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Design of a Novel Compact Cup Feed for Parabolic Reflector Antennas

Amir Moallemizadeh[1], R. Saraf-Shirazi[2], and Mohammad Bod[2, *]

Abstract—This paper describes the concept and design of a novel compact self-supported cup feed antenna for parabolic reflectors. The feed antenna consists of an open waveguide cup which is excited by a disk loaded dipole. This structure is fed by a coaxial waveguide through a split-coaxial balun and has a rear radiation pattern toward the reflector antenna. Two different types of this configuration are designed in this paper: a linearly-polarized grid reflector antenna fed by a single dipole excitation, and a circularly-polarized solid reflector antenna fed by a cross dipole excitation. The measurement is done for the former, and simulation results of the latter via two different software packages CST and HFSS are compared in this paper. Analyzing the results shows that both types of cup feed antenna have an excellent aperture efficiency and low side lobe level.

1. INTRODUCTION

Reflector antennas have been widely used in radio astronomy, microwave communication, tracking and telemetry because of their excellent electrical characteristics such as high gain, low side lobe level and low cross polarization. It is well known that the performance of these antennas is highly dependent on the feed that illuminates the main reflector [1]. In order to get a high constant gain from the reflector antenna, the antenna feed should be maintained at the focal point of the main reflector. However, the struts that maintain the feed, block the radiation pattern and cause lower efficiency and higher side lobe levels.

Self-supported feeds which have rear radiation can reduce blockage losses and improve antenna efficiency. In these structures mechanical support is provided by the feeding waveguides that extends from the reflector vertex to the feed antenna. Until now different type of self-supported feeds such as splash plate feed [2], cup feed [3, 4] hat feed [5], and even some types of microstrip feed [6, 7] have been designed for the reflector antenna. The bandwidth operation of these feeds depends on the efficient transition from the feeder line in the axial conductor to the radiator [8]. Unfortunately, most of the reported rear radiation antennas are having a single linear polarization with a narrow bandwidth. While, in many applications for the purpose of more flexible reciprocal orientation between the transmitting and receiving antennas and reducing multipath effects, an antenna with a circular polarization (CP) and wide impedance bandwidth is desired.

It has been shown that a cross dipole with unequal arms can create a circularly polarized band if the input admittances of each parts are equal with 90° phase difference [1]. This idea is used in [9, 10] to design a cavity backed circularly polarized cross dipole antenna. However, the radiation characteristics of these antennas in front of a parabolic reflector are not studied in these papers and because these feeds are very bulky they can highly block the antenna radiation if used with a paraboloid reflector.

In this paper two novel self-supported cup feeds for a parabolic reflector antenna are presented. First a linearly polarized (LP) rear radiation dipole feed is designed and fabricated (Antenna I). It consists of

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* Corresponding author: Mohammad Bod (Mbod@aut.ac.ir).
[1] Department of Electrical Engineering, Shahed University of Technology, Tehran, Iran. [2] Department of Electrical Engineering, Amirkabir University of Technology, Tehran, Iran.

a disk-loaded dipole antenna fed by a split-coaxial balun and installed on the reflector antenna by a self-supporting waveguide. By using two unequal crossed dipole arms a circularly polarized rear radiation feed can be created for the reflector antenna (Antenna II). Simulation results of both antennas with measurement results for a fabricated prototype of Antenna I are shown in this paper. The results show that these novel cup feed antennas have a very compact size and the reflector antenna has an excellent aperture efficiency with a low side lobe level. The designed antennas are suited for directional applications in 900 MHz, ISM and GSM frequency bands.

2. ANTENNA DESIGN

The geometry of the linearly polarized cup feed antenna, Antenna I, is shown in Fig. 1(a). As it can be seen, the proposed antenna consists of a disk loaded dipole inside an air filled cup structure. This antenna is mechanically support by a rigid coaxial waveguide.

