Shortened 3D Corner Reflector Antenna

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Abstract

In this text two 3D corner reflector antenna modifications are described.
The first modification is regarding the input impedance decrease from about 72 ohms of the original antenna, to about 50 ohms, which made possible supplying with usual coaxial cables of 50 ohms impedance. This is achieved by adding a passive element to the existing active element. This decreased impedance while retaining antenna's gain and its radiation diagram.
The second modification is regarding the alteration of the shape of the antenna by removing one piece of the bottom reflector surface. The result of this is smaller and more compact antenna with smaller resistance to the wind and accumulation of the snow, with very small change of radiation diagram and gain decrease of about 0.25 dB.
The practical solution of the construction of Shortened 3D Corner Reflector Antenna for 2.4 GHz is given at the end of the text.

Introduction

The original design of 3D Corner Reflector Antenna was for the first time described in: IEEE Transactions on Antennas and Propagation, July, 1974. "Three-Dimensional Corner Reflector Array" by Naoki Inagaki (pp. 580-582).
The precise and explicit results of computer analysis and simulation were reported in July 2003. by L.B. Cebik W4RNL in the article: “The 3-D Corner Reflector” (www.cebik.com/vhf/3c.html).

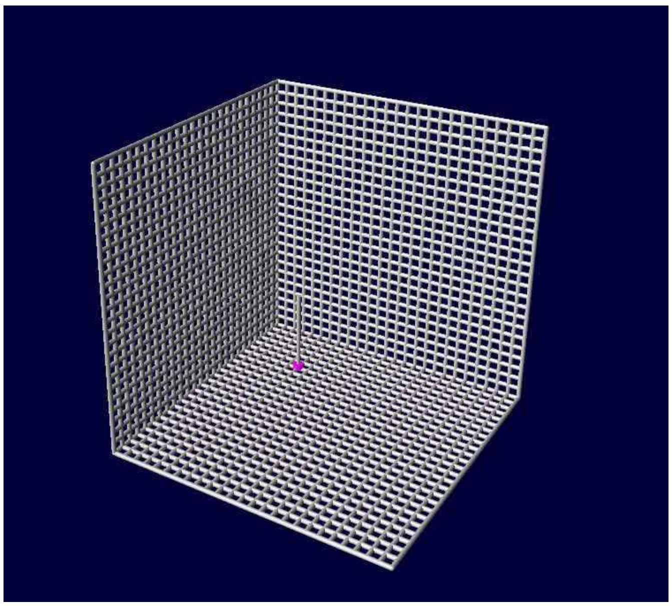

Fig. 1. Original 3D Corner Reflector Antenna.

The antenna consists of three square reflector surfaces placed among each other perpendicularly to form half of the cube, and with the active element in the form of monopole at one of them, as shown in figure 1. This structure concentrates electromagnetic energy in relatively narrow beam, whose direction of maximum radiation is in the line with the large diagonal of the cube, which begins in the apex, i.e. under angle of 45 degrees between the beam and all three reflector surfaces.
The reflector surfaces' dimensions are not critical. With the enlargement of the surfaces, antenna gain also increases, at first considerably and later on less and less.
Our analyses revealed that the practical maximum of the gain is achieved before we expected so far.
The optimal dimension is about 2.8 wavelengths. Further dimension enlargement leads to more and more insignificant increase of the gain of the antenna, and for 3-3.5 wavelengths the practical gain maximum is achieved. Further enlargement of reflector surfaces has no meaning, because it does not lead to the gain increase, as shown in the figure 2.

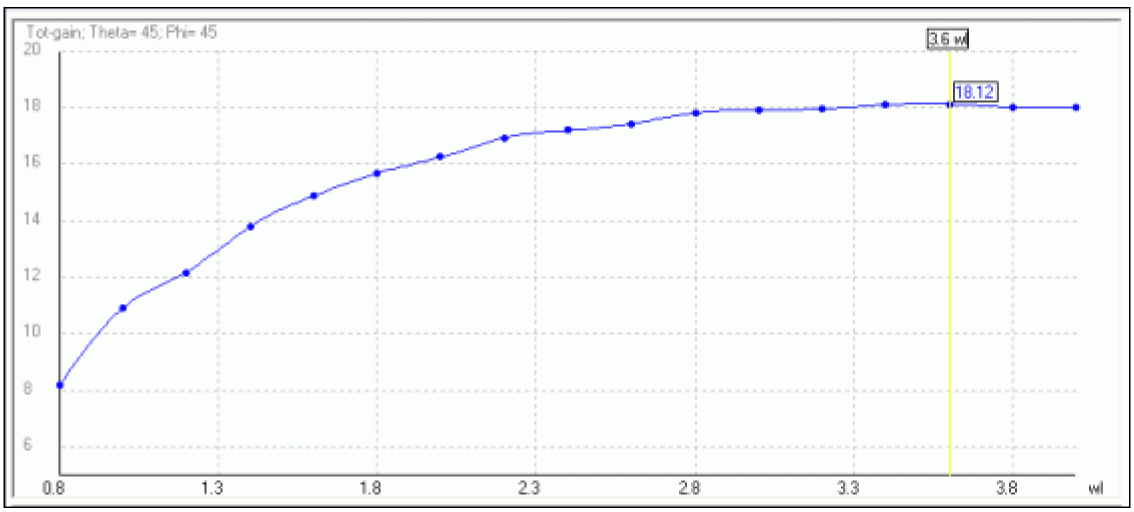

Fig. 2. Original 3D Corner Reflector Antenna gain with 0.8 to 4 wavelengths reflectors length.

Reflector surfaces can be made of full material, such as aluminum, copper or brass tin. At lower frequencies they can be made of metal wire grid, whose density must be determined in the way that the opening, measured parallel with the polarization plane, i.e. with the active element plane, has to be less than 0.1 wavelengths.
The thing that makes this antenna outstanding are its unique simplicity and design that is very tolerant to the errors in dimensions, which guarantees great reproducibility of practical results and the possibility of its use, along with recalculating its dimensions, at frequencies from couple of tens of MHz to several GHz.
Another good quality of this antenna is that it has excellent side lobe suppression, which makes it a very good choice when the noise and interference from the signals from other directions have to be pushed out as much as possible.

