Efficient Feed for Offset Parabolic Antennas for 2.4 GHz

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Resume

This article examines some of the possible solutions to the problems of efficiently illuminating SAT TV offset parabolic antennas in the use on WLAN frequencies of 2.4 GHz..

Introduction

The problems that occur while illuminating shallow offset parabolic dishes, in addition to those related to the efficient use of parabolic dishes generally are additionally aggravated by the specific geometry of the parabolic mirror itself. [2] Feed positioning in the way that its phase center exactly coincides with the focus of the offset parabolic dish and its aiming 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 is much confusion and many wrongly positioned feeds that do not correctly illuminate offset parabolic dishes, decreasing their efficiency and gain.

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 gain is -10dB in relation to the maximal value, has to match the subtended angle. The feed radiation angle, both in horizontal and in vertical plane has to be the same, regardless the ellipticity 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. The feed structure has to encroach as little as possible into the focal cone, 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 antenna structure.

It is not easy at all to accomplish all these demands. The efficiency and gain of parabolic antennas directly depend on the mode of accomplishing these demands. Therefore, in practice, it is common to make good feed first and then to choose or make a parabolic reflector with a F/D value that fits the best with the feed. [4, 5] However, if you want to use the cheap production of SAT TV offset parabolas for the work on HAM or WLAN frequencies; you have to try to construct a feed that matches those parabolic reflectors. SAT TV antennas usually have F/D in band from 0.7 to 0.9.

For efficient illumination, we need a feed with a clean diagram that has equal width of the main beam in both planes and gain of about 12-14 dBi. This fact at the start excludes some antennas as efficient feeds for SAT TV offset parabolas. Among them is, for example, the coffee can (simple open circular waveguide) antenna that has gain of about 6-7 dBi and is very inefficient as a feed for offset parabolas. It is acceptable only for parabolas that have F/D less than about 0.5. The bi-quad antenna is somewhat better, with its gain of about 10 dBi, and its optimal version with evened diagrams in both planes and a gain of 11 dBi is even better.

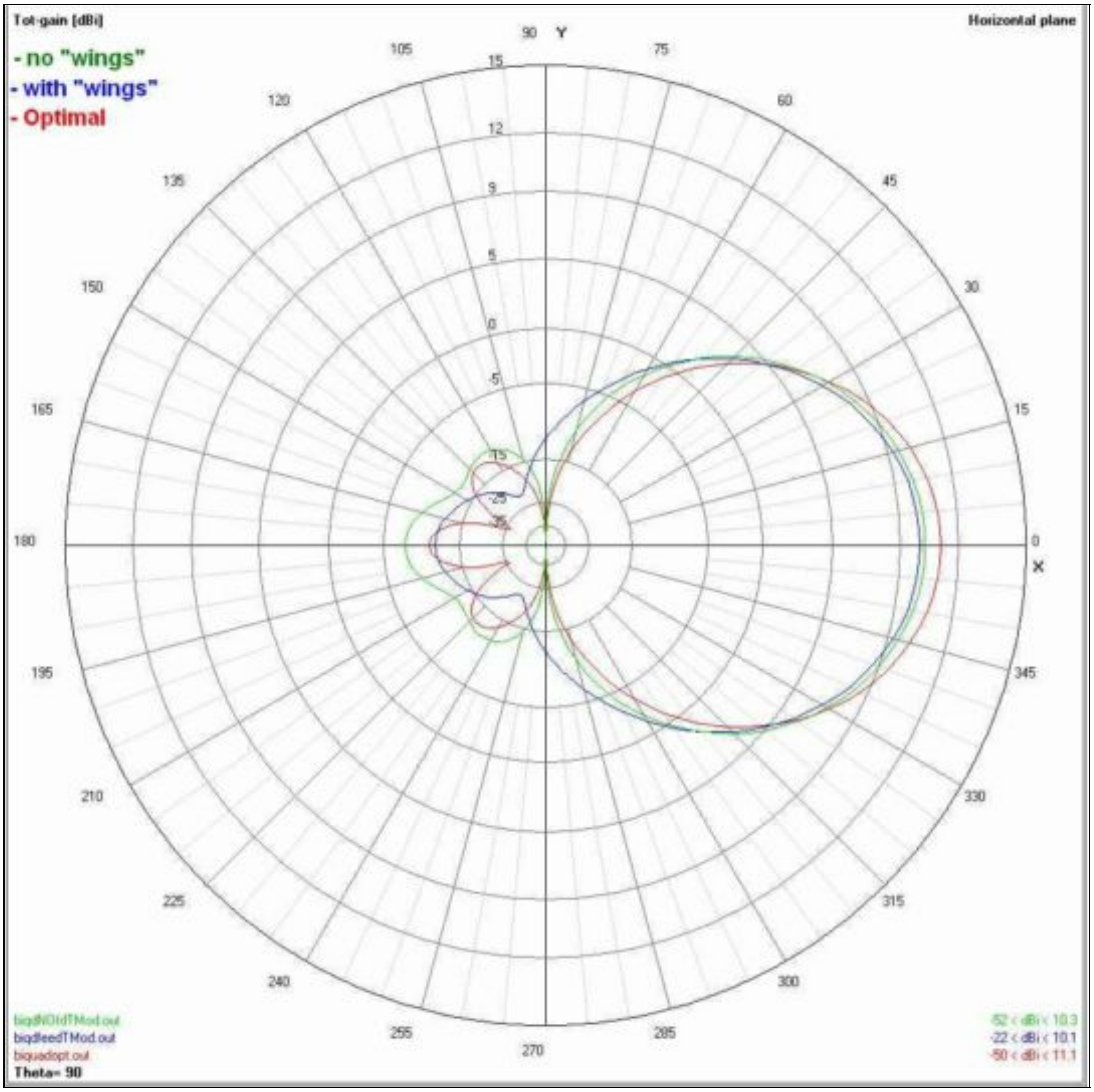

Fig. 1. Horizontal diagram of bi-quad antenna with and without "wings" and optimal bi-quad with evened diagrams.