In order to create the proposed antenna, first the disk loaded dipole antenna should be designed. The disk loaded dipole antenna is created by attaching two disk loaded arms to a rigid coaxial waveguide as shown in the left hand side of Fig. 1(a). The resonance of this disk loaded dipole is determined by the length of dipole arms and the radius of circular disks. Since dipole antennas have a balanced radiation and coaxial waveguides are unbalanced structures, a balanced to unbalanced transition (Balun) is needed in the dipole antenna design. In the proposed structure a split coaxial balun is used [11] which is designed by etching two slots on the outer conductor of a coaxial waveguide. The total length of these slots are chosen $\lambda g/2$ of the desired frequency band. By extending the rigid coaxial waveguide from the dipole antenna to the reflector vertex a novel self-supported structure with a good impedance bandwidth can be created.

This novel self-supported dipole should perfectly illuminate a reflector antenna by a rear radiation pattern. In order to create such a pattern, an air filled cup structure is surrounded the dipole antenna and create another open ended coaxial waveguide. In other word the reflector is fed by an open ended coaxial waveguide which is excited by a disk loaded dipole antenna. The radius of the open ended coaxial cup is selected in such a way that 10 dB illumination taper is obtained at the edge of paraboloid reflector antenna.

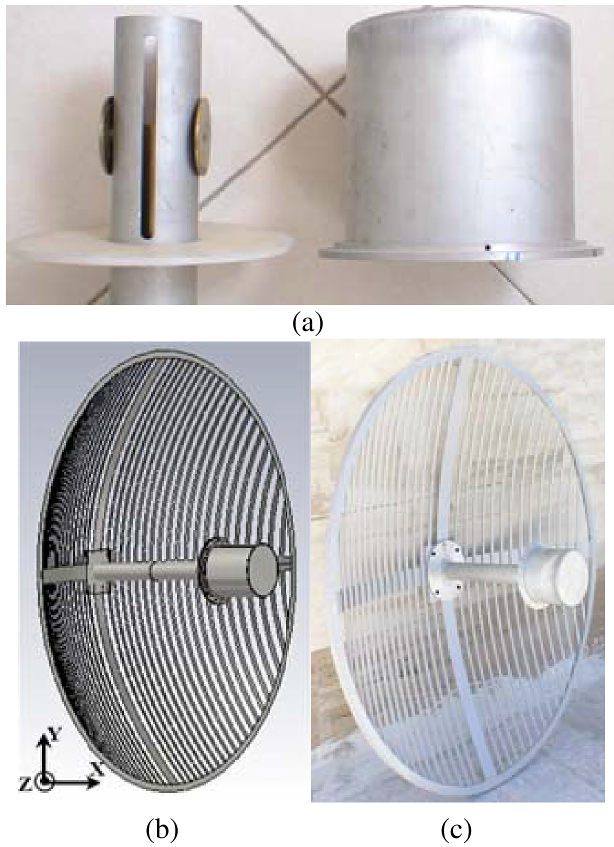
One should notice that the open ended coaxial waveguide works in TE_{11} mode while field distributions around the dipole excitation is as TM_{11} mode, Therefore, a $TM_{11}+TE_{11}$ mode combination is generated at the open end of coaxial waveguide [3, 4]. This well-known mode combination is used in the antenna feeds in order to illuminate the main reflector more uniformly and reducing side lobe levels in the reflector radiation pattern [1].

In order to protect the feed antenna from rain and corrosion, a Teflon dielectric with 6 mm thickness is attached at the open side of the cup feed as shown in Fig. 1(a). The designed cup feed antenna, Antenna I, has a linear polarized radiation pattern at 0.9 GHz frequency.

It can be shown that in low frequencies and for linear polarization the grid reflector can be used instead of the solid ones. Grid reflectors have the advantages of less wind resistance and low weight. Therefore, for the proposed linearly polarized feed, a 2 meter grid reflector is designed. This grid reflector has two orthogonal rims and 40 rigid strips as shown in Fig. 1(b). The space between strips is chosen about $\lambda g/10$ of the highest frequency (here is 1 GHz) in order to keep the reflector aperture efficiency as high as possible. A prototype of this linearly polarized antenna is fabricated and shown in Fig. 1(c).