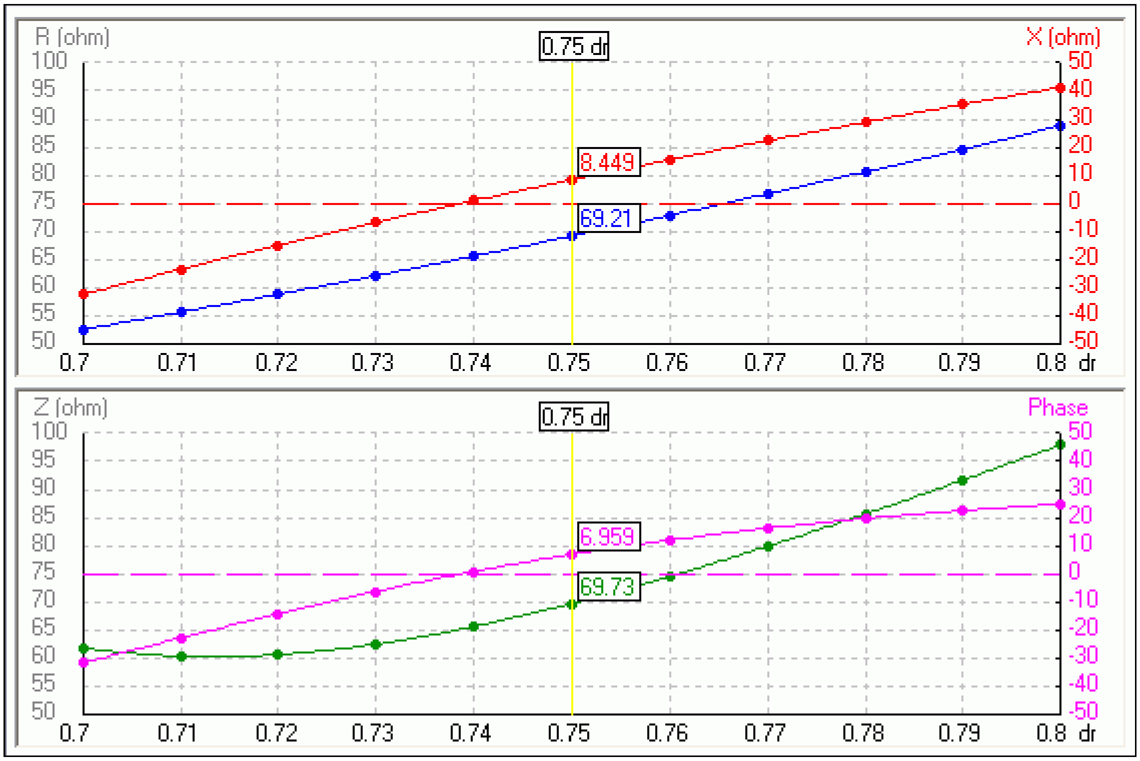

Fig. 3. Original antenna input impedance change with change of active element DR length in wavelengths.

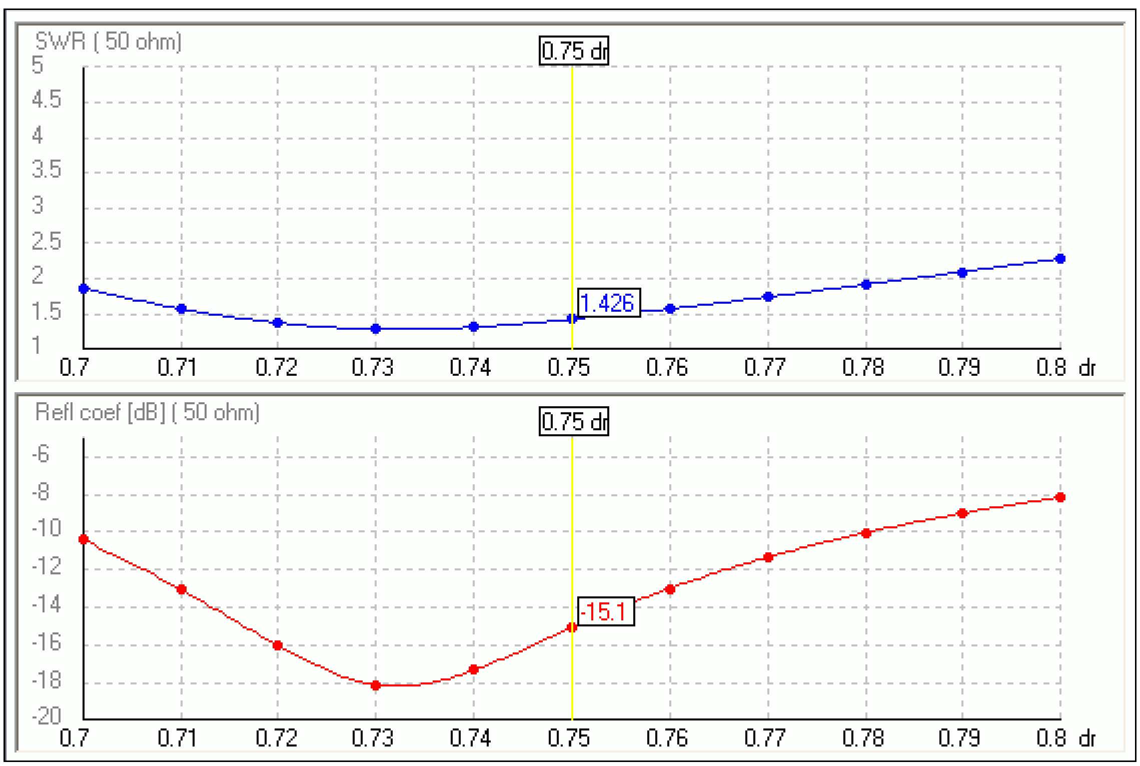

Fig. 4. Original antenna input matching with change of active element DR length in wavelengths.

The only disadvantage of the original version of this antenna is its input impedance. Regarding its position between three orthogonal planes, the input impedance of the active monopole changes with its position and length. In the same time, with these changes, the gain of the antenna also changes.

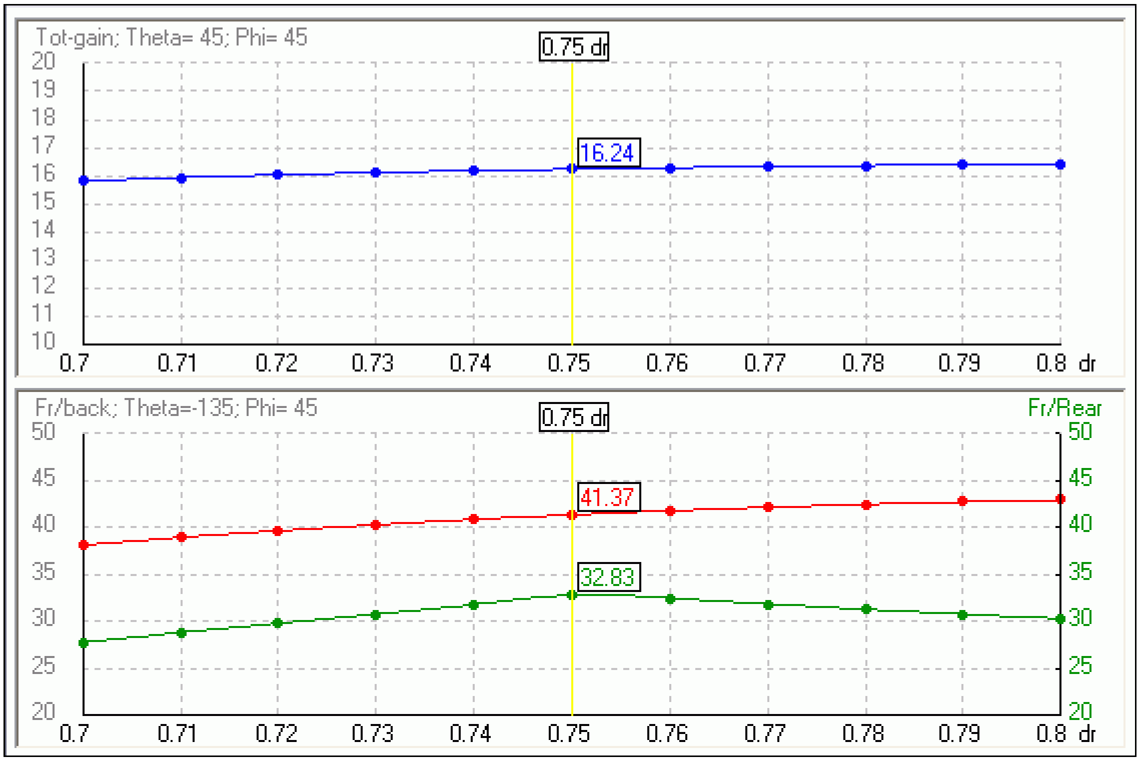

Fig. 5. Original antenna gain and side lobes suppression with change of active element DR length in wavelengths.

