3 D Corner Reflector Antenna as an efficient feed for offset parabolic antennas for 5.8 GHz

Dragoslav Dobričić, YU1AW

Abstract

In this article I present a modification of 3D corner reflector antenna in order to adjust it for the use as a feed for SAT TV offset parabolic antennas on 6 cm Ham band or WLAN frequencies of 5.8 GHz.

Introduction

The problems that occur while illuminating shallow offset parabolas, in addition to those related to the efficient use of parabolic generally, are additionally aggravated by the specific geometry of the parabolic mirror itself. Feed positioning in the way that its phase center exactly coincides with the focus of the offset parabola and its direction so that the radiation maximum falls in the geometric center of the elliptic reflector surface are not intuitive at all, as in classic parabolic antennas. Therefore, there are a many confusions and wrongly positioned feeds that don't correctly illuminate offset a parabolic dish, decreasing its efficacy and gain.

Classic and offset parabola

A parabolic surface or **paraboloid** is formed by rotation of parabolic curve around its axis of symmetry. The specificity of the surface gained in this way is that when the beam of rays parallel to its axis of rotation falls on it, the beam is reflected so that all the rays meet in one point, known as the focus, in the same way that optical lenses focus light rays in their focus.

When the piece of a (mathematically infinite) surface of paraboloid is cut off, a parabolic reflector or mirror is gained. Cutting off (cropping) can be carried out in many ways, but all of them can be classified in two groups: those whose surface of cropping is **perpendicular** on the axis of symmetry, and those whose surface of cropping are not perpendicular. When the plane that cuts off paraboloid is **perpendicular** on the axis of symmetry, a **round** segment of paraboloid is gained, whose focus is in the center, i.e. on the axis of symmetry on certain distance from geometric center of the surface, depending on the position of the cropping plane. Usually, the distance of the cropping plane is smaller than the equivalent focus and therefore in majority of dishes focus resides outside of the opening of the dish. **The segment gained in this way is classic parabolic antenna.**

All paraboloid segments gained in this way have one parameter by which they may be grouped regarding characteristics. That is the ratio between focal distance from center (F) and diameter of the segment of parabolic surface (D). All parabolic antennas that have equal ratio F/D may be illuminated by the same feed regardless its diameter, i.e. whether they are large or small, because their all other geometric dimensions are proportional, too. The ratio F/D is also crucial in determining the characteristics of the feed that will illuminate the dish. The reason for this is that ratio F/D determines the angle the edges of the parabola are seen from the focus. The smaller the ratio F/D, the deeper the dish is and this angle is greater, and vice versa, the greater the F/D ratio, the shallower the dish is and the angle are smaller. Since feed needs to be constructed in the way that it radiates only in the direction of the parabola, and that in all other directions it radiates as little as possible, this means that the ratio F/D, also determines the optimal radiation diagram of the feed. Hence, every F/D has its optimal feed, regardless all other dimensions! Therefore, when the optimal feed for a parabola is determined, the only thing that matters is its F/D!

When the plane that cuts the paraboloid is **not perpendicular** to the axis, elliptic segment of paraboloid is gained, whose focus is not in the geometric center of the parabolic surface, but is more or less shifted towards periphery, depending on the cut angle. **The offset parabolic antenna is gained in this way.** Because the cropping angle can be any one, the focus positions can also be in different places in relation to geometric center of gained parabolic surface. However, besides this difference in parameters, F/D still remains the only factor that determines the characteristics of the optimal feed for given offset parabola.

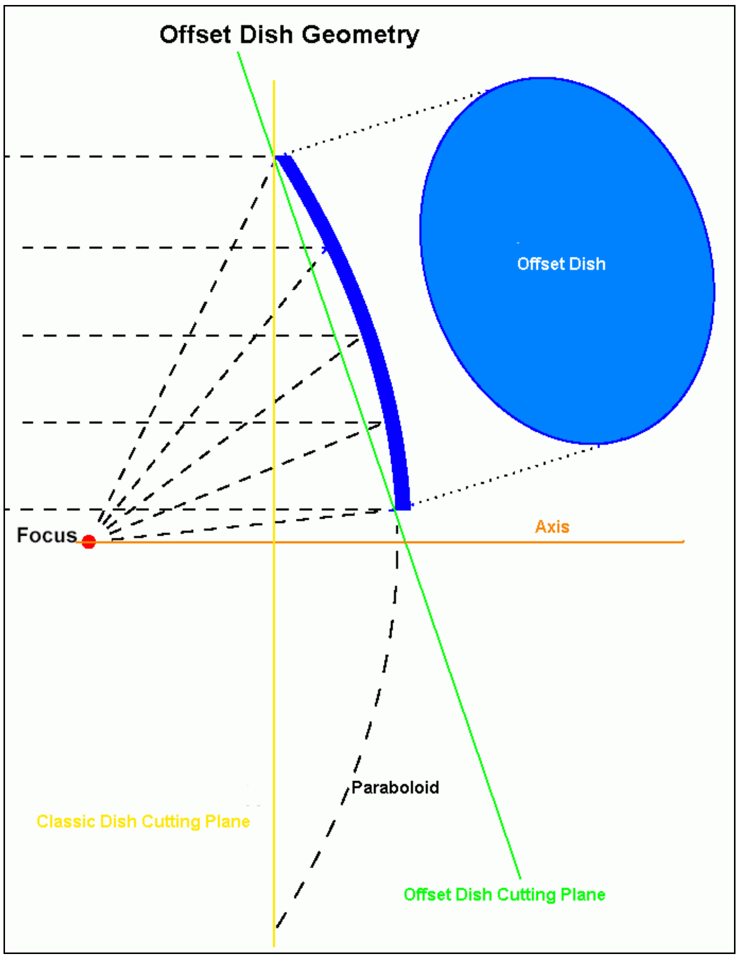

Fig. 1. Offset parabola geometry

In the case of an arbitrarily chosen segment of paraboloid, the problem is in determining F/D ratio. Without going in some specificities and possible exhibitions of different manufacturers of offset dishes, generally it can be said that the focal distance F is approximately equal to the distance between focus (in SAT TV antenna: from the opening of the converter waveguide) and parabola's geometric centre. For diameter D the smaller axis of the ellipse, i.e. the antenna's wideness, is taken. In offset parabolic antennas F/D is usually two times greater than in classic ones.

The optimal feed

The optimal feed for some given parabola has to fulfill several important characteristics:

1. The radiation angle of the main beam, between the points in which the radiated power is -10dB in relation to the maximal value, has to match the subtended angle. In fact, that is the angle with the angular point in focus and with the arms of the angles that touch the edges of parabolic reflector. The feed radiation angle both in horizontal and in vertical plane has to be the same, regardless the elipticity of offset parabola.
2. The phase center of the feed has to be well defined and stable with changes of frequencies within the working range. The change of the phase within the whole angle of illumination has to be as small as possible.
3. The feed characteristics must not change much in the presence of the parabolic reflector and carrier structure.
4. Feed radiation diagram has to be very clean, i.e. with low side lobes and rear lobes.
5. Feed structure has to encroach as little as possible in focal cones, i.e. in the space between focus and the antenna surface. Therefore, it is good when the feed phase center is on the front edge or directly in front of the feed antenna structure toward reflector.