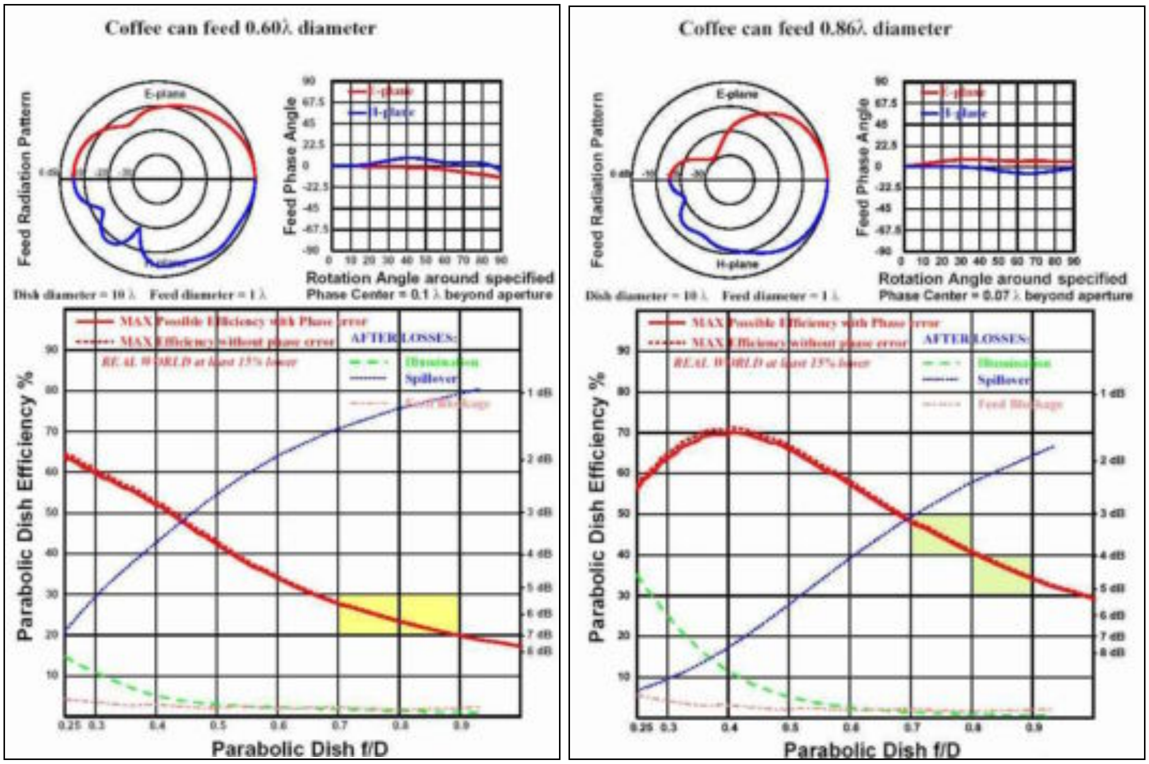

Fig. 2. Efficiency of coffee can antenna feed with different waveguide diameter

I presented some diagrams of efficiency of some antennas that are used 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 band 0.7-0.9 (colored band). For example, it is clear that an offset parabola with a coffee can antenna whose diameter is 0.6 wavelengths, i.e. about 74 mm at 2.45 GHz, has an efficiency of about 25%, a value that consequently decreases the gain of antenna by 6 dBi in relation to its theoretic value. That is exactly how much it would be gained with twice as small, efficiently illuminated offset parabola! [3] Even coffee can antennas with a diameter of 0.86 wavelengths, or 106 mm, do not work brilliantly. They give about 4 dB loss of antenna gain in relation to the theoretic value with an efficiency of 100%. Greater diameters of coffee can antenna have problems with the appearance of higher modes of EM waves and consequently very problematic diagrams and phase centers, so they have not recommended. The addition of conic funnel can partially improve the situation, but such **horn** antennas have uneven diagrams in the vertical and horizontal planes, which is very undesirable for antennas that pretend to be good and efficient feeds for dish.

The **bi-quad antenna** is somewhat better feed for offset parabola than coffee can antenna. Adding “wings” to reflector, which some authors use in order to improve illumination efficiency of dish, change only back side lobe radiation. The front diagram is almost unchanged and as a feed it has unchanged efficiency. The **optimal bi-quad,** according to **L.B. Cebik** [1], with reflector dimensions 150x200 mm, is even better and gives about 5% higher efficiency than other variants of bi-quad.

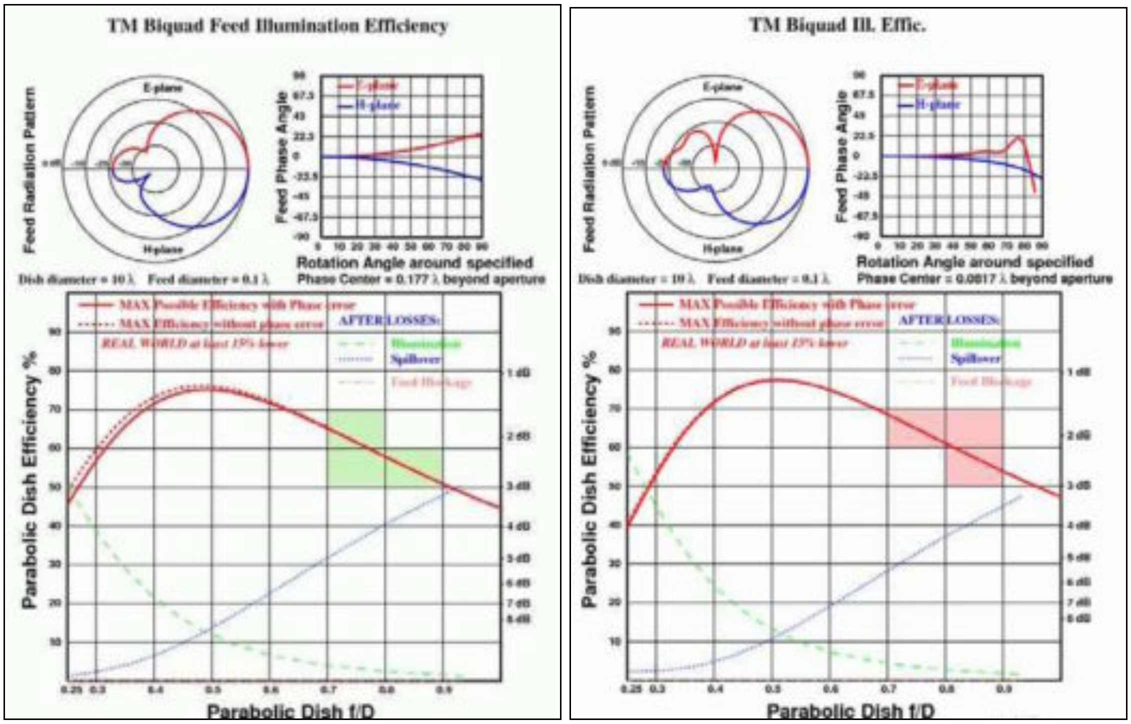

Fig. 3. Bi-quad antenna feed efficiency with "wings" (left) and without "wings" (right)

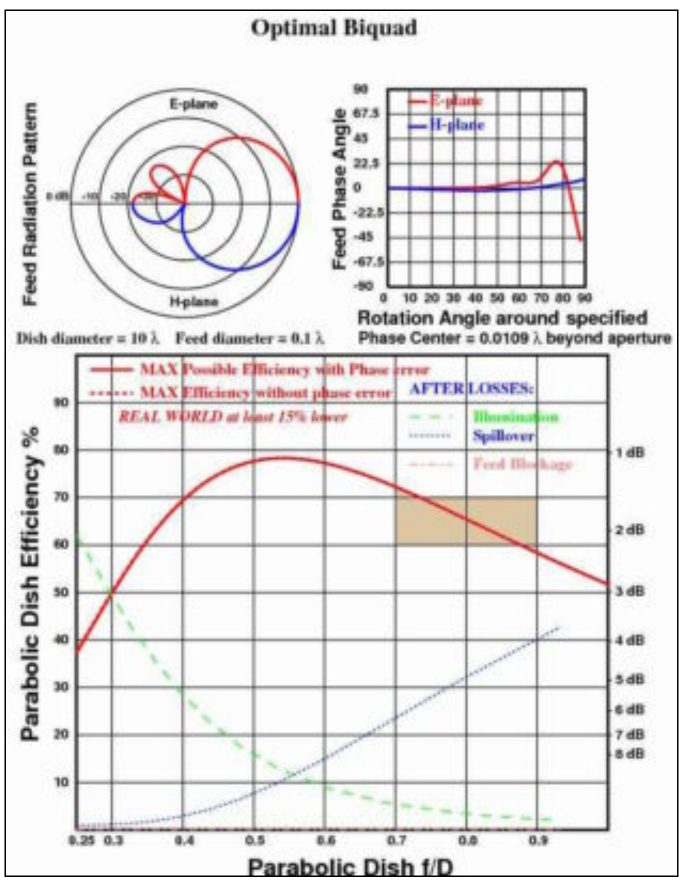

Fig. 4. Efficiency of optimal bi-quad as feed for offset dish

Two-element bi-quad feed for 2.4 GHz

As shown in the picture above, the optimal bi-quad has very high efficiency when it is illuminating dishes whose F/D is 0.5-0.6. It is obvious that it could also be adjusted for dishes with higher F/D, if the diagram could be narrowed in both planes and at the same time retain all other good characteristics. Since narrowing of the diagram, i.e. increasing of gain of the antenna, is possible only by addition of director element, that was the course I took. However, the addition of a resonant parasitic element as a director to this relatively complex structure was not such an easy thing to do! I found and looked at several reported two-element bi-quads on the Internet and by short analysis I realized that neither of them had nearly optimal performances. Some of them even worked worse with an added director than without it!

By detailed analysis and optimization I realized that director has to have approximately the **same electrical length as the active element** if you want to retain an optimal diagram for use with an offset parabola. With different dimensions of the director and distances between elements, somewhat higher gain can be achieved, but then the diagram is not optimal for the illumination of the offset parabolas. Also, the reflector has to be increased in relation to the one in the optimal bi-quad and is square shaped with the side of 1.6 wavelengths. Some minor asymmetry in horizontal plane diagram of two-element bi-quad feed antenna is due to asymmetrical feeding of antenna radiator.