The change of the input impedance and 50 ohms matching of the original antenna with the change of the length of the active monopole is shown in the figure 3 and 4.

The gain maximum is reached with the position of the active element at about x=0.6 and y=0.6 wavelengths measured from apex, and with the optimal length of DR=0.75 wavelengths measured from the reflector surface. In that case, input impedance is about 72 ohms when the antenna is in resonance, which leads to minimal SWR of about 1.4 for matching on 50 ohms. This SWR is acceptable at lower frequencies where the losses in cables are small, but at UHF and SHF band it becomes unacceptable, because the losses in cables due to SWR are considerable. The alternative is supplying the antenna with 75 ohms cable, which decreases the losses, but the problem of adequate matching to TX/RX devices intended for working with the 50 ohms impedance remains.

The change of the gain of the original 3D corner antenna with the reflector of 2 wavelengths, depending on the length of the active element DR expressed in wavelengths, is shown in figure 5.

The working band width of the original antenna, i.e. the change of the input impedance with the change of the working frequency in the band from -10% to +10% of the resonant frequency, is shown in figure 6.

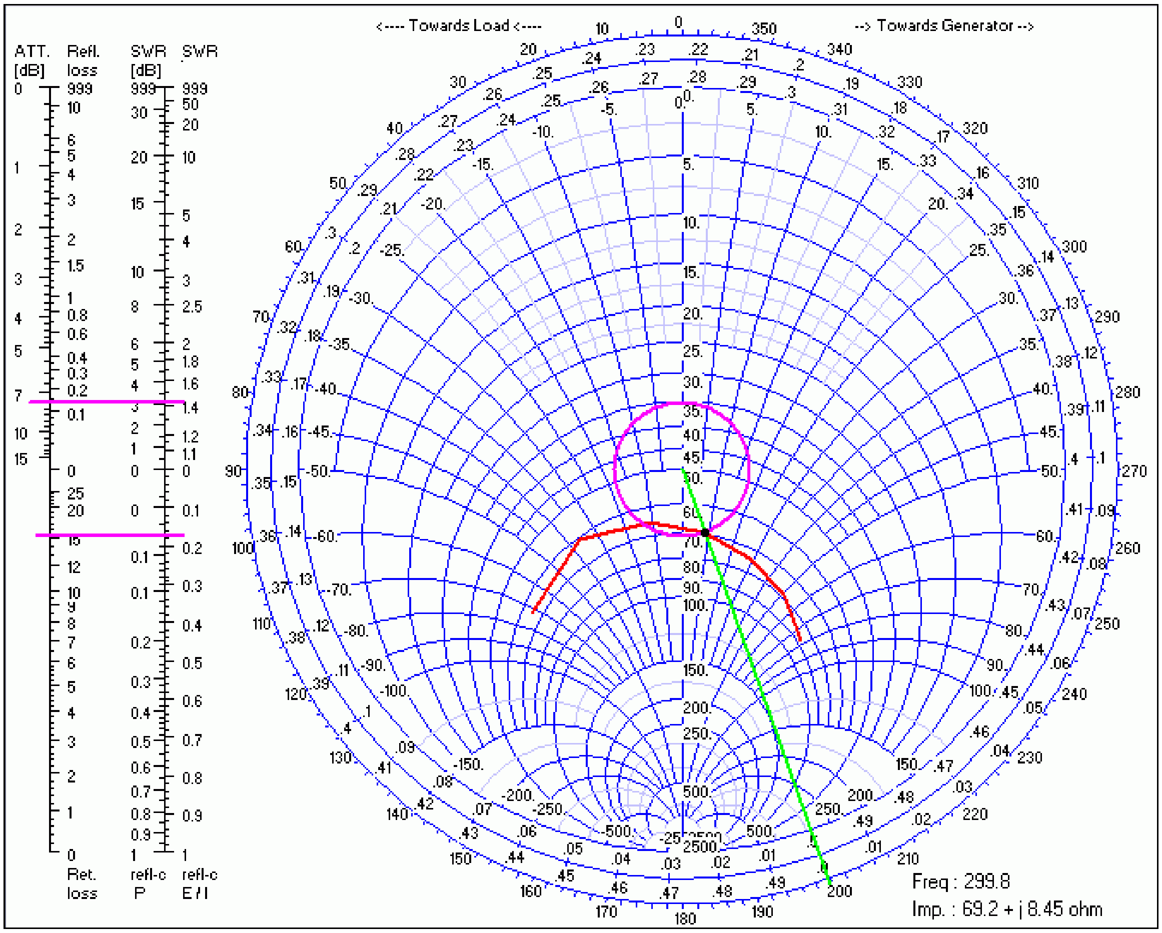

Fig. 6. 3D Corner Reflector Antenna input impedance change with change of working frequency +/- 10% from resonance.

Modification of the input impedance of the antenna

At first glance it was clear that it would be good if we could adjust this exceptional antenna in that way, from 72 to about 50 ohms, in order to match it to 50 ohms coaxial cable.

The first thing that could be considered was adding one passive element whose impact on the active element would be adjusted in the way to decrease the input impedance to 50 ohms. This attempt, of course, included maximal conservation of the existing good properties of the antenna.

For that job the best available programs for analysis needed to be used, because most of the programs for antenna analysis show the lowest accuracy in calculating input impedance. In addition, this is the case of so called aperture (surface) antenna that works mainly by using the laws of geometric optics, so it was needed to choose good program in simulating the aperture antennas. The famous professional program for simulating antennas NEC-2 was chosen with its derivative 4nec2, whose author is Arie Voors.

After completing analyses for several different position and element length variants, finally, one solution relieved: the solution with additional parasitic element DI which

would be positioned in front of the active element, similarly as the first director in Yagi antennas. Of course, it is only the analogy, because resolving the problem of the input impedance of this antenna is just similar to the solutions in Yagi antennas.
By putting the additional passive element and adjusting its length and distance from the active element, almost ideal matching of 50 ohms was achieved.

Model testing and simulation results

Before the final determination of the positions and the lengths of the elements, we needed to verify the accuracy of the model used to simulate the antennas.
L.B.Cebik's simulation, described in the mentioned article, for original antenna with reflector of 2 wavelengths and monopole of 0.75 wavelengths at position x=0.6 and y=0.6 wavelengths, has gain of 16.19 dBi with input impedance of 71+j7 ohms.