It is not easy at all to accomplish all these demands. Efficiency and gain of a parabolic antenna directly depend on the degree of accomplishing of these demands. Therefore, in practice, it is common to make a good feed first and then, according to it, choose or make parabolic reflector with F/D that fits the best. However, if you want to use the cheap production of SAT TV offset parabolas for the work on 13cm Ham band or WLAN frequencies; you have to try to construct the feed that matches existing parabolas. SAT TV antennas usually have F/D in range from 0.7 to 0.9. For efficient illumination, a feed with a clean diagram that has equal width of the main beam in both planes and gain of about 12-14 dBi is needed. This fact excludes some antennas as efficient feeds for SAT TV offset parabolas. Among them is, for example, the coffee can (simple open waveguide) that has gain of about 6-7 dBi and is very inefficient as feed for offset parabolas. It is acceptable only for parabolas that have F/D less than about 0.5. The bi-quad is a somewhat better, with its gain of about 10 dBi, and its optimal version with evened diagrams in both planes and gain of 11 dBi is even better. The addition of director element in 2 element bi-quad feeds gave high values of efficiency of illumination of offset parabolas. However, an additional problem is the range of 5.8 GHz where building the bi-quad antenna represents big problem because of very small tolerances and high precision that needs to be achieved.

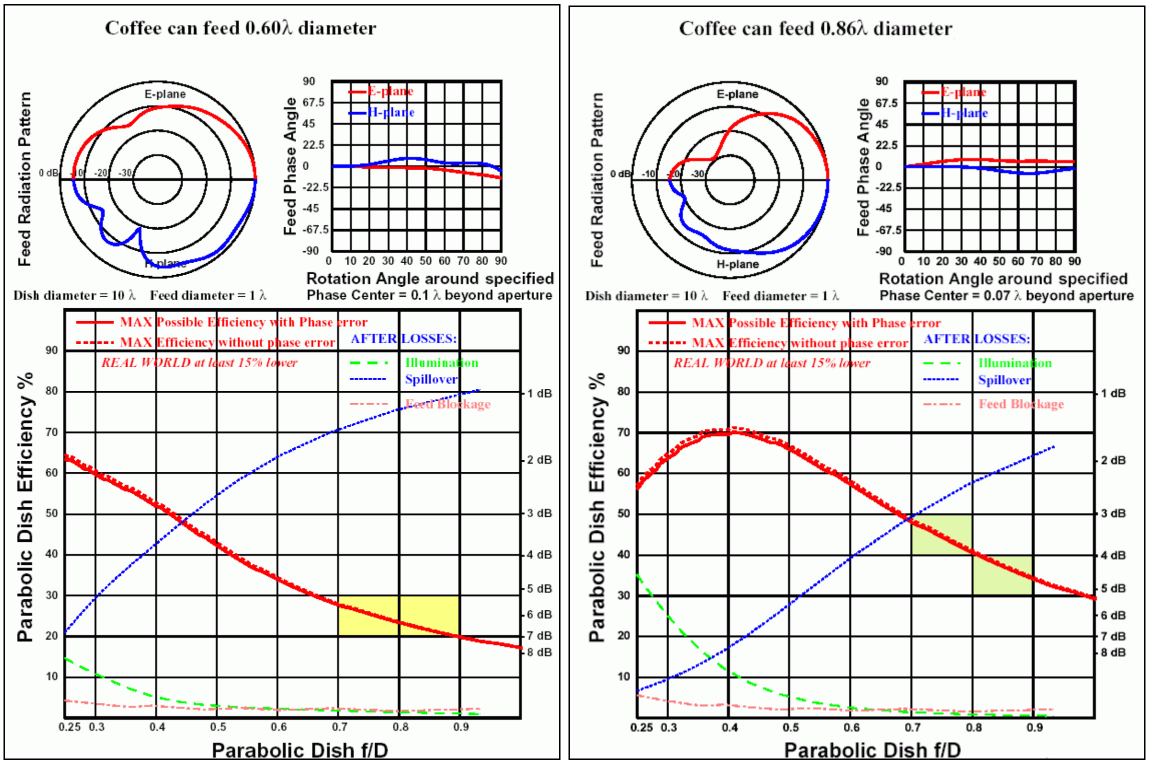

Fig. 2. Offset parabola efficiency with 31 and 44 mm diameter coffee can feed at 5.8 GHz frequency.

3D corner reflector antennas, and especially the shortened version, are good candidates for feed, but the problem is that it has very unequal diagram – in horizontal plane it is much wider than in vertical plane. By diminution of the antenna to 1.7 wavelengths, to decrease the gain to needed 13 dBi, this unevenness is further increased. Therefore, I modified this antenna in order to get more even diagram, which will be discussed in this article. I achieved, although not perfect, yet a very simple and reliable feed for 5.8 GHz range with acceptable efficiency.

For those who will, while reading this, say they tried Coffee can, biquad, 3D corner or any other randomly chosen antenna as feed for offset parabola and that 'it works', I will only say that **any antenna or piece of wire put approximately in focus of the offset parabola has to work by the laws of physics!** So, it is not the question **'does it work?**' The question is **'how it works?'** in relation to how it **could and should work**! I presented some diagrams of efficiency of a coffee can with different diameters as feeds for parabolas with different F/D and it is very clear how efficiently they work with offset dishes whose F/D is in the range 0.7-0.9 (colored range). It is clear that offset parabola with a coffee can whose diameter is 0.6 wave lengths, i.e. about 31 mm, has efficiency of about 25%, that consequently decreases the gain of antenna for 6 dBi in relation to theoretic value, and that is exactly how much it would be gained with two times smaller, efficiently illuminated offset parabola! Even a coffee can with diameter of 0.86 wavelengths, or 44 mm doesn't work brilliantly. It gives about 4 dB loss of gain of antenna in relation to theoretic value with an efficiency of 100%. Greater diameters of coffee can have problem with appearance of **higher modes of EM waves** and consequently very problematic diagram and phase center, so they are not recommended.

The addition of conic funnet can partially improve the situation, but such **horn** antennas have uneven diagrams in vertical and horizontal planes, which is very undesirable for antennas that pretend to be good and efficient feed for dish.

A **3D corner reflector antenna,** with dimensions of 1.7 wavelengths, still has too narrow a vertical diagram and is suitable only for very shallow offset parabolas, with **F/D of about 1 and more.**

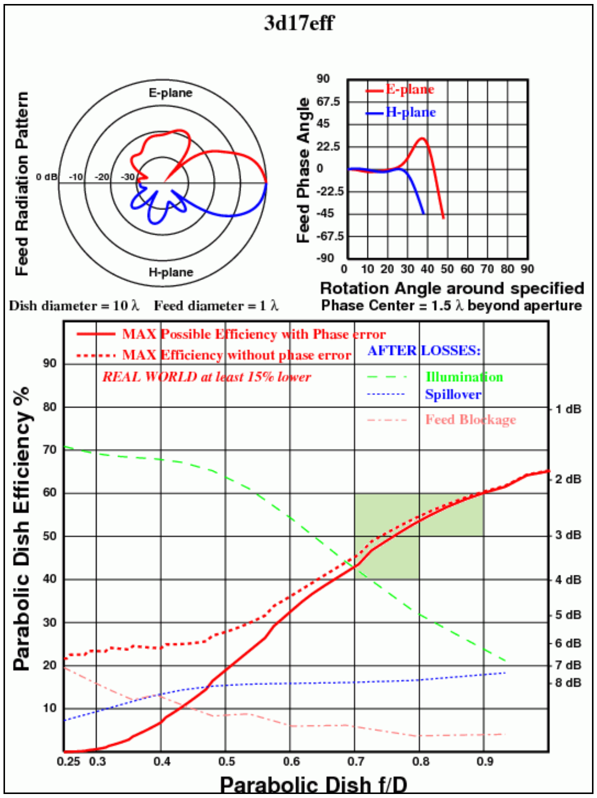

Fig. 3. Offset parabola efficiency with 3D corner reflector antenna of 1.7 wavelength feed at 5.8 GHz frequency.