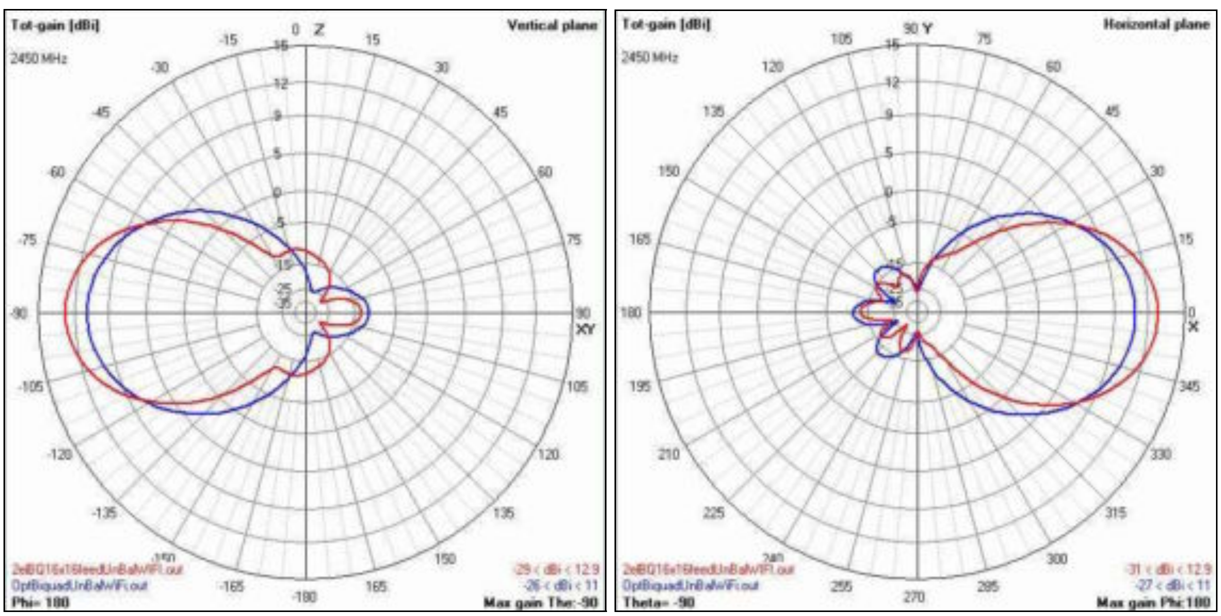

Fig. 5. Horizontal and vertical diagrams of optimal bi-quad and 2 element bi-quad feed