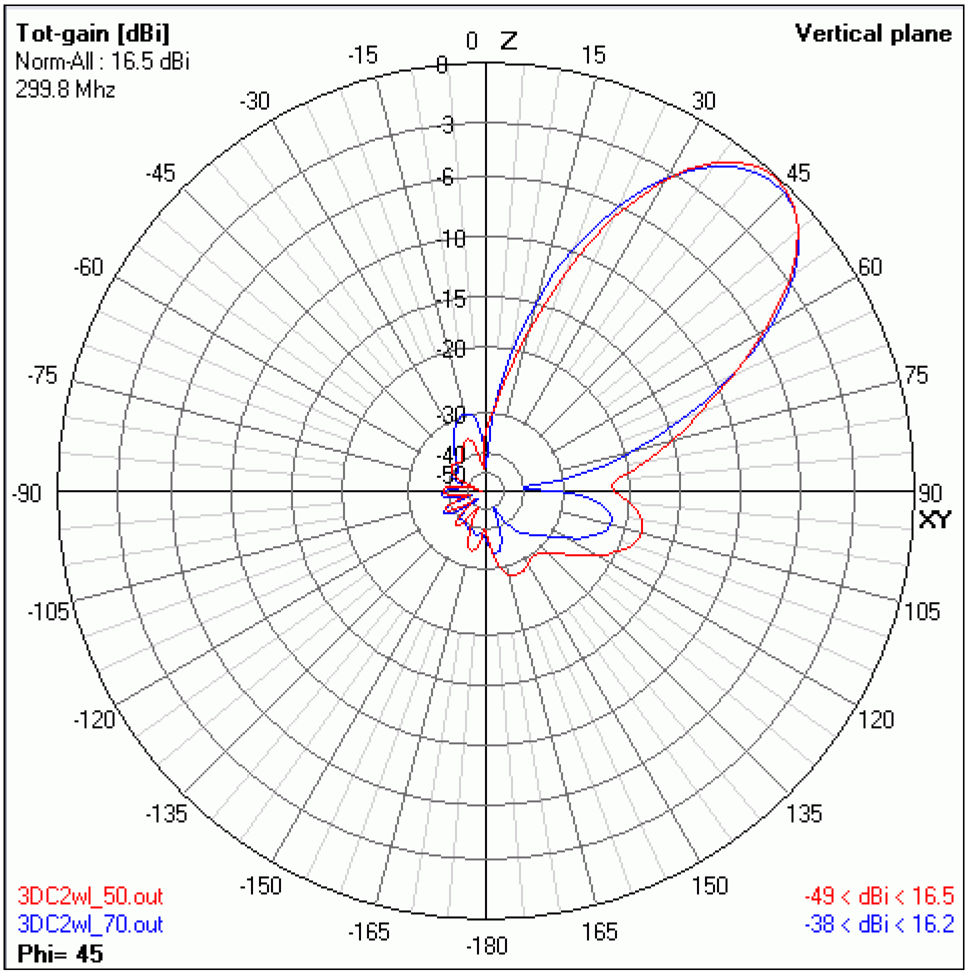

Fig. 7. Vertical diagram of original and modified 3D Corner Reflector Antene with 2 wavelengths reflector length.

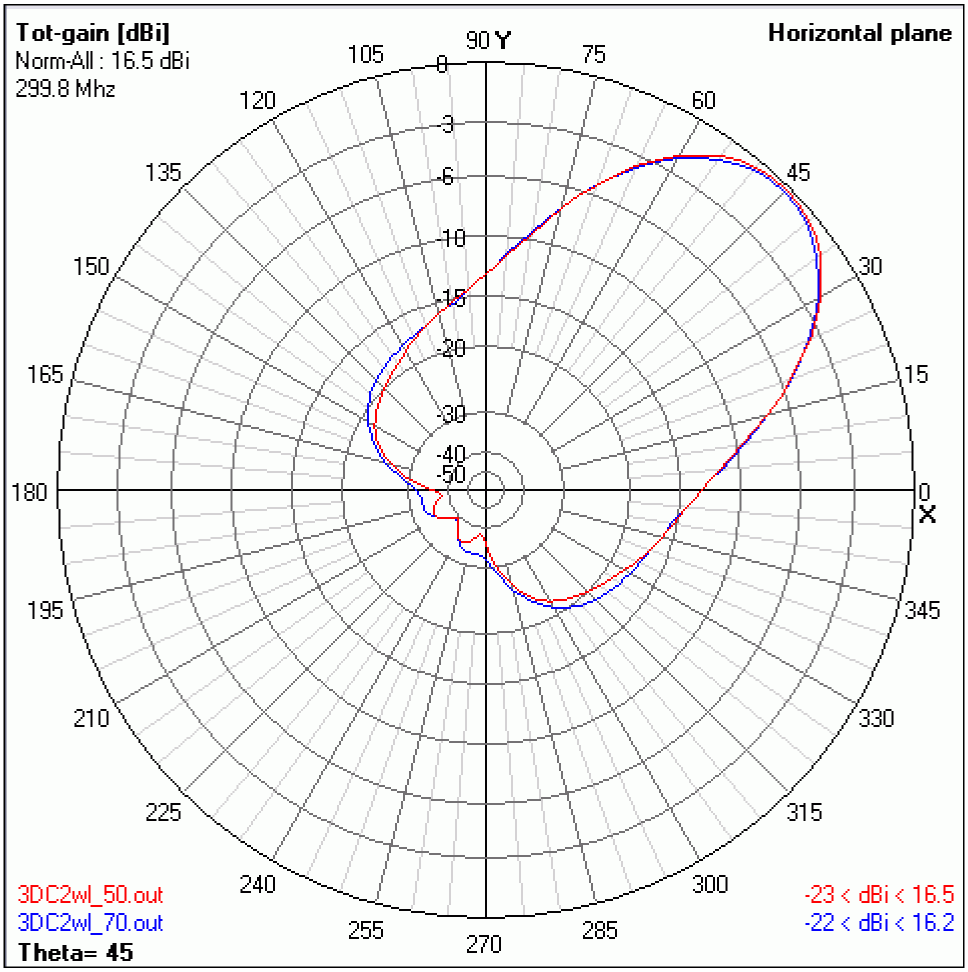

Fig. 8. Horizontal diagram of original and modified 3D Corner Reflector Antene with 2 wavelengths reflector length.

Our simulation for the same antenna exhibited almost identical results of 16.2 dBi with impedance of 69.2+j8.5 ohms! In this way, we compared and tested the accuracy of our model and the simulation in relation to the professional version of the NEC-4 program.
After the verification of the model and the accuracy of the simulation, we simulated modified antenna of 2 wavelengths with additional passive element for impedance adjustment. The gain of modified antenna was 16.46 dBi with input impedance of 49.7+j1.1 ohms, with a slight change of the vertical radiation diagram. The vertical and horizontal radiation diagrams of the original and the modified antennas are shown side by side in figures 7 and 8. As shown in the figure, horizontal radiation diagram remained practically intact. Modified antenna exhibited slightly higher gain in relation to the unmodified, which is the result of the decrease of the radiation resistance of the antenna from 72 to 50 ohms and effect of added passive element.

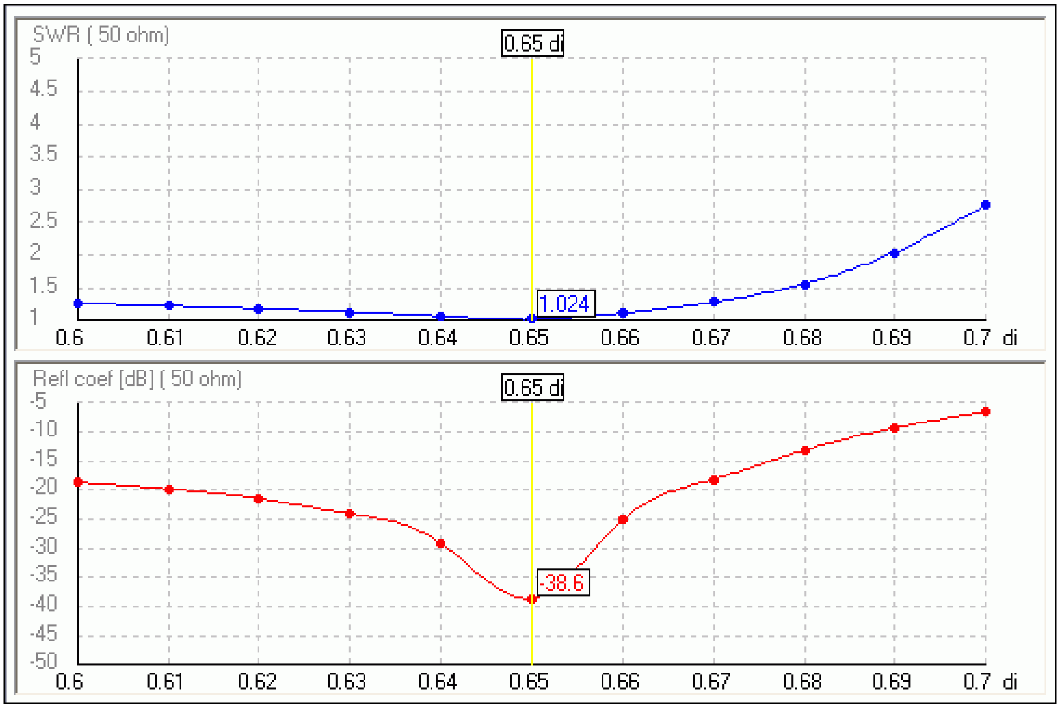

Fig. 9. Modified antenna input matching change with change of passive element DI length and constant length of active element DR=0.75 wavelengths.