In order to create a circularly polarized radiation, another mode with equal amplitude and 90-degree phase difference should be created inside an open ended coaxial waveguide. For this purpose, the single dipole used in the previous case is replaced by two orthogonal dipoles as shown in Figs. 2(a) and (b). These two crossed dipoles have unequal arms and loaded by unequal disks. Therefore, two orthogonal TM_{11} modes with 90-degree phase difference are created inside an open ended coaxial cup. At the aperture end of the cup feed these two modes are combined with TE_{11} mode of coaxial waveguide and create a hybrid circularly polarized mode which illuminates the main reflector uniformly.

Figure 2(c) shows the cross section of the proposed circularly polarized feed, referred to as Antenna II. As can be seen in this figure, in order to have a better impedance matching in the proposed feed the inner conductor of the coaxial waveguide is slightly increased in the cup space and the cross dipole antenna is fed by a $40\,\Omega$ quarter wave impedance transformer.



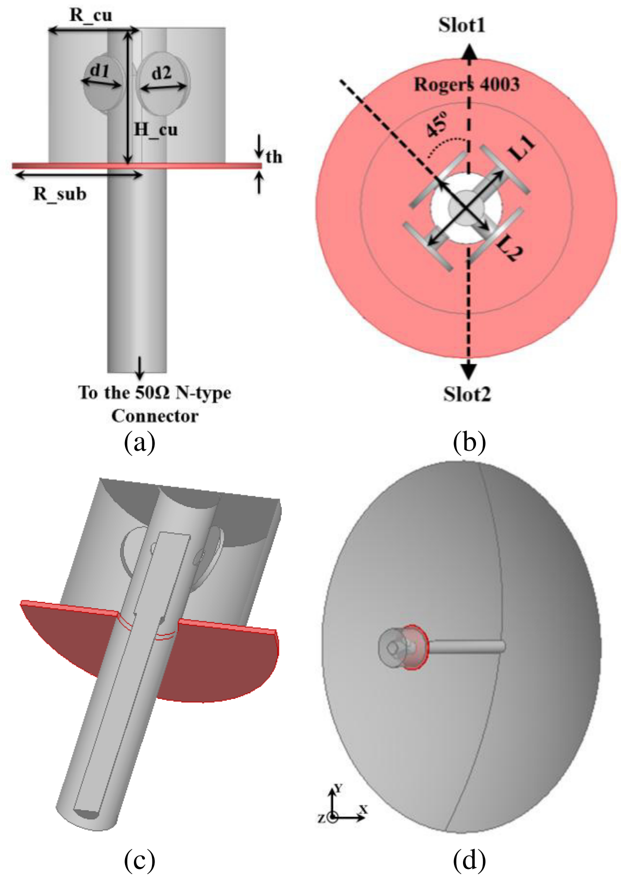


Figure 1. Configuration of the reflector antenna with a linearly polarized cup feed (Antenna I). (a) Feed structure, (b) the grid reflector and feed antenna in CST software, (c) fabricated prototype of grid reflector antenna with cup feed installation on it.

Figure 2. Configuration of the reflector antenna with a circularly polarized cup feed (Antenna II). (a) Side view of the feed, (b) top view of the feed, (c) cross section of the feed and (d) the feed and the reflector antenna in HFSS software.

Table 1. Dimensions of the proposed self-supported cup feed Antenna I, and II.

	R_cu	R_sub	H_cu	d1	d2	L1	L2	th	F	D	F/D
Antenna I	100	127	224	76	---	82.5	50	6	600	2000	0.3
Antenna II	103	120	181	76	65	83.5	112	6	750	2000	0.375

Note: The unit of all dimensions are in mm.

Like Antenna I, the proposed self-supported circularly polarized feed could illuminate a reflector antenna perfectly. It should be mentioned for Antenna II a solid (or meshed) surface is required to support circular polarization. Therefore, the proposed circularly polarized feed antenna is simulated with a solid reflector antenna as shown in Fig. 2(d).