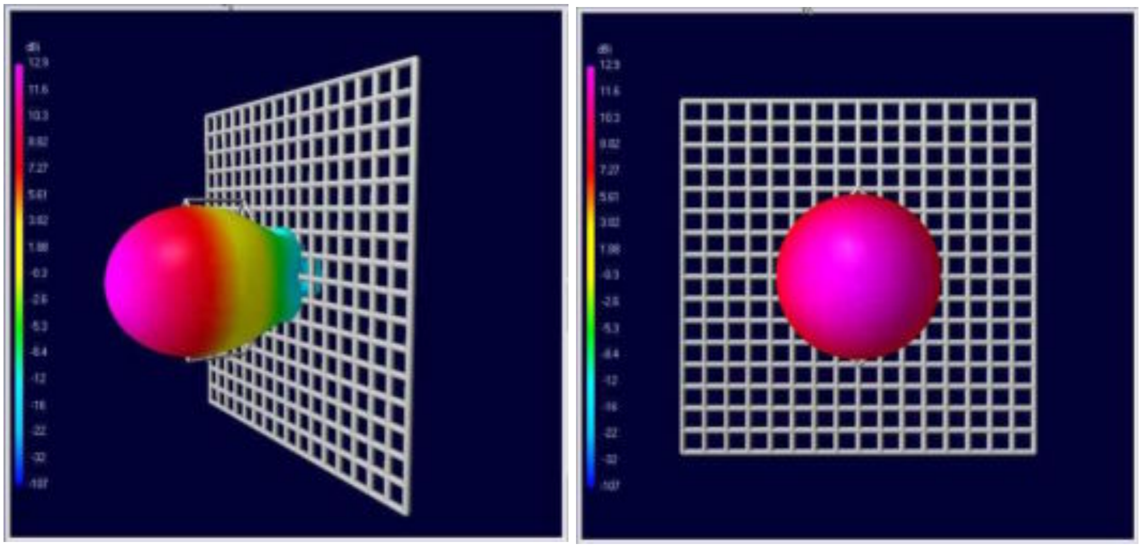

Fig. 6. Side and front view of 2-element bi-quad feed diagrams

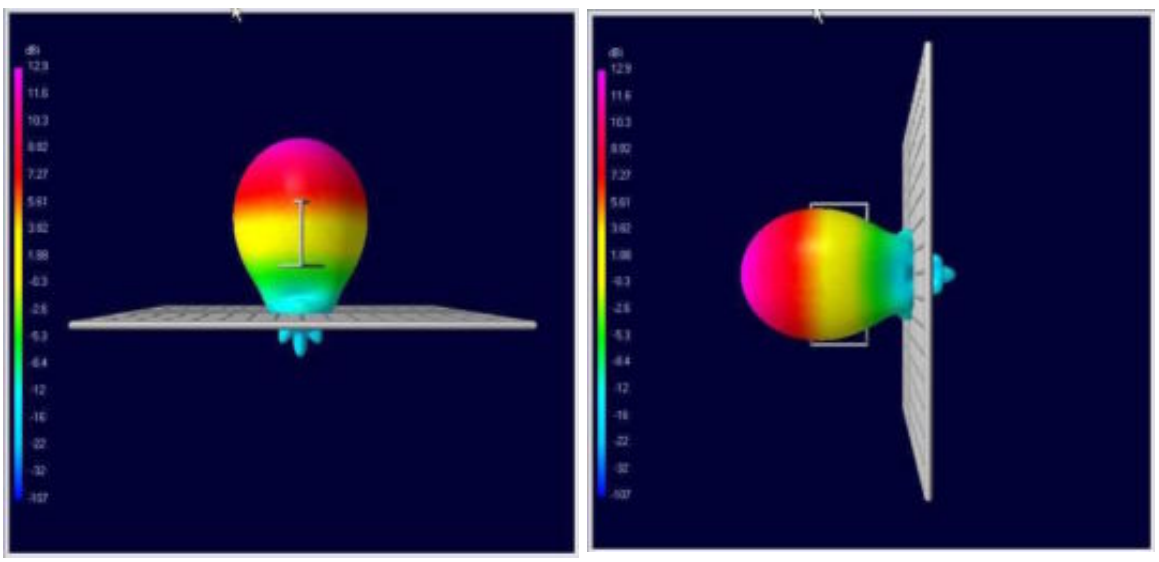

Fig. 7. Horizontal and vertical diagram of 2-element bi-quad feed

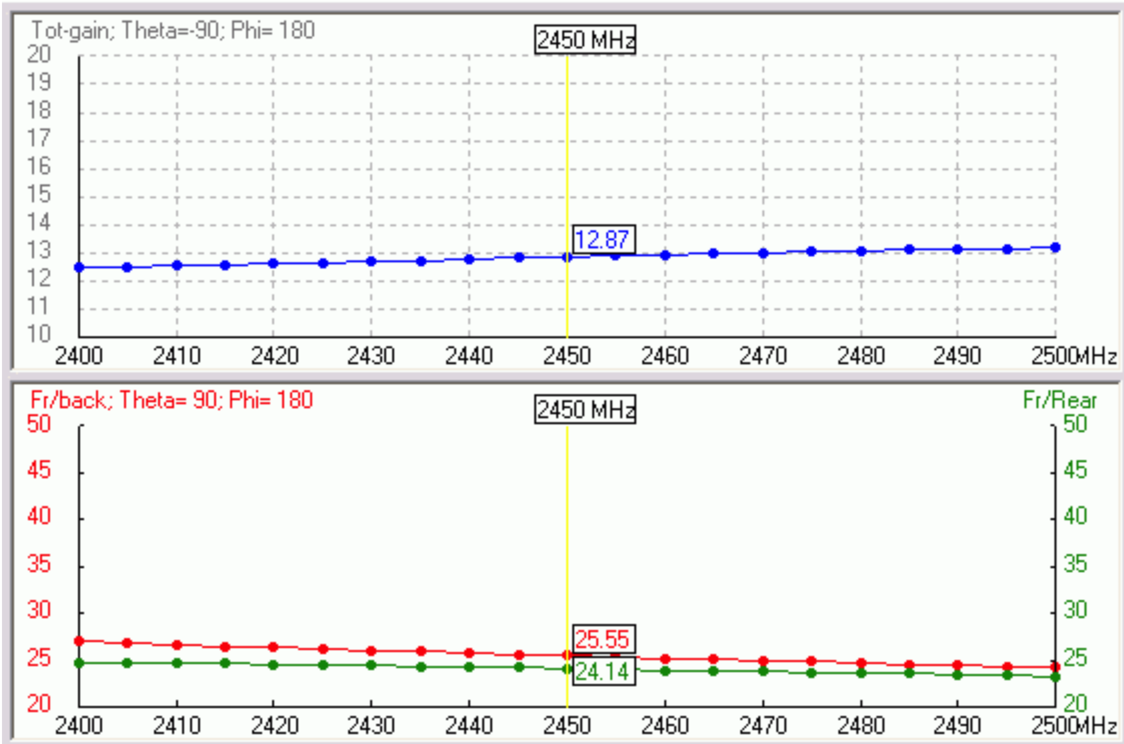

Fig. 8. Gain, F/B and F/R of 2 el. bi-quad feed for different frequencies

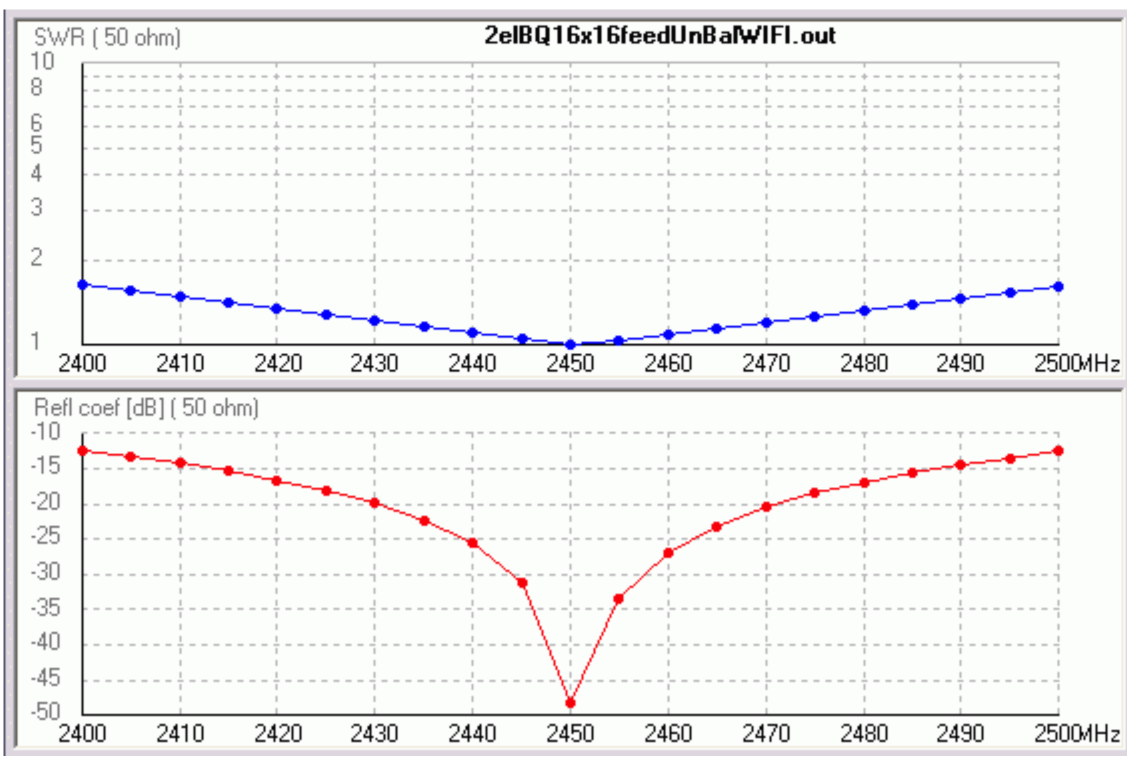

Fig. 9. SWR and Reflection coefficient of 2 el. bi-quad feed for different frequencies