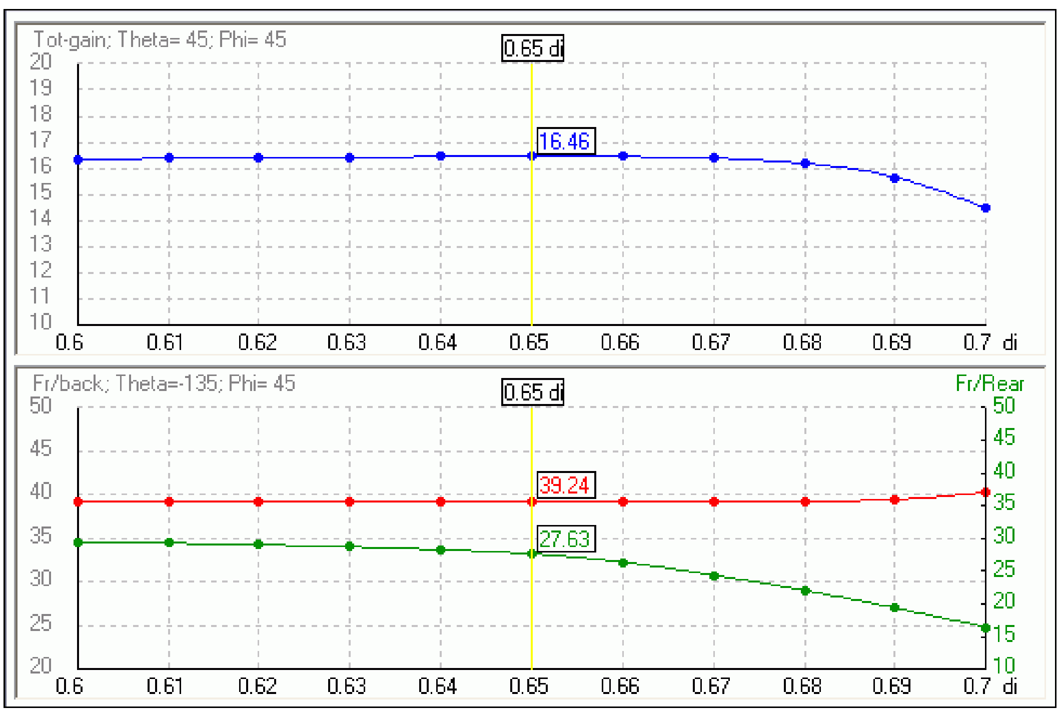

Fig. 10. Modified antenna gain and side lobe suppression with change of passive element DI length and constant length of active element DR=0.75 wavelengths.

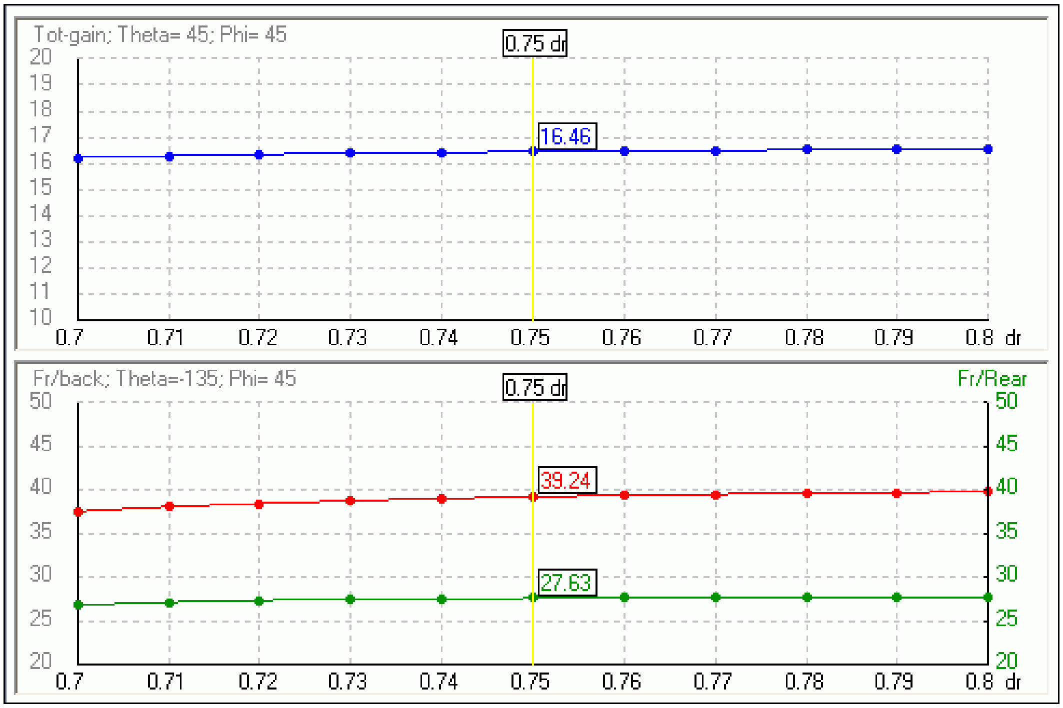

Fig. 11. Modified antenna gain and side lobe suppression with change of active element DR length and constant length of passive element DI=0.65 wavelengths.

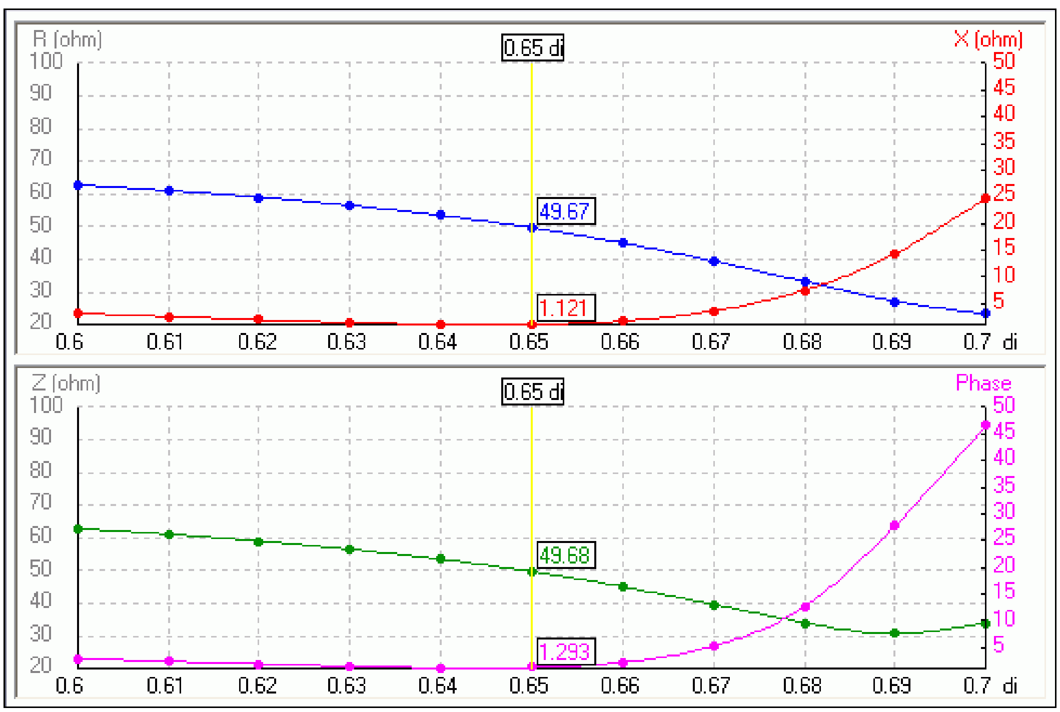

Fig. 12. Modified antenna input impedance change with change of passive element DI length and constant length of active element DR=0.75 wavelengths.