All design parameters of the self-supported linearly polarized dipole antenna (Antenna I) and the circularly polarized cross dipole version (Antenna II) for 0.9 GHz frequency band are shown in Table 1.

3. RESULTS AND DISCUSSION

The simulated reflection coefficient of the CP feed reflector antenna (Antenna II) in CST and HFSS software package is shown and compared with the simulated and measured reflection coefficients of the LP cup feed reflector antenna (Antenna I) in Fig. 3. As can be seen, the circularly polarized antenna has about 39% impedance bandwidth (from 607–940 MHz), and the linearly polarized antenna has about 43% impedance bandwidth (from 630–980 MHz). These relative bandwidths are greater than most of the previous reported cup feed reflector antennas [8].

The simulated reflection coefficient of Antenna II in Fig. 3 clearly shows two different resonant modes at 670 MHz and 870 MHz frequencies, which are created by two different cross dipoles with slightly different lengths and loaded disks. These two linear polarized modes that have near resonances and are orthogonal to each other create a circular polarized radiation.

Figure 4 shows the simulated axial ratio of Antenna II in CST and HFSS software package. From the simulated results it can be seen that Antenna II has a circular polarization radiation from 790–890 MHz. The 3 dB axial ratio bandwidth of this antenna is about 11% at the center frequency. The

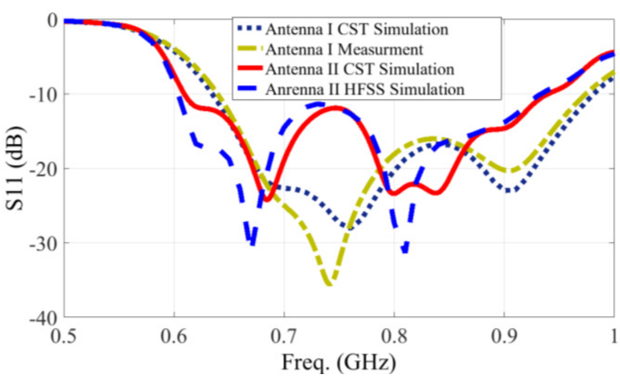


Figure 3. Simulated and measured reflection coefficients of Antenna I (Linearly polarized cup feed reflector). Simulated reflection coefficient of Antenna II in CST software package (Circularly polarized cup feed reflector), Antenna II in HFSS software packages.

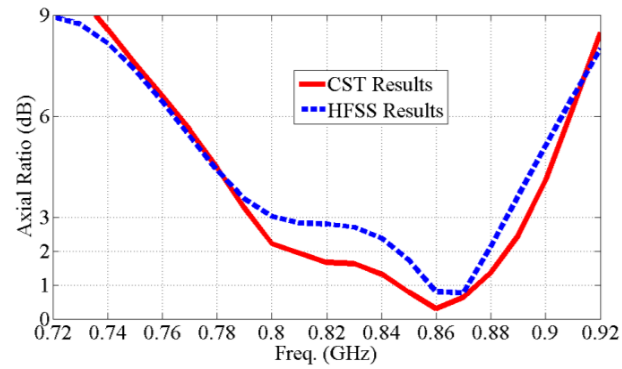


Figure 4. Simulated axial ratio of Antenna II in CST and HFSS software packages.

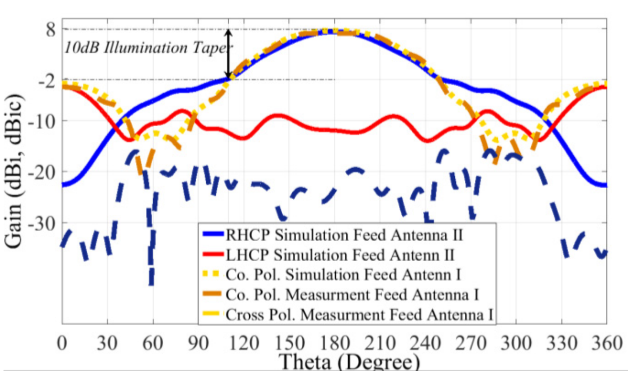


Figure 5. Simulated XZ-plane RHCP gain of Antenna II feed in CST at 0.84 GHz. Simulated and measured E-plane radiation patterns of Antenna I feed at 0.84 GHz.