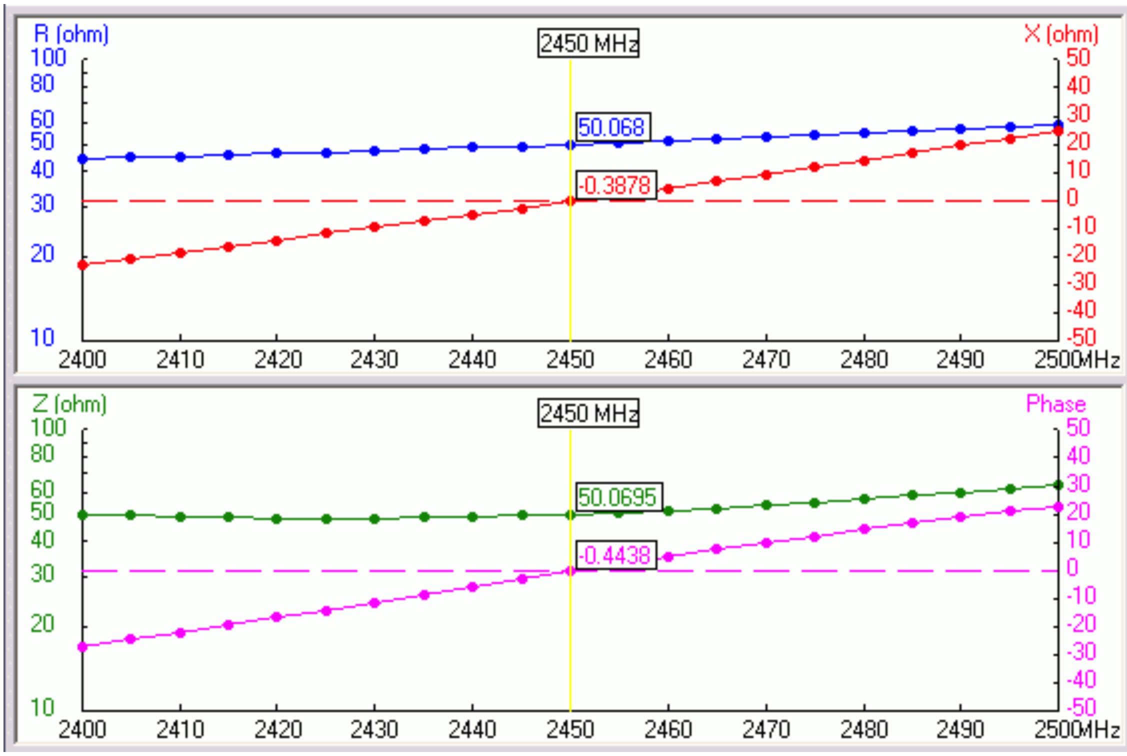

Fig. 10. Input impedance of 2 el. bi-quad feed for different frequencies

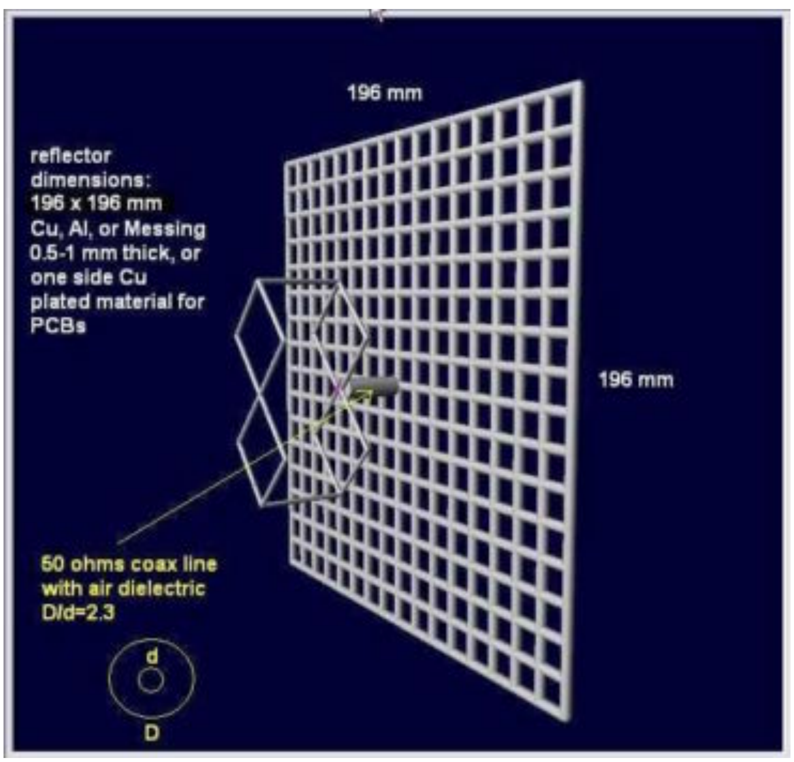

Fig. 11. Look-out of 2 el. bi-quad feed with reflector dimensions

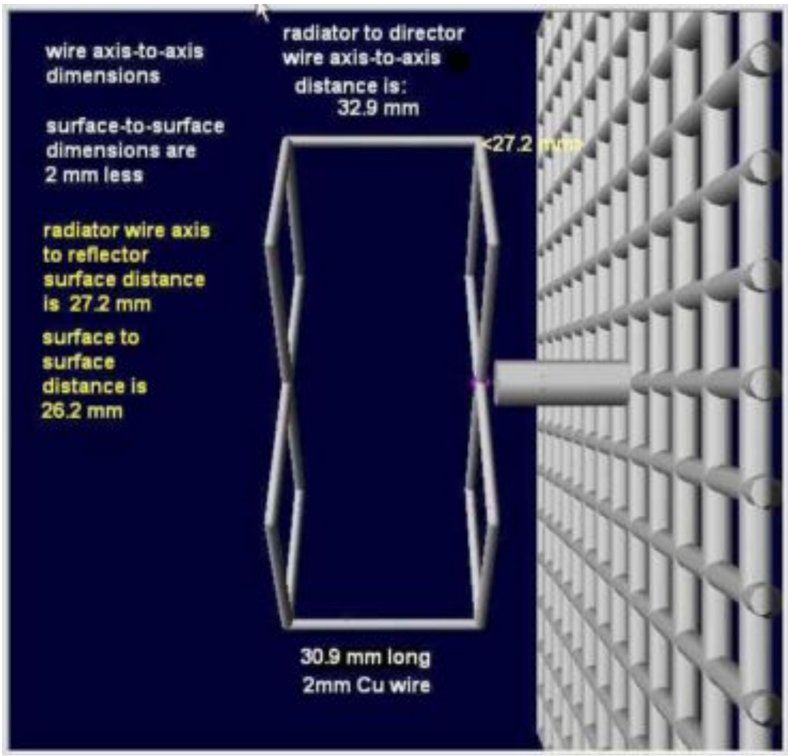

Fig. 12. Distances between elements

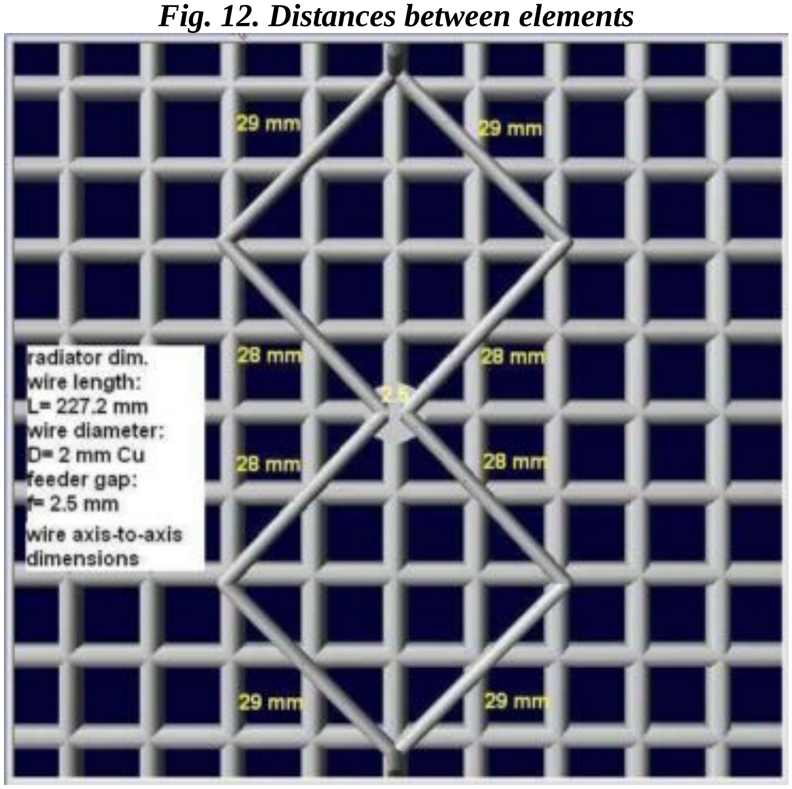

Fig. 13. Radiator element dimensions

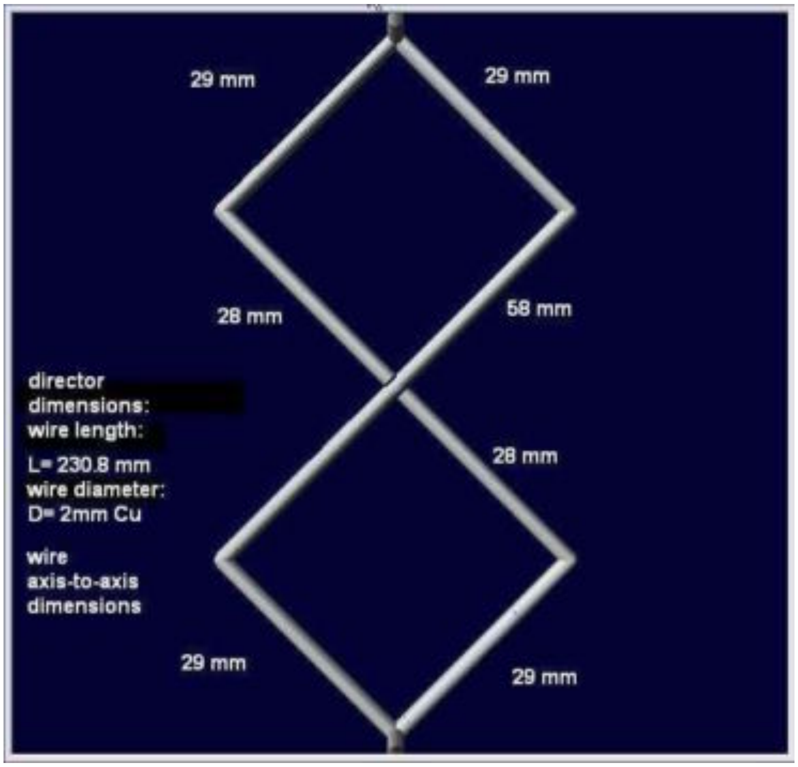

Fig. 14. Director element dimensions

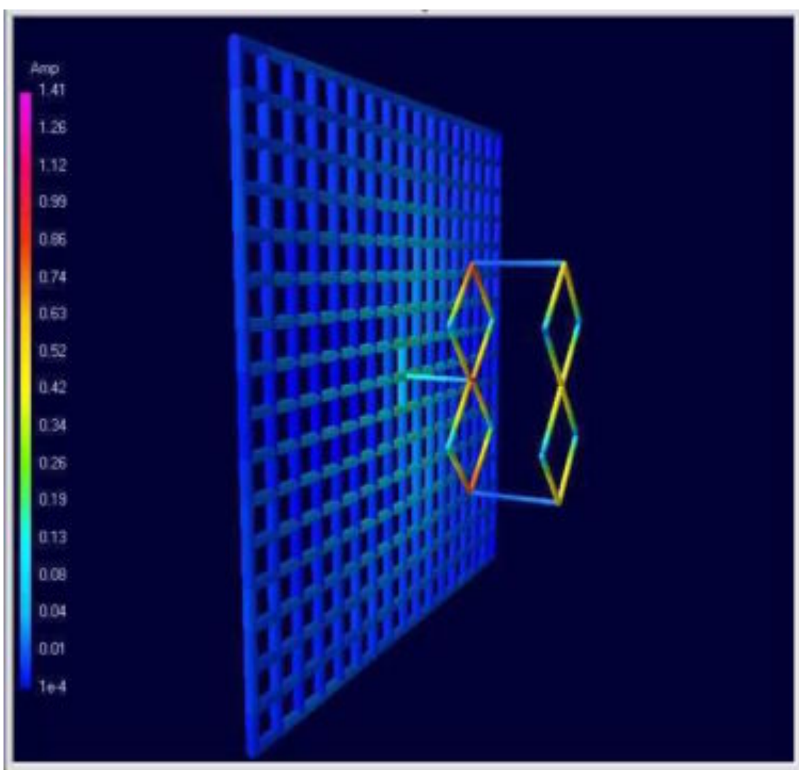

Fig. 15. Currents in 2 el. bi-quad feed with 100 W power input

Mechanical construction of the antenna

The radiator and director are made of two pieces of copper wire, with a diameter 2-2.3 mm and a total length of 227.2 mm for the radiator and 230.8 mm for the director. Each piece of wire is folded in a little different way, as shown in pictures. The radiator is folded as in a common bi-quad, i.e., in the way that the ends of the wire come in the center of the element and join perpendicularly. The director is folded as one usually writes number 8, i.e. in the way that the ends of the wire come in the center from the same course but from the different aim, i.e., under the angle of 180 degrees. Before bending, one should measure and cut off very precisely the needed length of wire, and then measure and mark spots where the wire will be folded perpendicularly.