The changes of input impedance and gain of the antenna with only the change of the length of either the passive or the active element, while the other retains the length at which it gave the best results, are given in figures 9, 10, 11 and 12.

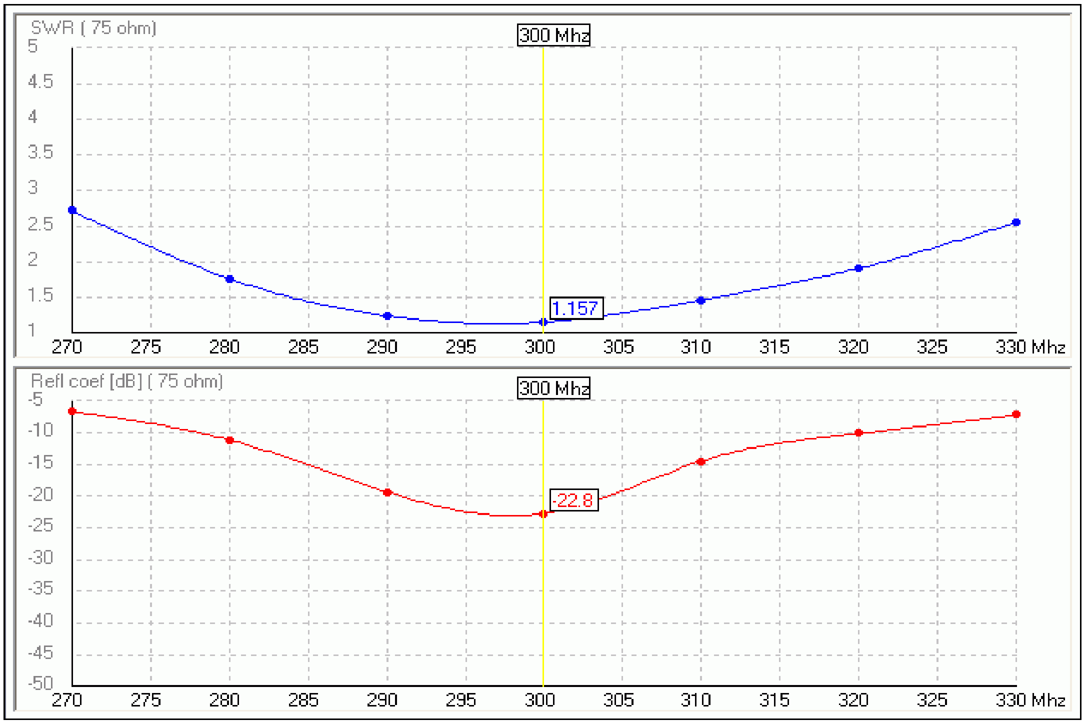

Fig. 13. Input matching and bandwidth of original antenna with 75 ohms feed.

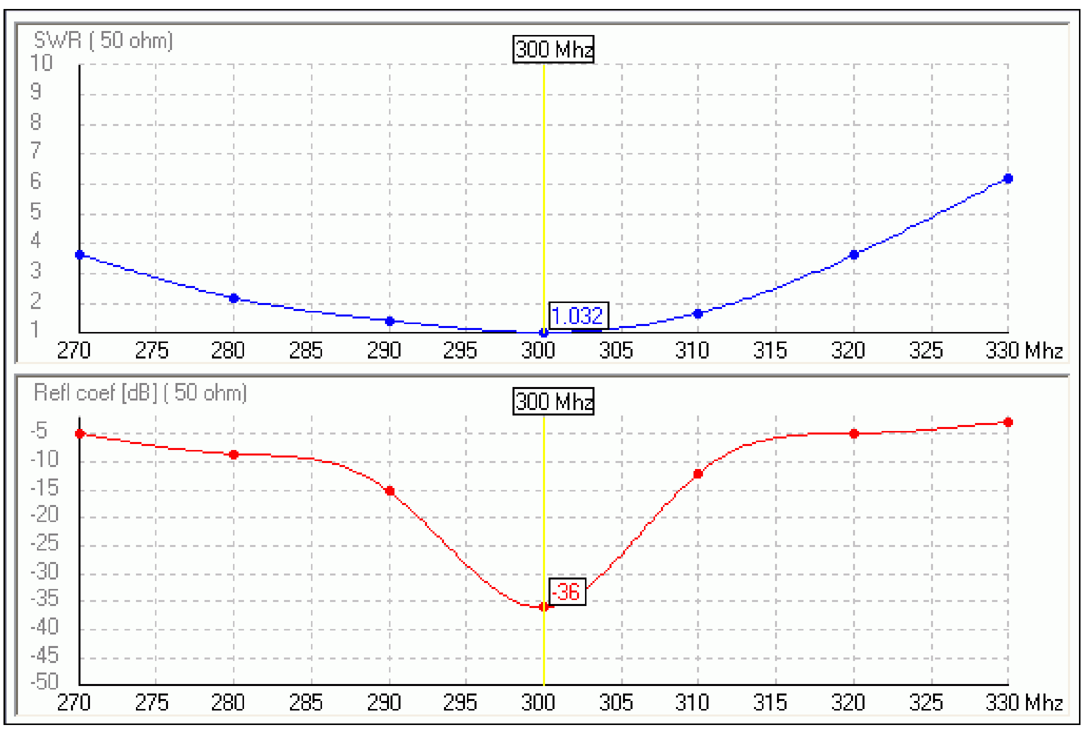

Fig. 14. Input matching and bandwidth of modified antenna with 50 ohms feed.

It became clear that, for the best performances of the antenna, the length of the active element, even after addition of the passive element, should remain unchanged in regard to the original antenna.