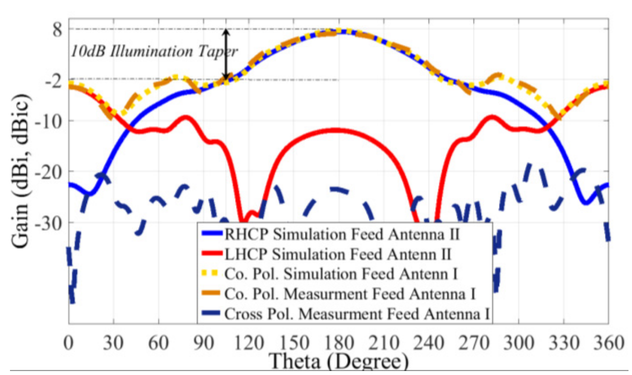


Figure 6. Simulated YZ-plane RHCP gain of Antenna II feed in CST and HFSS software packages at 0.84 GHz. Simulated and measured H-plane radiation patterns of Antenna I feed at 0.84 GHz.

results of CST and HFSS are clearly matched with each other in that figure.

In order to study the radiation characteristics of the proposed LP and CP cup feeds, the reflector feed patterns are plotted in XZ and YZ planes (E and H-plane of the LP feed) at 0.84 GHz in Figs. 5 and 6 respectively. In these figures for Antenna II, the simulated RHCP and LHCP gain of the feed are plotted and for Antenna I, the measured co- and cross polarized radiation pattern of the feeds are shown. The simulated co-polarized radiation of Antenna I feed is also available in these figure for further comparison. As it can be seen from these figures the peak gain of both feeds are about 8 dBi (dBic for CP feed). The 10 dB illumination taper of both feeds are cover about 140° of the feeds radiation. From these figures it can be seen that the proposed feeds can create a nearly uniform illumination at the parabolic reflector and therefore a high level of efficiency can be expected from the reflector antenna.

The simulated XZ plane gains of Antenna II at 0.84 GHz in CST and HFSS software are compared in Fig. 7. From this figure it is obvious that the 2-meter solid reflector antenna has 23.5 dBi main lobe gain which means that the antenna has about 75% aperture efficiency. Such a high efficiency from the reflector antenna is obtained because of two important reasons: 1. Reducing the aperture blockage by using a small self-supported feed (the cup feed radius is about 0.1 of the main reflector radius) and 2. Uniform illumination of the main reflector antenna by an axial symmetric feed. The first side lobe level of Antenna II in Fig. 7 is more than 20 dB below the antenna boresight gain.

The simulated and measured E-plane gains of Antenna I at 0.84 GHz are also shown in Fig. 7. As discussed in the previous section, the linearly polarized feed is fabricated with a 2-meter grid reflector antenna. It is clear from this figure that using a grid reflector does not degrade the aperture efficiency of the antenna and the overall gain of the linearly polarized grid reflector antenna is almost the same as

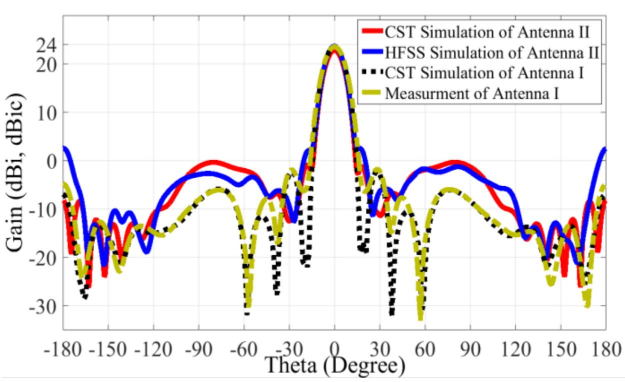


Figure 7. Simulated XZ-plane radiation patterns of Antenna II in CST and HFSS software packages at 0.84 GHz. Simulated and measured E-plane radiation patterns of Antenna I at 0.84 GHz.