Truncated 3D corner reflector feed for 5.8 GHz

As shown in the picture above, 3D corner reflector antenna has relatively good efficiency when it is illuminating dishes whose F/D is 0.9 and higher. The reason for this is its very narrow vertical radiation angle. That is, the vertical radiation angle is too narrow for the illumination of SAT TV offset parabolas, and horizontal is too wide, as shown in the figures. It is obvious that 3D corner reflector antenna could be also adjusted for offset parabolas with a lower F/D if the diagram could be widen in vertical plane and narrowed in horizontal plane so that they are approximately equal to each other and at the same time retain all other good characteristics of this antenna. Since widening and narrowing of the diagram is possible only by modifying of the geometry of reflector, the change of dimensions and shape of the reflector was the course I took. However, the change of geometry on this geometrically symmetrical reflector carried the danger of loosing some of the basic characteristics of geometric optics, by whose principles this antenna functions.

That would immediately mean the complete change of the most of the essential and valuable characteristics of the antenna, too.

By small changes, actually by gradually removing the parts of the reflector responsible for vertical radiation beam narrowing, I succeeded in progressively widening the vertical diagram. At the same time, in order to narrow the horizontal radiation diagram, I increased the length of the sides of the reflector. With constant monitoring of the achieved results, I made the radiation diagram angles in both planes approximately equal, which is needed for efficient illumination of parabolas whose F/D is about 0.7-0.9. In the end, the result was the optimal diagram for the use with SAT TV offset parabolas. The input impedance of the antenna, the wideness of the frequency working range and purity of the diagram of the antenna remained practically unchanged.

The vertical diagram, of the main beam in addition to widening, became much cleaner, which additionally improved the characteristics of the feed. The gain of the feed antenna is practically unchangeable (about 14.8 dBi), and input SWR is below 1.5:1 in the whole working range.

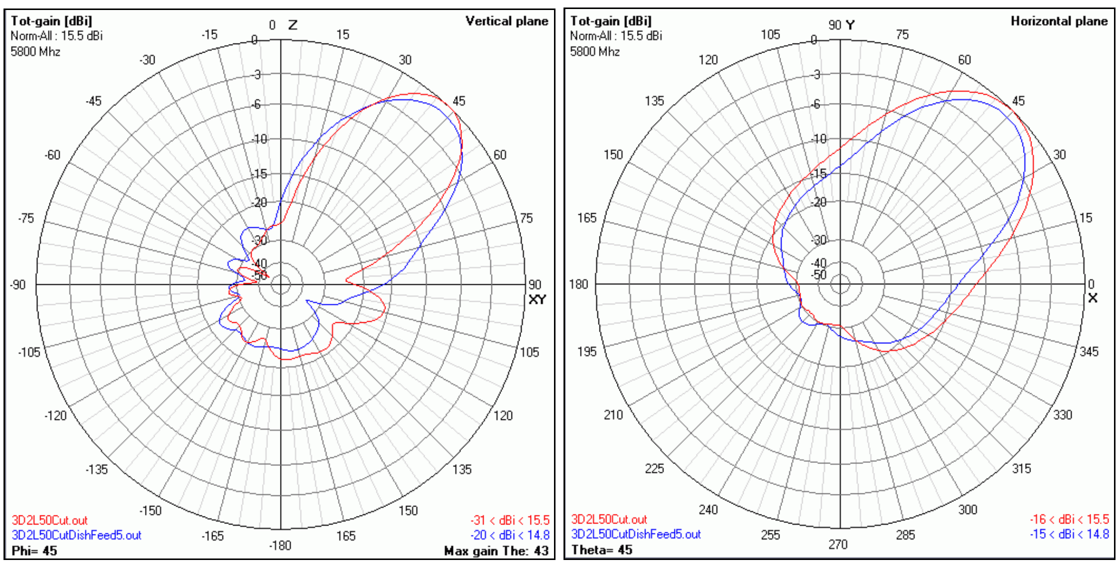

Fig. 4. Comparative diagrams for shortened 3D corner reflector antenna of 2 wavelengths and truncated 3D corner reflector feed