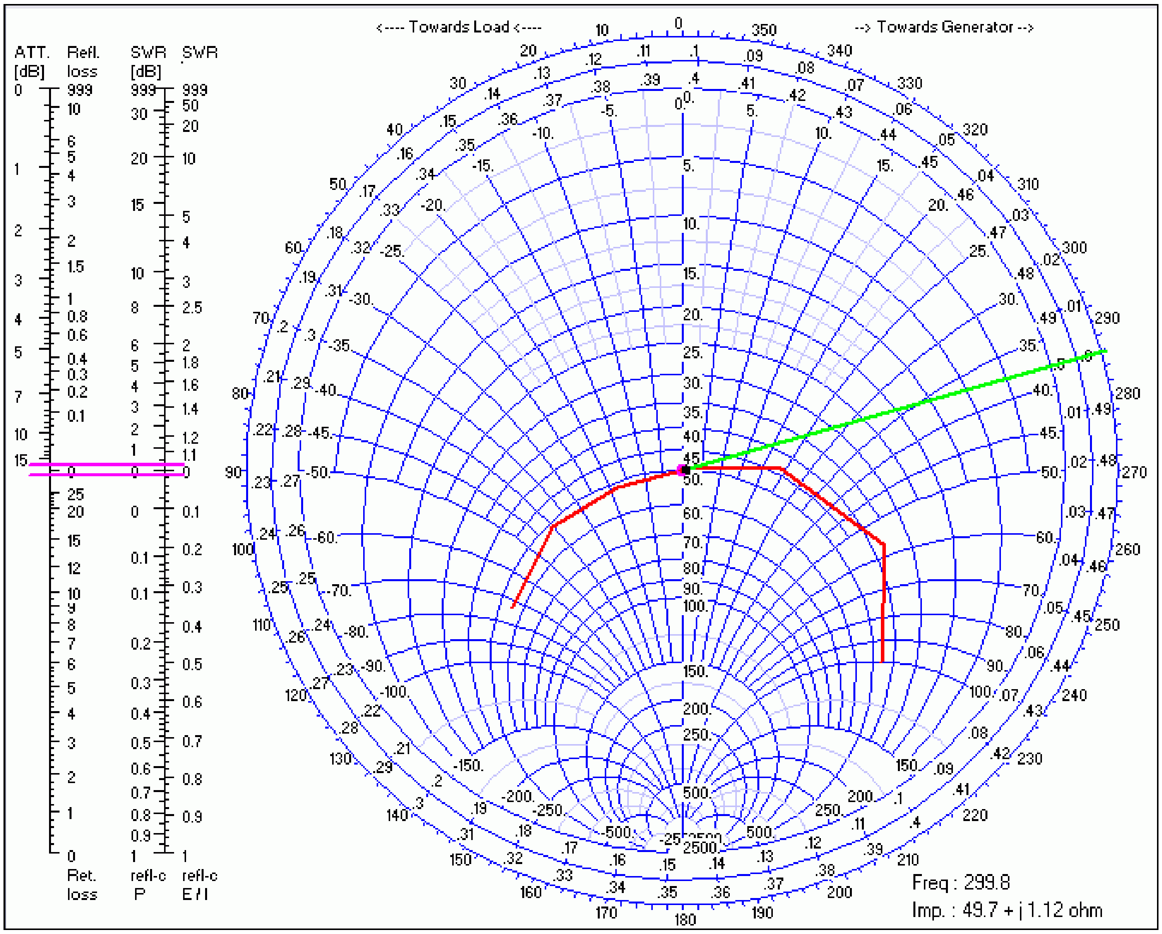

Fig. 15. Modified 3D Corner Reflector Antenna input impedance change with change of working frequency +/- 10% from resonance.

With this modification, due to decreasing of the radiation resistance of the antenna, we expected slight decrease of the width of the frequency working band of the antenna, which was also analyzed. Achieved values of matching with changing frequencies are given in the figure 13. for unmodified (75ohms) and in the figure 14 for modified (50 ohms) antenna.

We also analyzed the changing of the gain of the antenna with the increase of the length of the reflector surfaces, in order to compare it to the original antenna and to determine the optimal reflector dimensions for achieving the gain maximum. The result of this analysis is given in figure 16.

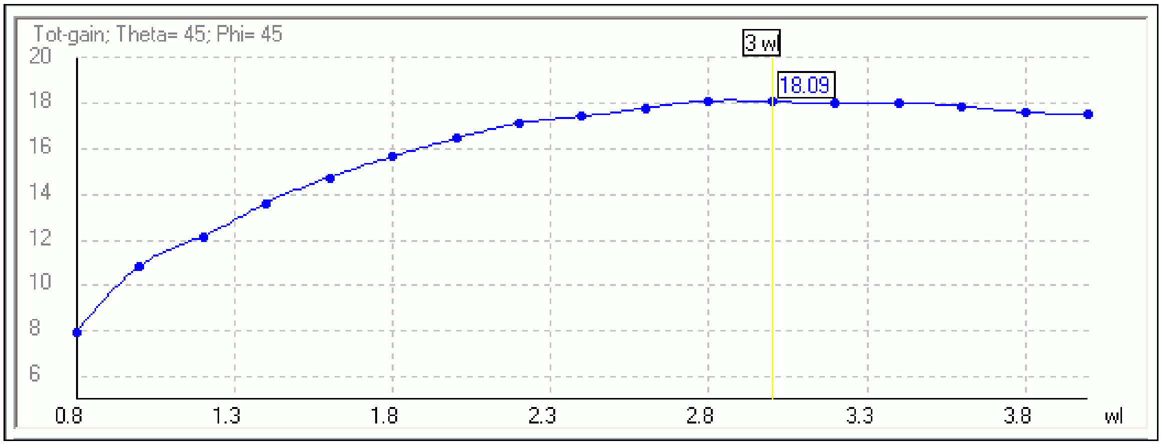

Fig.16. Modified 3D Corner Reflector Antenna gain with 0.8 to 4 wavelengths reflectors length.

Shape modification

Computer simulations revealed that part of the bottom reflector surface which is the most distant from active and passive element very little influences focusing electromagnetic energy and formation of radiation diagram. That gave us the idea to try to modify the shape of the antenna by cutting the half of the bottom reflector surface. By doing this, we achieved much more compact and half shorter antenna. The analysis of the influence of this intervention revealed that performances of the antenna remained unchanged.
The decrease of the overall length of the antenna to the half without any serious consequences indicates that the other two reflector surfaces actually play the main role in focusing electromagnetic energy and formation of very directional radiation diagram with excellent side lobes suppression in both planes.
The bottom reflector surface has more impact on the formation of the radiation diagram only between apex and active and passive element and closely around them. The influence decreases with distance from elements towards periphery of the bottom reflector surface.
As a logic step in further improving and increasing the gain of the antenna was to elongate both vertical planes to the overall length of 3 wavelengths and in that way to achieve practical maximum of the antenna gain. This modification also increased the distance between passive element and the outer edge of the bottom reflector surface, because of the increase of the diagonal of the reflector surface itself. The removal of the half of the bottom reflector at the antennas with reflectors of 3 wavelengths has less influence on the diagram than at the antennas with smaller reflector, and that's because of the fixed positions of the active and passive element regardless of the length of the reflector.
This kind of antenna was submitted to the detailed computer analysis and comparison with previous versions. Without any doubt, achieved performances were superior and with half shorter and more compact antenna the maximum of practical gain was achieved.
The difference in the shape of the diagram and gain between shortened and full antenna with 3 wavelengths reflector are shown in figures 17 and 18.