Director wire ends are soldered together in the center of figure-8 shaped director element. Reflector surface may be made of copper or brass tin. It is possible to use one-sided copper clad epoxy substrate for PCBs. Two carriers (or supports) of the director element, length 30.9 mm, are also made of copper wire, diameter 2 mm. They are soldered directly to the elements, as shown in picture. This solution made building easier and ensured good mechanical stability of the whole antenna.

It is important to keep in mind that dimensions in the pictures are given from axis to axis of wires! Dimensions from surface to surface of wire are less by 2 mm! The distance between the radiator and the reflector is given from the axis of wire to the reflector surface! From the surface of the radiator wire to the surface of reflector, the distance is less by 1 mm, i.e. 26.2 mm! In the same way, wires that connect the radiator and the director are given as the axis distance of these two-elements. To reach this distance, the wires that connect them have to be cut off shorter for 2 mm, i.e. 30.9 mm!

Feeding

Feeding the bi-quad can be accomplished in several ways. The radiator can be installed to a coaxial cable made of copper wire and a small copper or brass tube, whose diameters are in approximately ratio 1:2.3 to give a 50-ohm characteristic impedance. For example, standard copper wire with a diameter of 2.3 mm and a copper tube with inner diameter 5 mm work well. The 5.5 mm diameter hole is drilled on the reflector and the tube is soldered well to the reflector around whole circumference on the front side of the reflector**.** The wire that will be the central coax conductor and that is connected to the radiator should be soldered to the connector, and then the connector is soldered or screwed to the backside of the reflector.

Also, instead of complete air coax, one can solder only the tube through which coax cable without its outer plastic jacket comes in tightly, so that outer conductor rests tightly to the inner wall of the tube. After that, the braid is soldered well to the both sides of the tube. If you use cable with larger diameter that is stiff enough, or semi-rigid cable, only the end of the cable without its outer plastic jacket can be pulled through reflector and soldered to the reflector surface at the place where the cable passes through the reflector.

Protection from atmospheric action

It is best that this protection is done while the copper is still light and corrosion-free and the antenna is covered by thin layer of transparent varnish. Before that, spots where cables are soldered and opened cross sections of cables are protected with 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!** It is wrong to put large amounts of plastic in thick layer to the connection, because the added thickness is useless and serves only to worsen the impedance matching of antenna! Also, the use of silicone is strictly forbidden because of its chemical aggressiveness and great losses at higher frequencies!

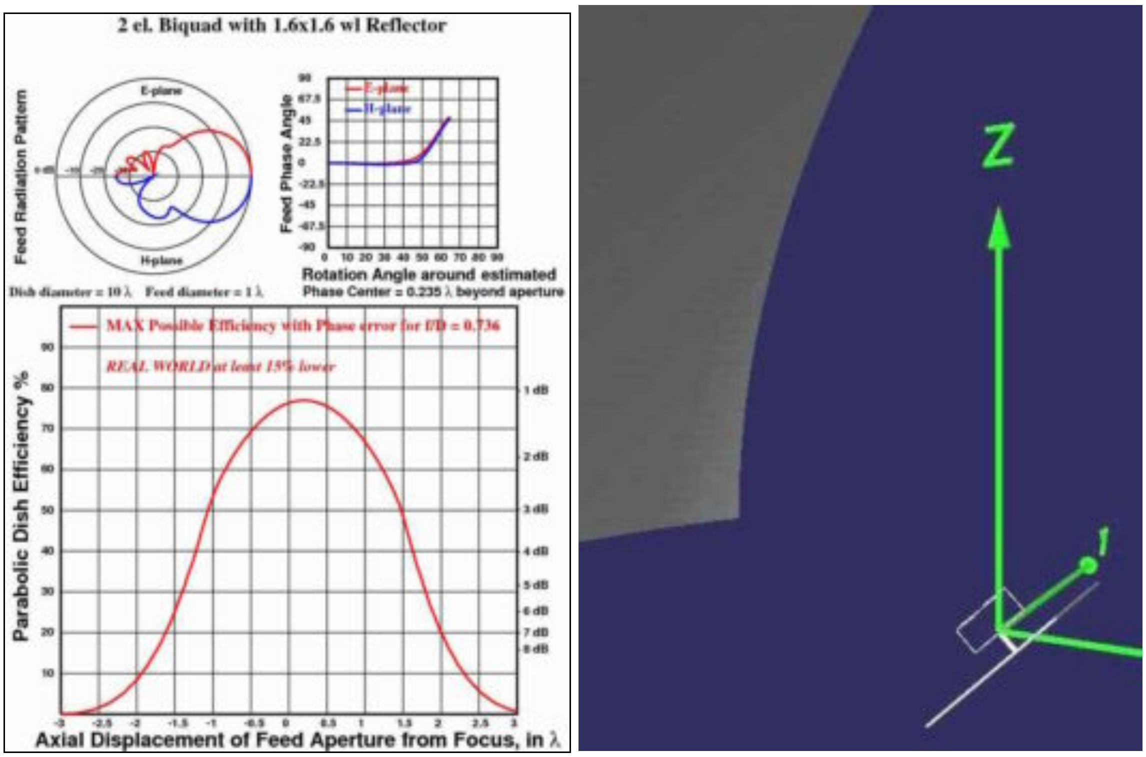

Fig. 16. Two-element bi-quad feed phase center allocation and its position at dish focus point

Placing the feed in the focus of the offset parabola

In the case of the optimal bi-quad, the phase center is in the plane of the reflector. In the case of two-element bi-quad, because the director is added, the phase center is moved towards the radiator. The analysis of the phase center of two-element bi-quad revealed that it is positioned 0.235 wavelengths or 29 mm in front of the reflector. That means that, approximately, the feeding point of the radiator is the phase center of two-element bi-quad. That point must be placed in the focus 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 offset parabola.

When SAT TV offset parabolas are used, focus is determined by the position of the SAT TV converter. 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 that case that, after the correction of the feed carrier, the position of the parabola's focus is lost and it can not be restored if there is no information, i.e. space coordinates in relation to parabolic surface.

Results with offset parabola

We achieved very good results by analysis of two-element bi-quad as feed of rectangle shaped offset parabola, with dimensions 100x120 cm and F/D=0.75. We confirmed very high efficiency on the basis of achieved gain of parabolic antenna in relation to theoretic value. The calculation of the efficiency of illumination of parabola from its gain gave the value of about 77%, which well coincides with calculations of efficiency derived from the shape of the feed diagram given in Figure 18.