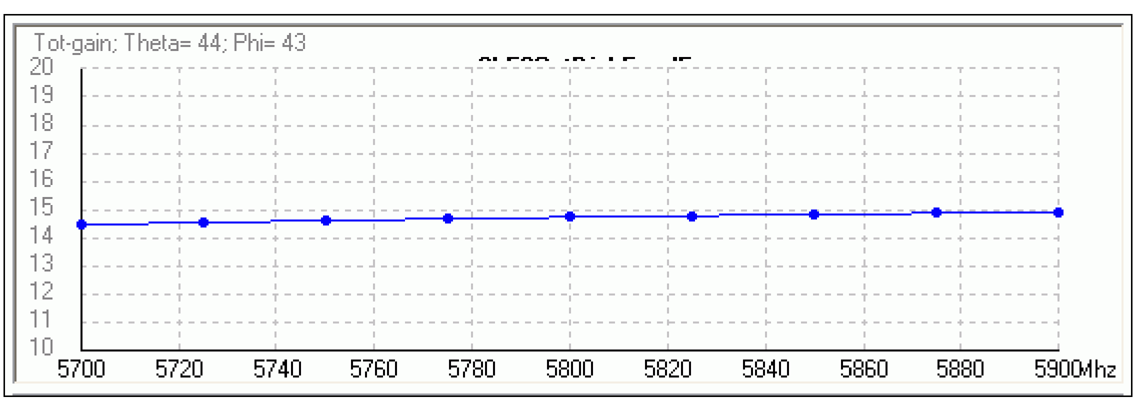

Fig. 5. Truncated 3D Corner Reflector Feed gain

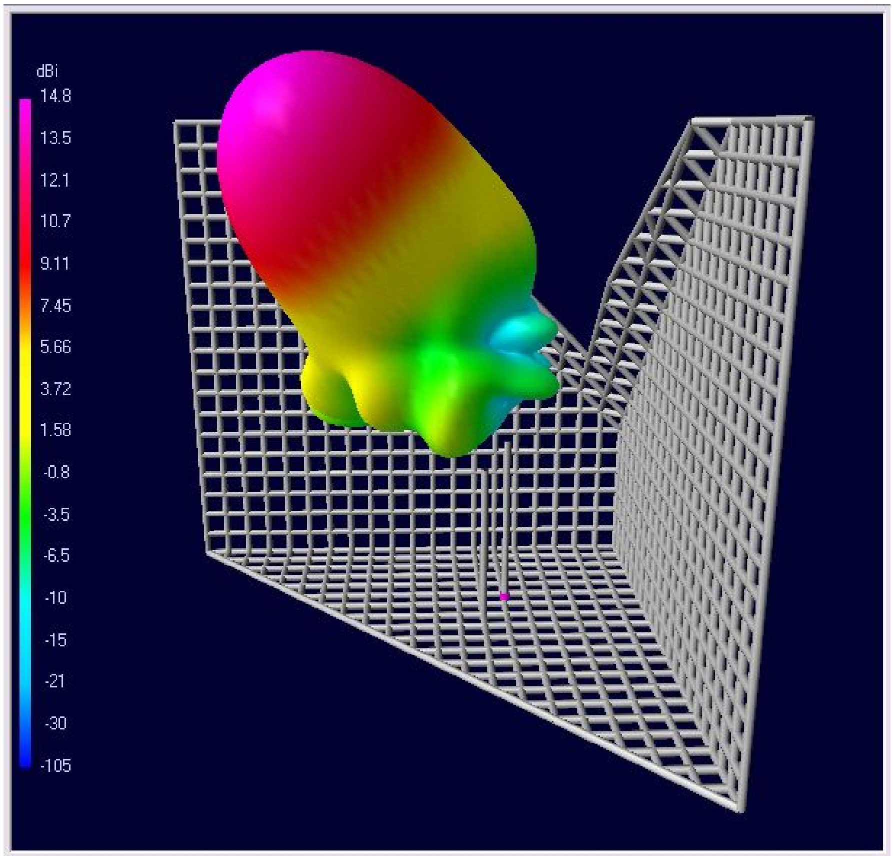

Fig. 6. 3D radiation diagram of Truncated 3D Corner Reflector Feed

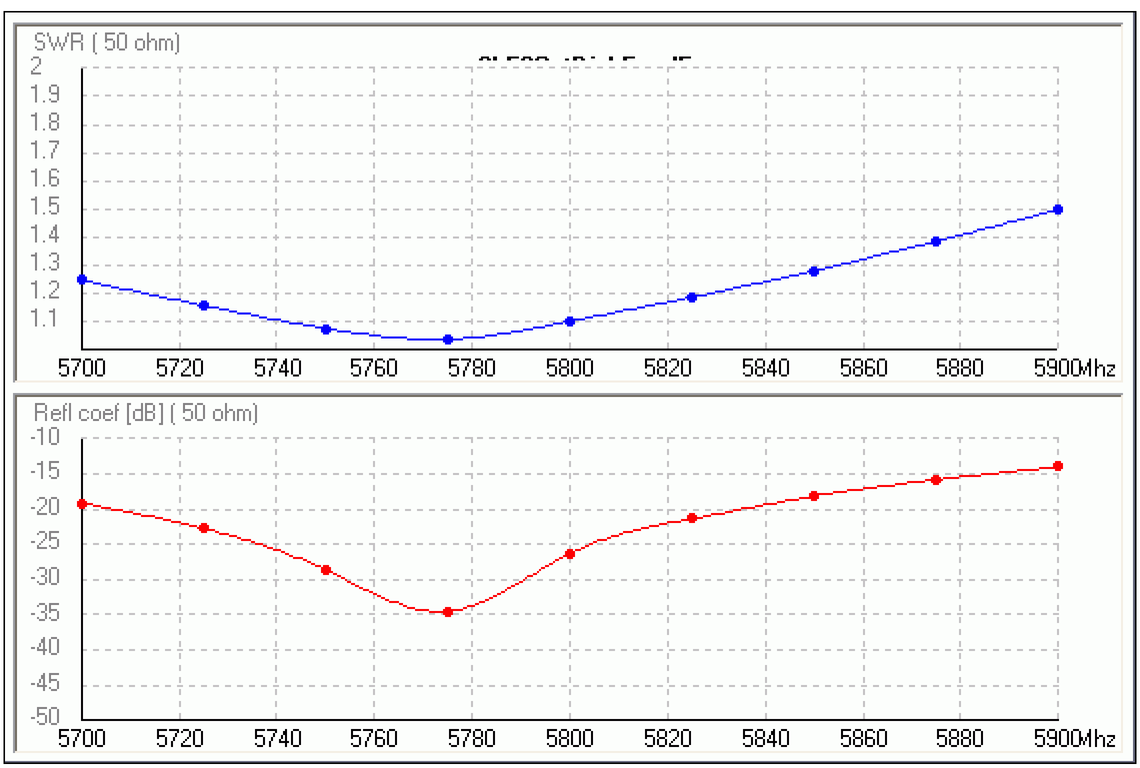

Fig. 7. Truncated 3D Corner Reflector Feed input matching

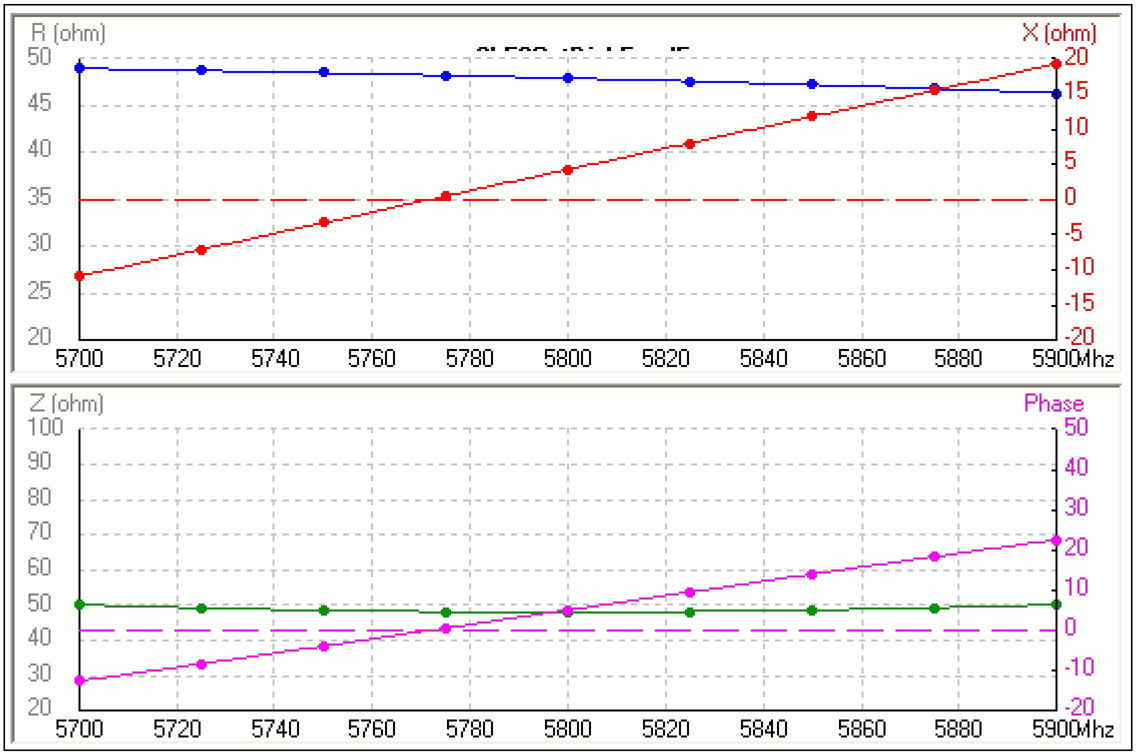

Fig. 8. Input impedance of Truncated 3D Corner Reflector Feed

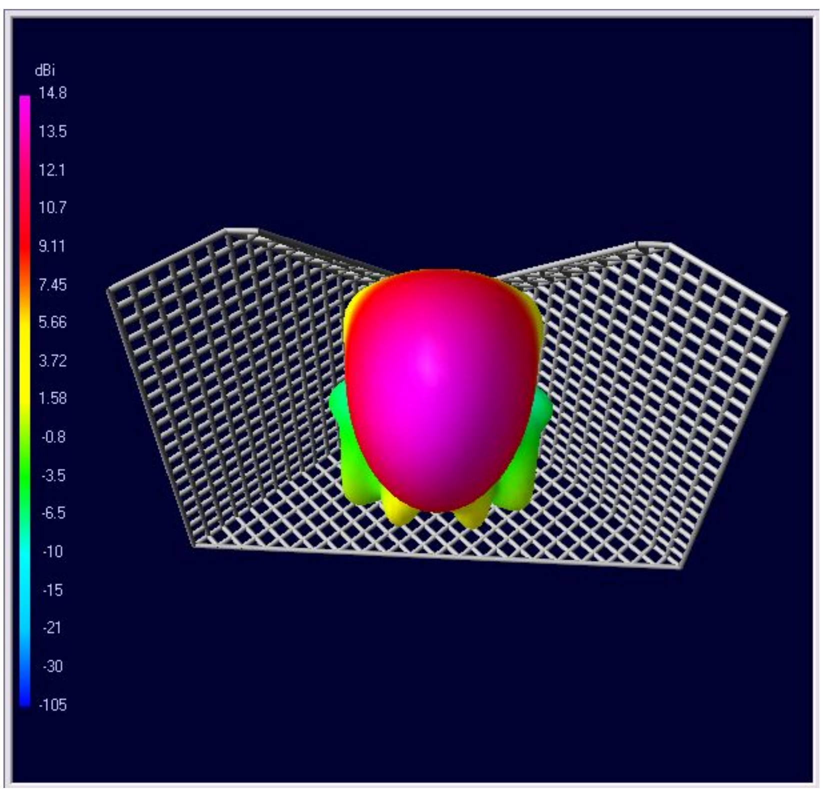

Fig. 9. Main beam of Truncated 3D Corner Reflector Feed

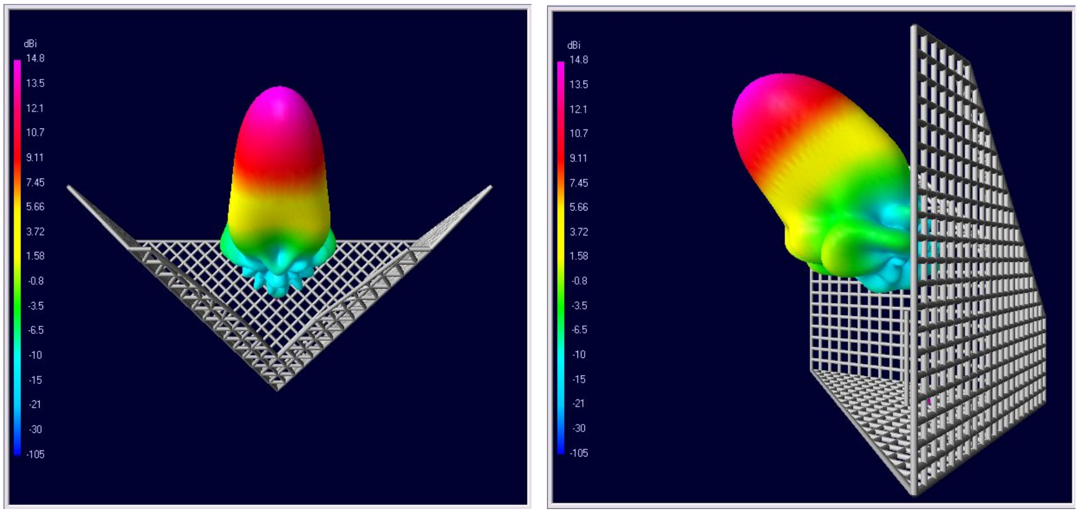

Fig. 10. Horizontal and vertical diagram of Truncated 3D Corner Reflector Feed

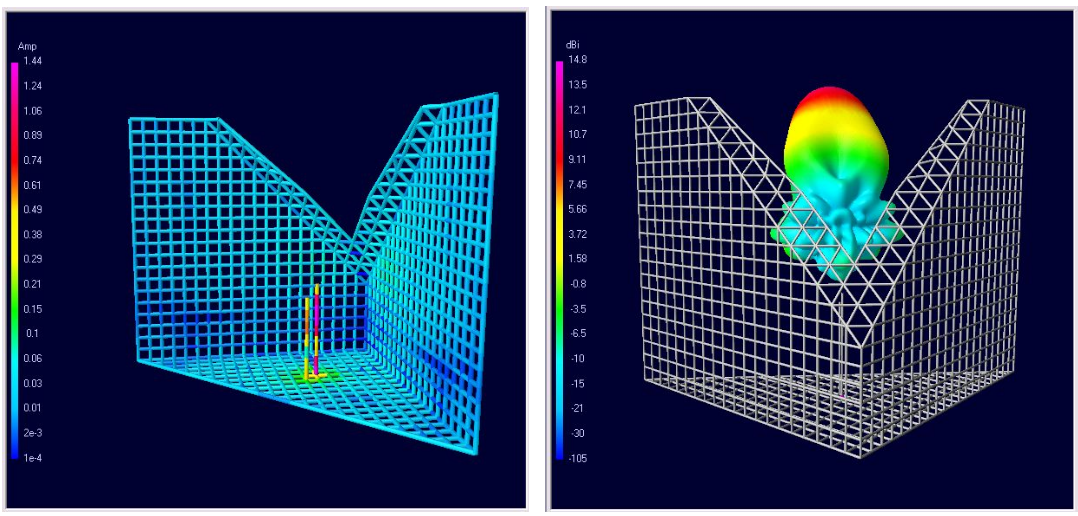