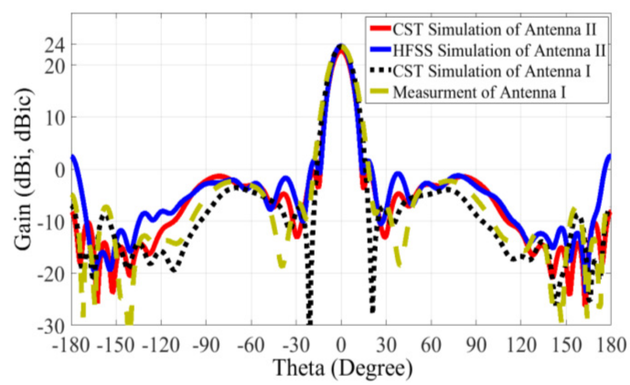


Figure 8. Simulated YZ-plane radiation patterns of Antenna II in CST and HFSS software packages at 0.84 GHz. Simulated and measured H-plane radiation patterns of Antenna I at 0.84 GHz.

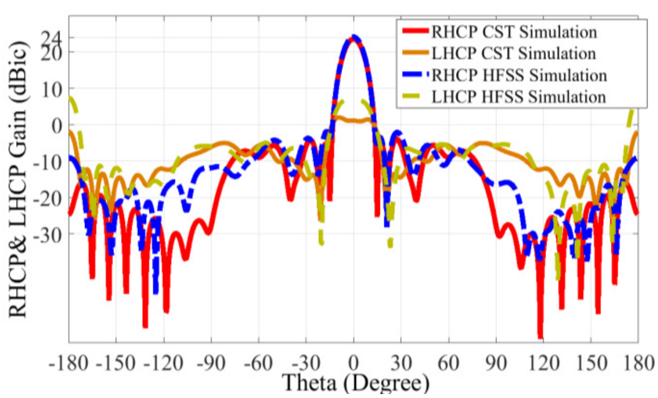


Figure 9. Simulated RHCP and LHCP gains of Antenna II in CST and HFSS software packages at 0.88 GHz.

Antenna II which is simulated by a solid reflector. From this figure it is also obvious that the side lobe level of the linearly polarized reflector antenna is well below 25 dB which is better than the circularly polarized reflector antenna.

Figure 8 shows the simulated YZ-plane radiation patterns of Antenna II in CST and HFSS and the measured H-plane radiation pattern of Antenna I at 0.84 GHz. Similar results can be concluded from the H-plane radiation pattern of the designed antennas.

The simulated RHCP and LHCP gains of Antenna I in CST and HFSS at 0.88 GHz are shown in Fig. 9. The difference between RHCP and LHCP components of the antenna is greater than 15 dB in the main beam angles. This difference confirms the circularly polarized radiation of Antenna II at main beam angles.

From all of these results it can be concluded that both linear and circular polarized self-supported cup feeds introduced in this paper are a suitable choice for paraboloid reflector antennas especially at low frequencies.

4. CONCLUSION

The design of a novel compact cup feed antenna for a parabolic reflector is presented in this paper. The feed antenna is created by exciting a cup feed structure with a disk loaded dipoles. Two different types of this antenna are designed in the paper. The first antenna is a linearly polarized cup feed designed by a single dipole and has about 43% impedance bandwidth at 805 MHz frequency. A prototype of this antenna is fabricated, and the measured results are shown in the paper. The second antenna is a circularly polarized cup feed designed by a crossed dipole antenna and has about 11% axial ratio bandwidth at 840 MHz frequency band. The simulated results of this antenna via two different software packages CST and HFSS are shown in the paper. The results of both antennas show a radiation pattern with a high efficiency and low side lobe level. Therefore, the proposed antennas are good candidate for feeding paraboloid reflector antenna especially at low frequencies.

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