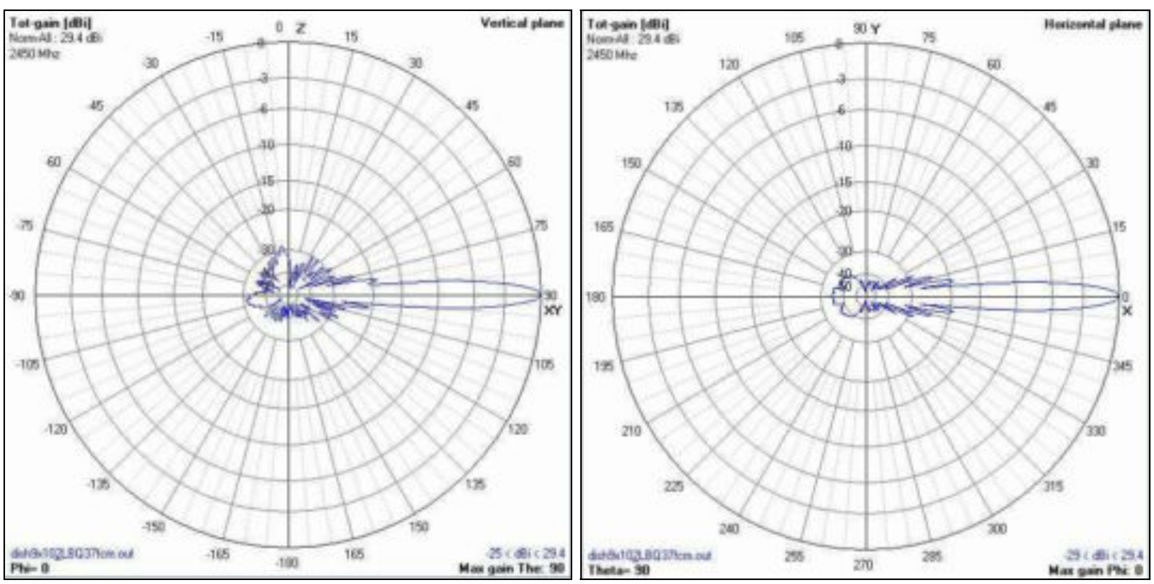

Fig. 17. Vertical and horizontal diagram of offset dish with 2 el. bi-quad feed

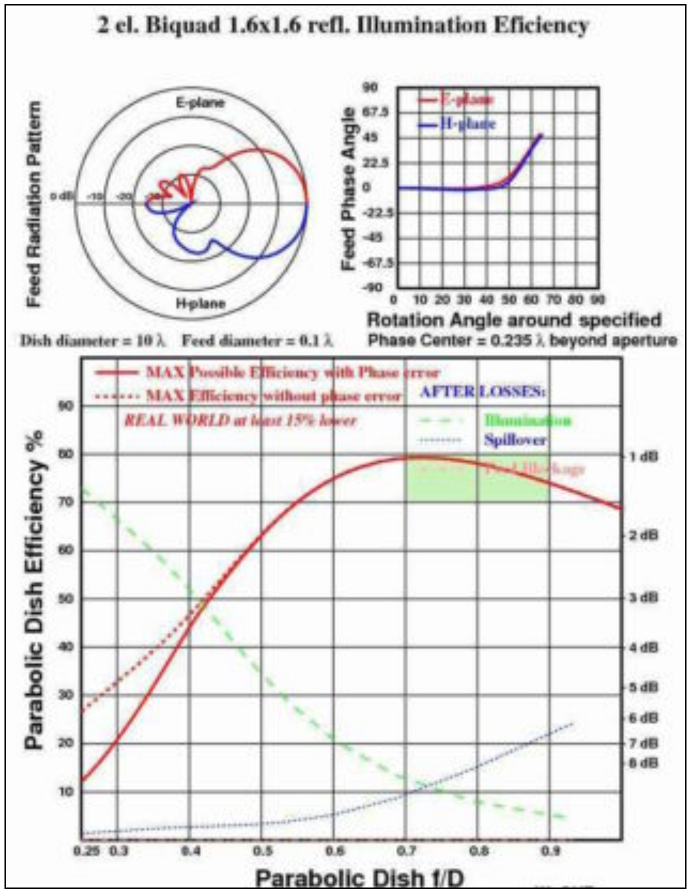

Fig. 18. Efficiency of 2 el. bi-quad feed with parabolas having different F/D ratio

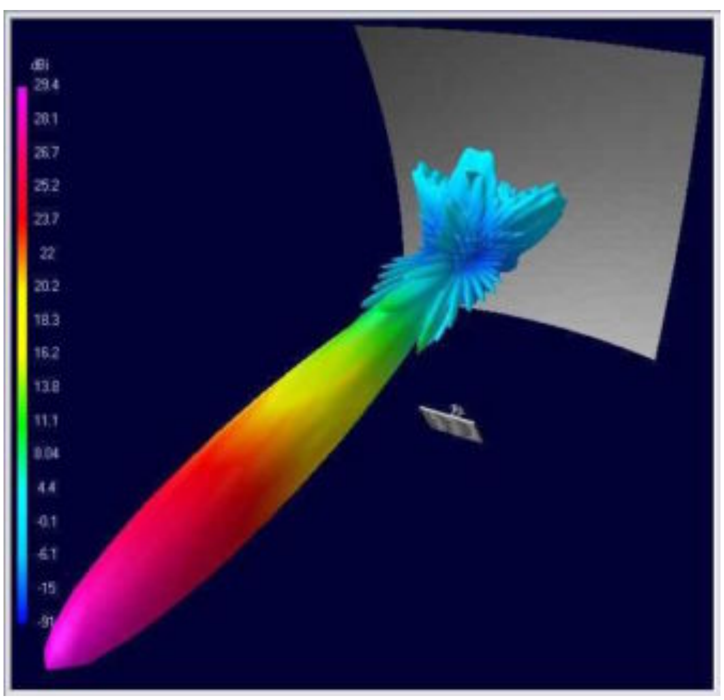

Fig. 19. 3D diagram of offset parabola with 2 el. bi-quad feed

An elliptic parabola with the same dimensions would have a smaller gain by about 1 dB in relation to this analyzed rectangular version, with the same efficiency, because of the somewhat smaller geometric surface of elliptic parabola. Another confirmation that this is a very good feed is the purity of achieved radiant diagram of parabola. First side lobes are suppressed by about 20 dB and the front to back ratio is about 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 axis of bi-quad, i.e. maximum of radiant diagram of the main beam is aimed directly into the geometric center of parabolic surface that is in the crosshair of the large and small axes of the ellipse. The input impedance of bi-quad remained practically unchanged when placed in focus of parabola, which was expected from this antenna that is known by its relatively low Q factor.