Fig. 11. Elements current and back lobes of Truncated 3D Corner Reflector Feed

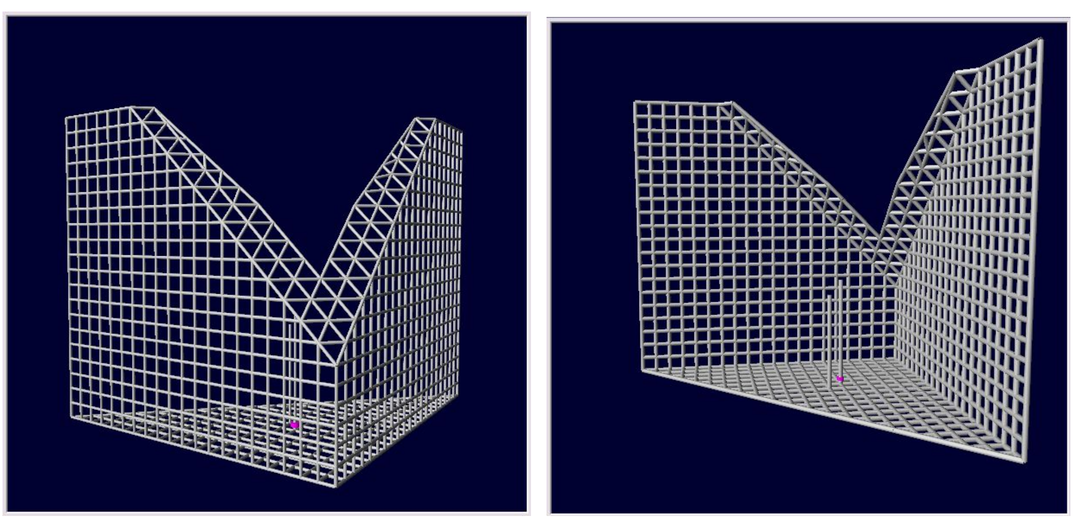

Fig. 12. End view and side view of Truncated 3D Corner Reflector Feed

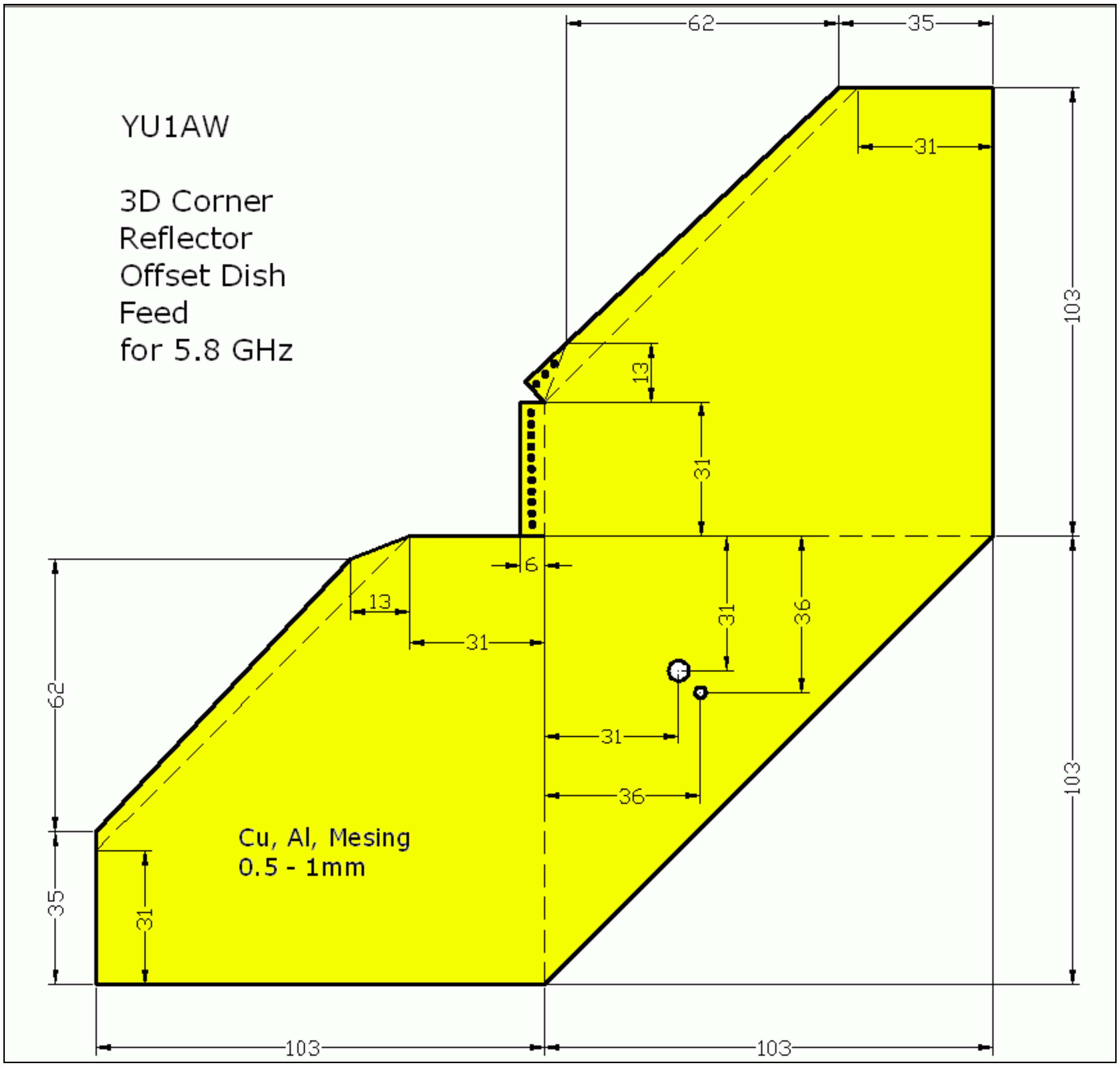

Fig. 13. Cut dimensions and bending lines for reflector of Truncated 3D Corner Reflector Feed

Mechanical construction of the antenna

The radiator and director are made out of two pieces of copper wire, diameter 1.6 mm and total length of 37.9 mm for radiator and 33.4 mm for director, measured from the reflector surface! The reflector surface may be only made out of copper, aluminum or brass tin. The reflector is cut off according to given dimensions and folded at a 90 deg. angle according to dashed lines. The backside can be soldered at the junction if the reflector is made out of copper or brass and in that case the overlapping field is not necessary. The backside can also be fixed by screwing or pop-riveting in very densely overlapping fields. Overlapping fields must always be on the backside of the reflector. I also tried a feed antenna whose bottom reflector surface was left unshortened for better mechanical stiffness. The impact of this additional surface is very small, although it slightly narrows the vertical diagram and consequently slightly spoils efficiency.

