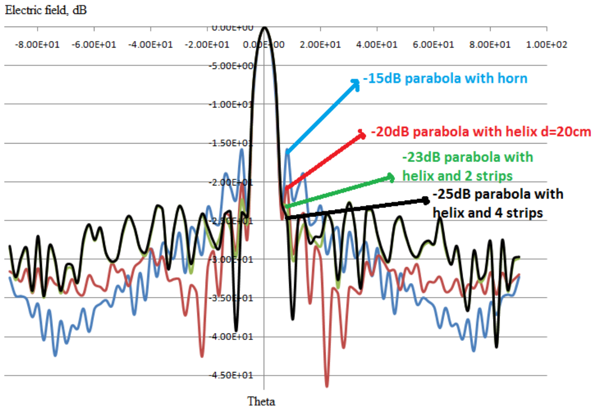

Fig. 11: Comparative estimation of the already simulated antennas.

6 Conclusion

As a conclusion, circularly polarized parabolic antennas are of great importance especially in radiolocation and navigation systems where noise immunity is strictly required. In addition to that the antenna must provide the best electrical and mechanical characteristics, so designers try their best to improve their directional characteristics but not in the expense of other parameters. Sidelobes, as was mentioned before, are one of the major reasons of interference and must be minimized using simple techniques and without any significant change in the designed antenna. In this study this has been successfully accomplished by simply adding 2 or 4 metallic cheap scatters that are simply attached to the parabola at specific positions. This approach has led to a sidelobe reduction of about 8 to 10 dB which is considered as a big achievement compared to other techniques. In addition to that, our approach is so simple and does not require a significant change in the already existed antennas in the market. It requires only attaching strips that are inexpensive, simple, and achievable.

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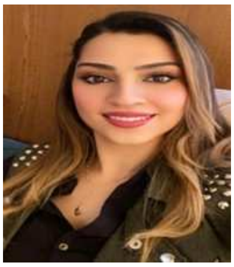

Farah Chakra received her master's degree in computer and communication engineering from Arts Science and Technology University of Lebanon. With over eight years of professional experience, she has established herself as a highly skilled and knowledgeable professional in the industry. Her research expertise is in the area of enhancement of circularly polarized dish parabolic antennas using metallic scatters. She has worked with some of the leading organizations in Lebanon and has demonstrated her technical and analytical skills in various projects. Her ability to develop innovative technological solutions has led to increased efficiency and productivity in the organizations she has worked with. Her technical expertise and strong communication skills enable her to collaborate effectively with a diverse range of stakeholders, making her a trustworthy professional and an excellent team player.