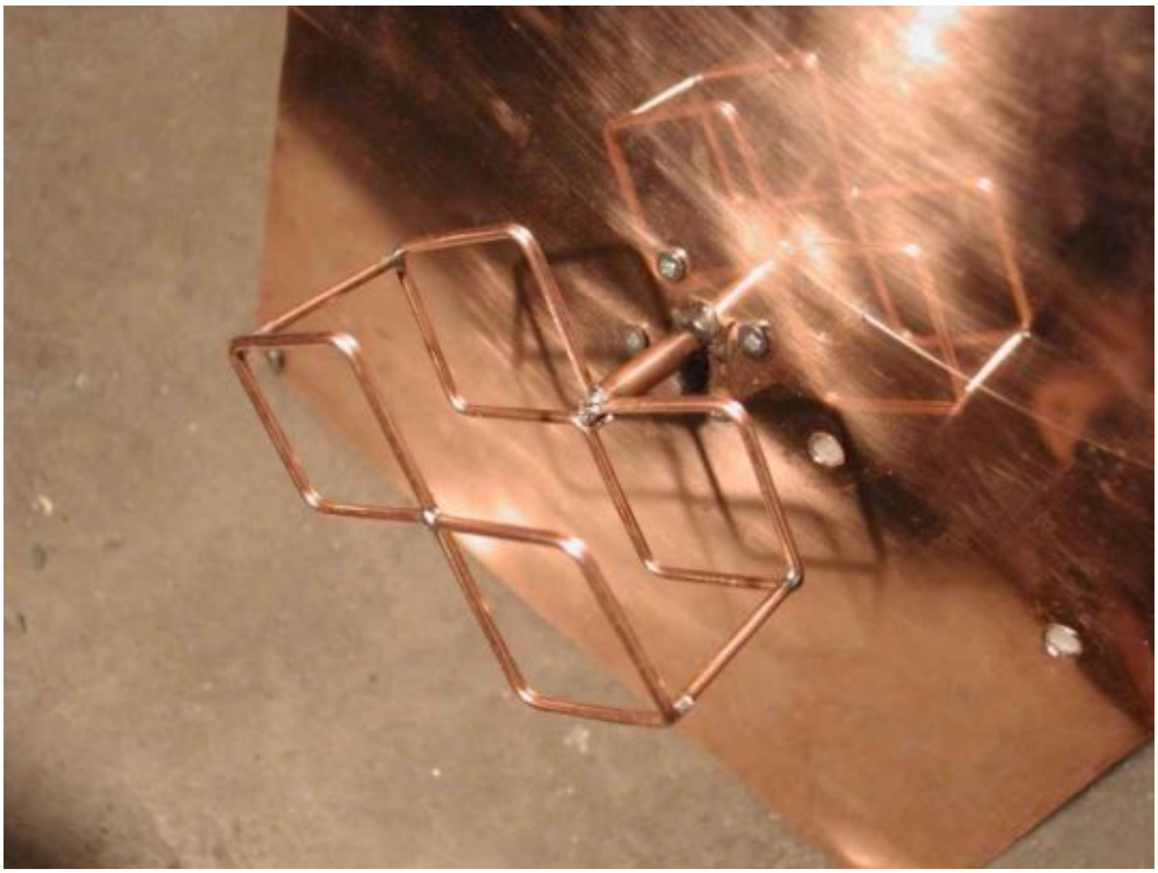

Fig. 20. Outlook of built 2 el. bi-quad feed antenna

Fig. 21. Feeding of 2 el. bi-quad feed antenna

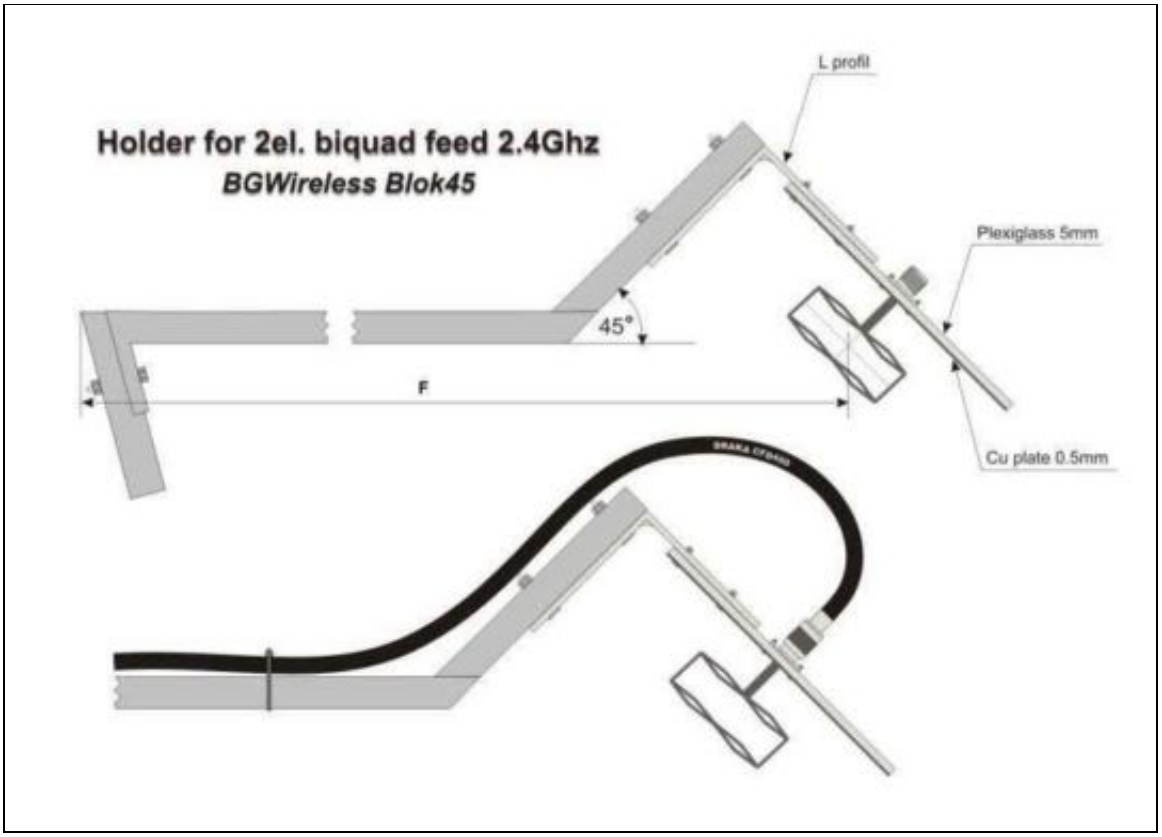

Fig. 22. Example of holder for 2 el. bi-quad feed antenna

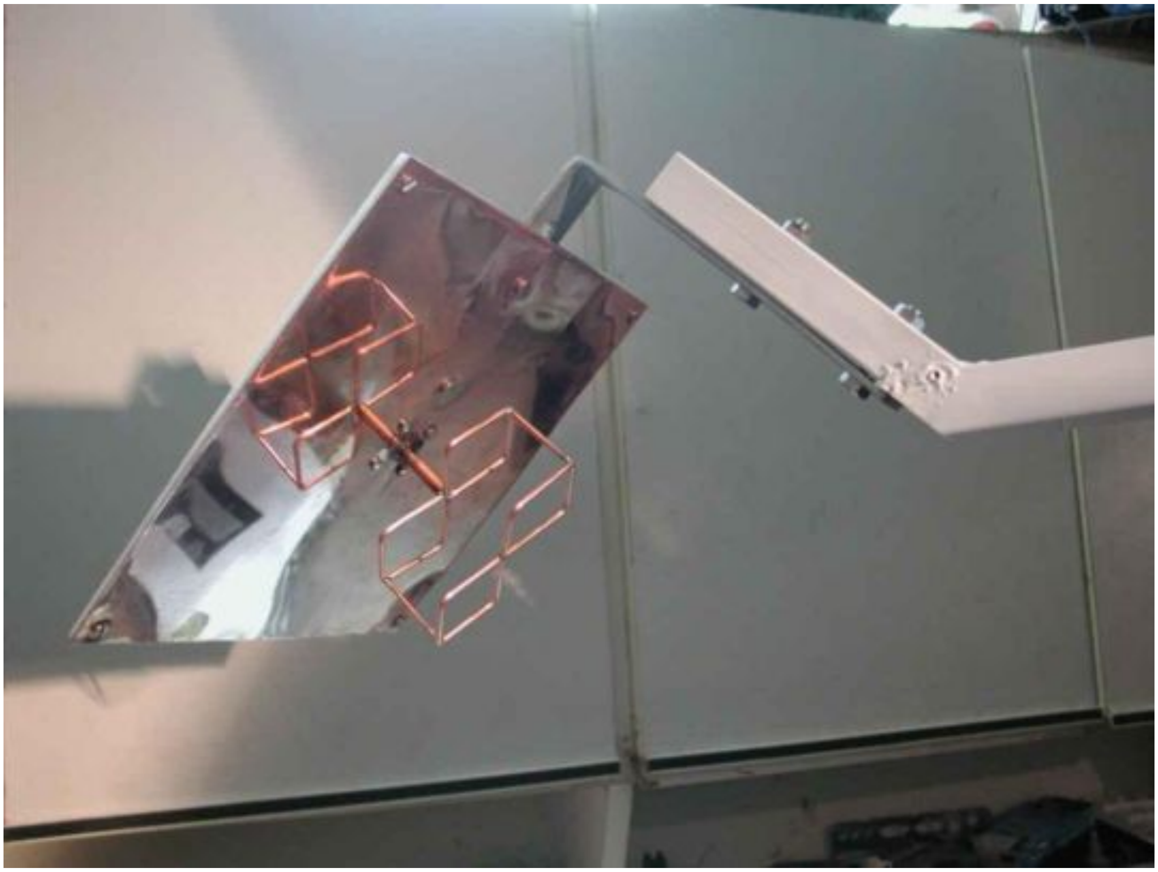

Fig. 23. Two-elements bi-quad feed antenna on its carrier

Fig. 24. Offset dish with 2 el. bi-quad feed antenna

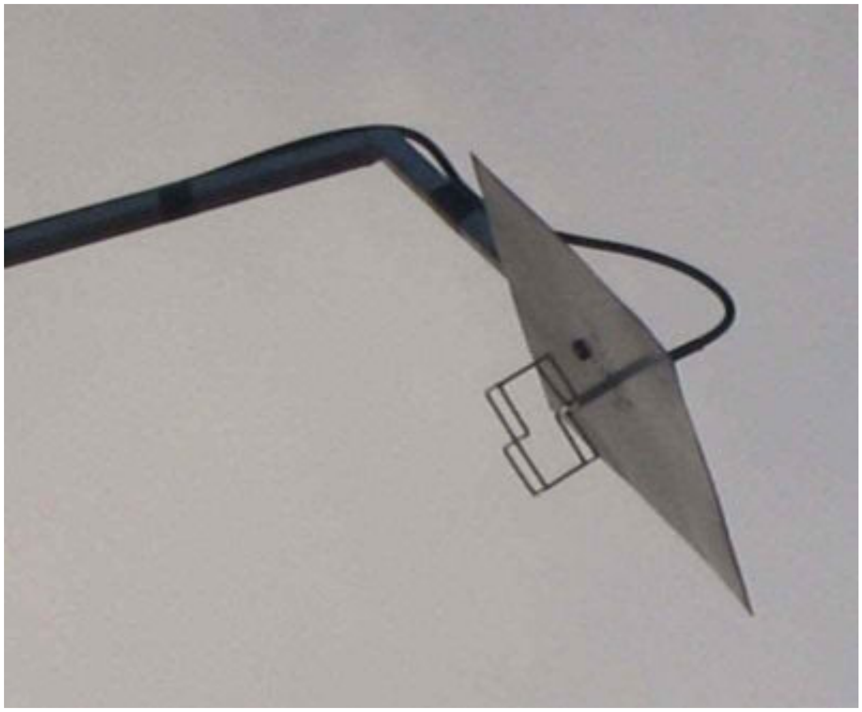

Fig. 25. Close-up view of 2 el. bi-quad feed antenna mounted on carrier

Conclusion

In this article we showed and, by precise computer simulations [6] and practical measurements, confirmed the possibility of using a two-element bi-quad for efficient illumination SAT TV offset parabolic mirror. The very pure and symmetrical diagram of two-element bi-quad, with equal width of the main beam in both planes, proved to be a very efficient feed for offset parabolic antennas whose F/D is 0.7-0.9. **-30-**

Literature

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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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