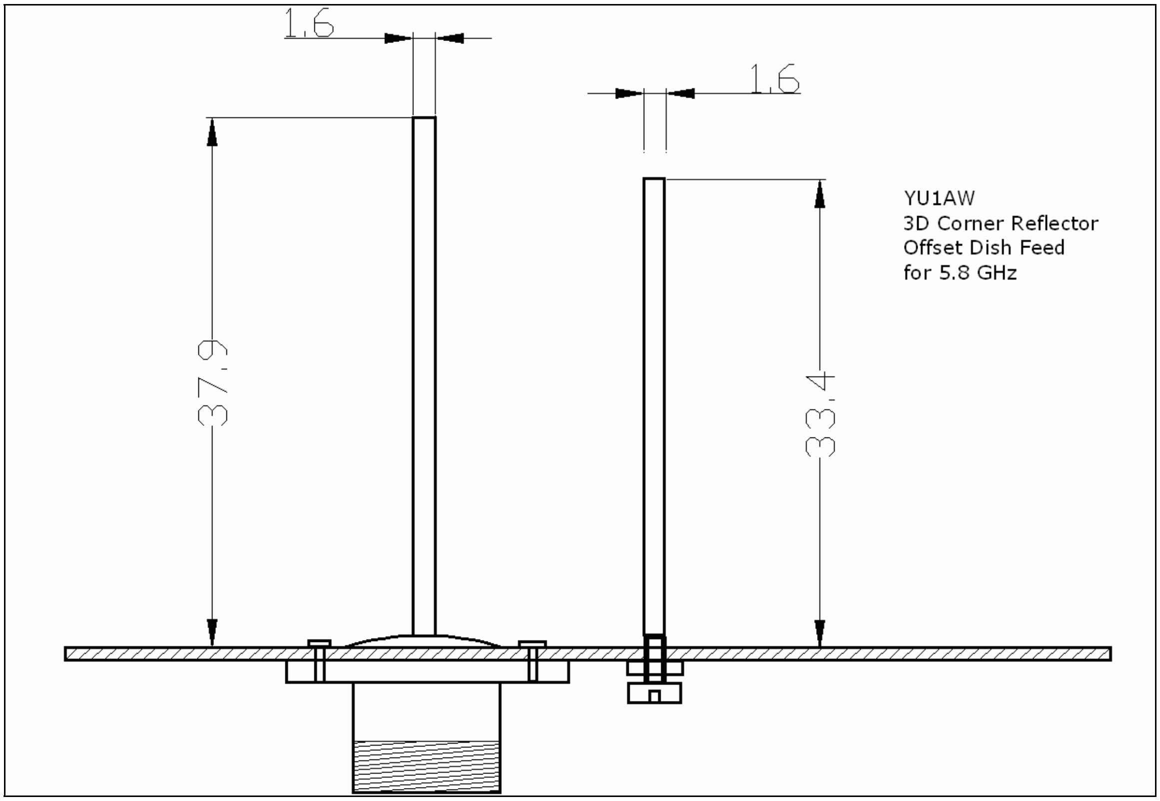

Fig. 14. Elements dimension of Truncated 3D Corner Reflector Feed

Protection from atmospheric action

It is the best that this protection is done while the metal is still light and without corrosion and antenna is covered by thin layer of varnish. Before that, the upper opened part of the connector is protected with a thin layer of polyethylene, using the pistol that melts polyethylene bars and deposits liquid plastic on the desired surface. The layer of polyethylene should be waterproof, **but as thin as possible!** So, it is wrong to put large amounts of plastic in thick layer to the connection, because it's useless and serves only to worsen impedance matching! Also, the use of silicone is strictly forbidden because of its chemical aggressiveness and great losses at higher frequencies!

Placing the feed in the focus of the offset parabola

The analysis of the phase center of truncated 3D corner feed revealed that it is positioned 1.63 wavelengths or 83 mm in front of the reflector measured from the apex along a large diagonal that is 45 degrees in relation to all three reflector surfaces, i.e. in direction of the maximal radiance. That point (that is in the figure given as coordinate center) must be placed in the focus point of the parabola as precisely as possible! The direction of maximal radiation of the main beam must be directed into the geometrical center of the elliptic surface of the parabola.

When SAT TV offset parabolas are used, focus is determinate by the position of the SAT TV converter. The focus of the parabola, practically, is in the entrance in the waveguide of the converter. By measuring the distances between the entrance of the converter and at least 3 fixed points at the edges of the parabola, one should keep the information about the position of the focus, so that it could be precisely determined and restored when the SAT TV converter and original carrier are taken off or adjusted in order to be able to carry a different feed. This is very important because it is very often the case that, after the correction of the feed carrier, the position of the parabola's focus is lost and it cannot be restored if there is no information, i.e. space coordinates in relation to the parabolic surface.

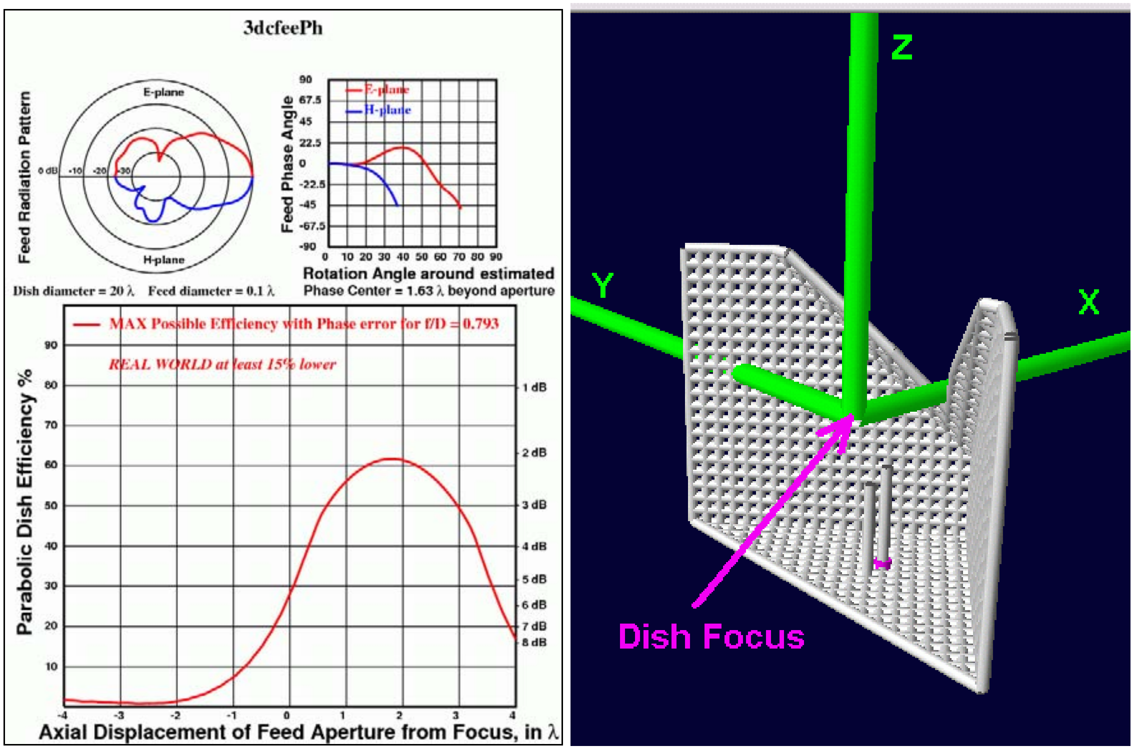

Fig. 15. Phase center position of Truncated 3D Corner Reflector Feed and its location in relation to parabola focus

Results with an offset parabola

We achieved very good results by analysis of truncated 3D corner feed with rectangle shaped offset parabola, with dimensions 100x110 cm and F/D=0.8. We confirmed very high efficiency on the basis of achieved gain of the parabolic antenna in relation to theoretic value. The calculation of the efficiency of illumination of parabola from its gain gave the value of about 57%, which relatively well coincides with calculations of efficiency derived from the shape of the feed diagram given in **Figure 17**. An elliptical parabola with the same dimensions would have smaller gain by about 1 dB in relation to this analyzed rectangular, with the same efficiency, because of smaller geometric surface of the elliptic parabola.

Another confirmation that this is a very good feed is the purity of achieved radiation diagram of parabola. First side lobes are suppressed **20 dB,** and F/B is more than **30 dB**. Maximal gain of the antenna is achieved when the phase center of the feed is exactly in the focus of parabola and when the large diagonal of truncated 3d corner feed, i.e. maximum of radiation diagram of the main beam, is directional into the geometric center of parabolic surface that is in the crosshair of large and small axis of ellipse. The input impedance of the feed remained practically unchanged when placed in focus of parabola, which was expected from this antenna that is known by its low Q factor.

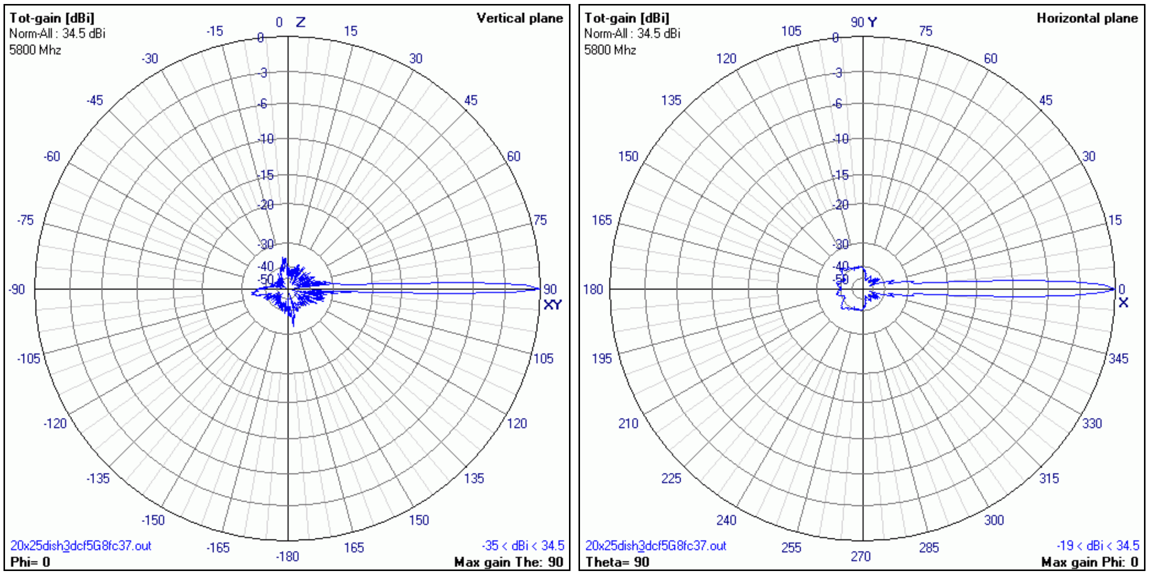

Fig. 16. Vertical and horizontal diagrams of offset parabola with Truncated 3D Corner Reflector Feed

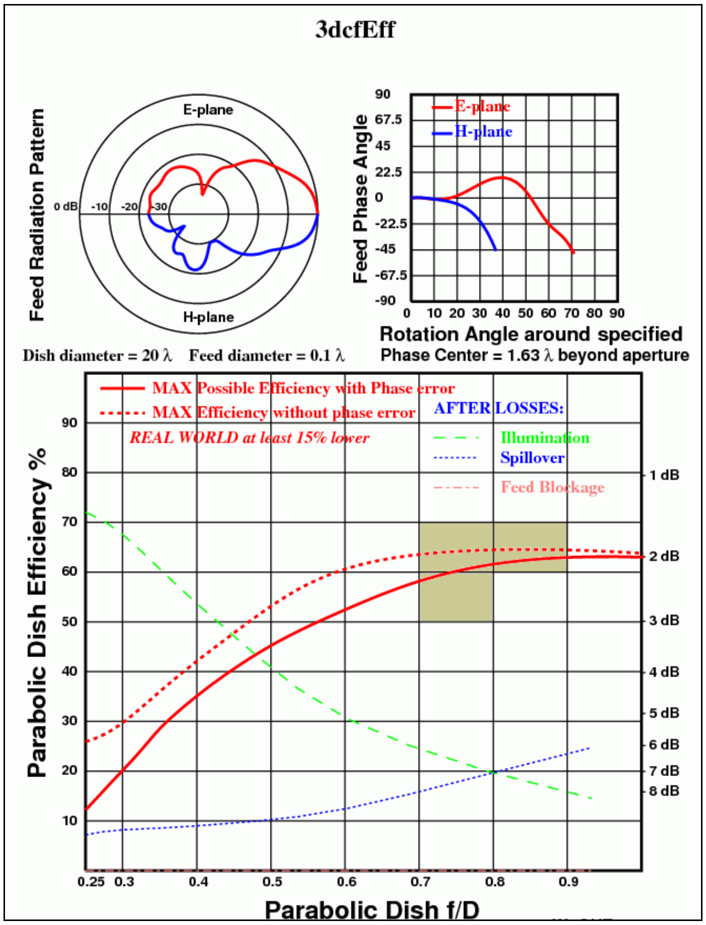

Fig. 17. Parabola efficiency with Truncated 3D Corner Reflector Feed in relation to its F/D ratio

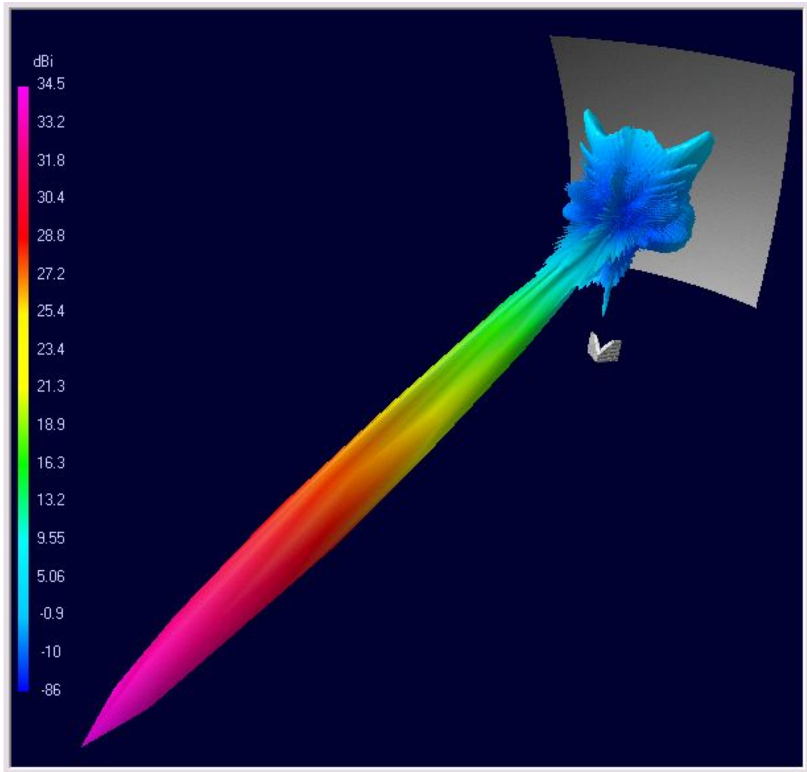

Fig. 18. 3D diagram of rectangular offset parabola with Truncated 3D Corner Reflector Feed

Fig. 19. Practical use of Truncated 3D Corner Reflector Feed with SAT TV offset parabola

Fig. 20. Outlook of Truncated 3D Corner Reflector Feed mounted in focus of offset parabola

Conclusion

In this article we showed and, by precise computer simulations, confirmed the possibility of using truncated 3D corner reflector feed for efficient illumination SAT TV offset parabolic dish. Pure diagrams of truncated 3D corner reflector feed, with approximately equal width of the main beam in both planes, proved it to be a very simple and efficient feed for offset parabolic antennas whose F/D is 0.7-0.9. As a result we achieved high efficiency, directivity and purity of the diagram SAT TV offset parabolic antenna on 5.8 GHz.

Fig. 21. 50 km 5.8 GHz link using offset parabola dish
and Truncated 3D Corner Reflector Feed

Acknowledgements

I thank the boys from BG Wireless, and especially Spider, for the help on practical realization and verification of this feed. The feed is tentatively projected for 5.8 GHz links in BG Wireless network and so far it has been successfully tested at a distance of about 50 km.

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BRIEF BIOGRAPHY OF THE AUTHOR

Dragoslav Dobričić, YU1AW, is a retired electronic engineer and worked for 40 years in Radio Television Belgrade on installing, maintaining and servicing radio and television transmitters, microwave links, TV and FM repeaters and antennas. At the end of his career, he mostly worked on various projects for power amplifiers, RF filters and multiplexers, communications systems and VHF and UHF antennas.

For over 40 years, Dragan has published articles with different original constructions of power amplifiers, low noise preamplifiers, antennas for HF, VHF, UHF and SHF bands. He has been a licensed Ham radio since 1964. Married and has two grown up children, a son and a daughter.

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