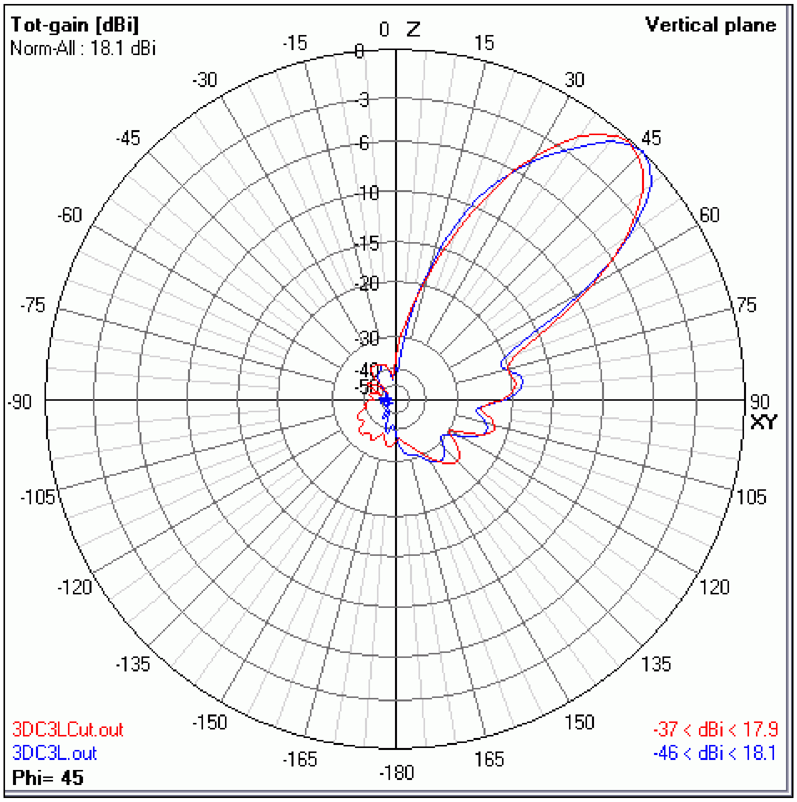

Fig. 17. Vertical diagram and gain of shortened and full antenna.

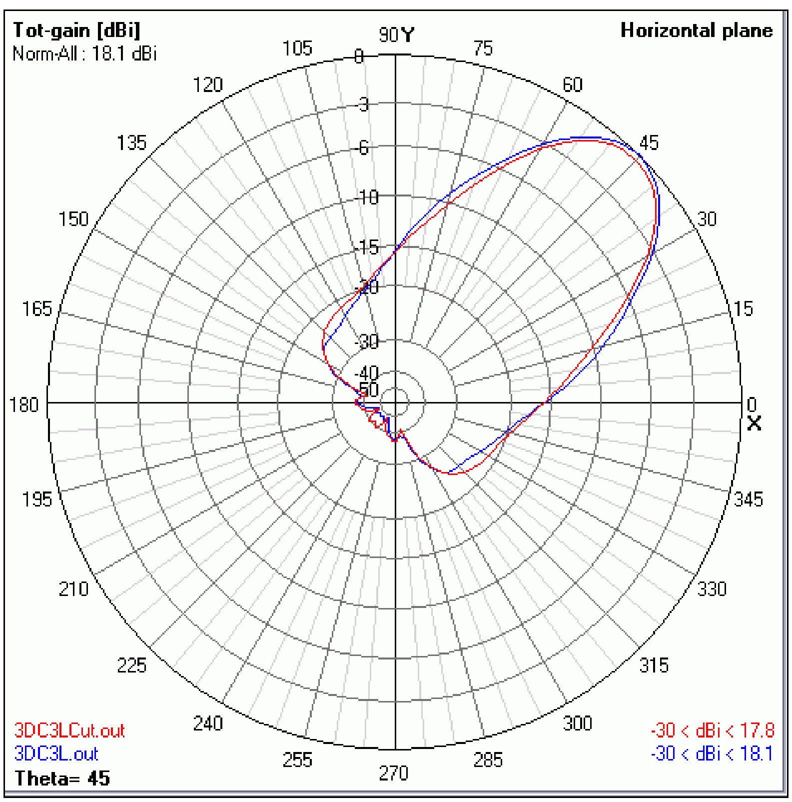

Fig. 18. Horizontal diagram and gain of shortened and full antenna.

Small change in position of the main beam and suppression of the side lobes in vertical diagram and even small narrowing of the horizontal diagram reveal that because of the absence of the half of the bottom surface destructive changes in behavior and parameters of the antenna did not occur. The input impedance remained unchanged and gain decreased for about 0.25 dB due to decrease of the aperture of the antenna.
The results of the computer simulations are used for building experimental specimen of the antenna which were then used for laboratory measurements and testing.
The measured values of input matching and gain of the antennas very well corresponded to computer predictions.

Conclusion

From all stated above, we can conclude that on the basis of the obtained results of the computer simulations and laboratory measurements we confirmed the possibility of decreasing the radiation resistance of the antenna by adding passive element near the active monopole. This gave very good results regarding the value of obtained input impedance of the antenna, width of the frequency working band, the shape of the diagram and gain of the antenna.
Also, we confirmed the possibility of significant shortage of the length of the antenna with negligible change of gain, input impedance and diagram shape of the antenna. In this way we achieved smaller and more compact antenna while retaining good characteristics of the original antenna.

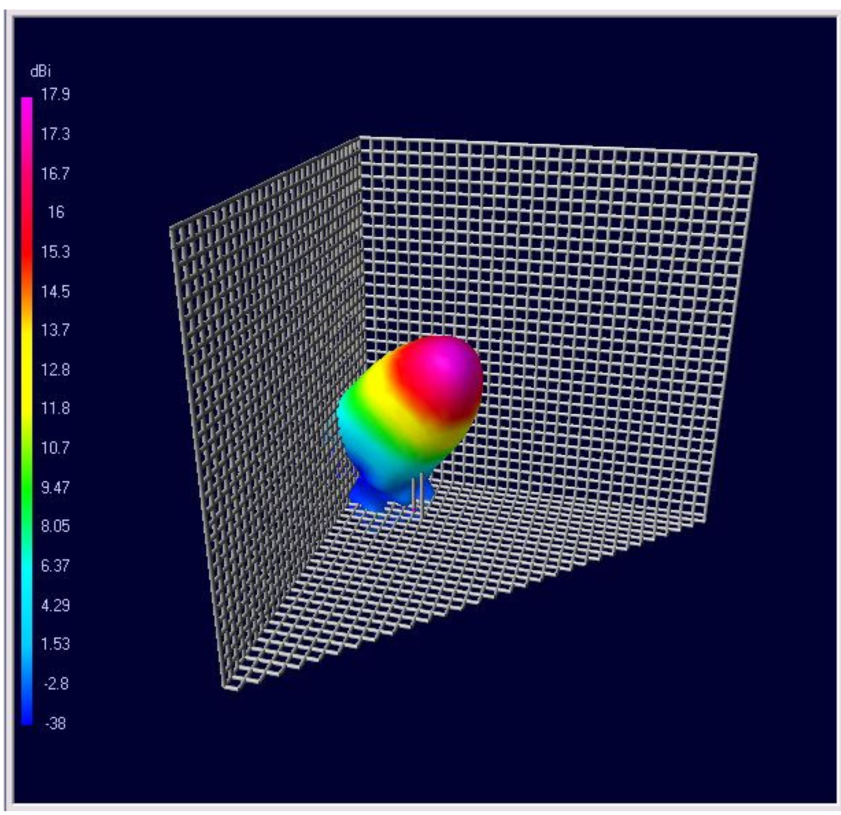

Fig. 19. Main beam of antenna.

In addition to optimization of the input impedance and the shape of the antenna described in this article, we also analyzed the possibility of changing the shape of the reflector surfaces in order to achieve approximately equal width of horizontal and vertical angle of radiation diagram. In this way, it would be possible to use 3D corner reflector antenna as efficient illuminator for parabolic reflectors.
The results obtained in that direction show that, with specially modified shapes of the reflector surfaces, it is possible to achieve optimal angles of radiation diagrams for the use with offset parabolic reflectors. In separate article we will describe one such shaped 3D corner antenna with additionally modified shape of the reflectors for the use with offset antennas.
We also analyzed the possibility of alteration of shape of antenna by changing the angles between the reflector surfaces. The results of the computer simulations for different angles between reflector surfaces are worse from those achieved for angles of 90 degrees.

The projection of Shortened 3D Corner Reflector Antenna for 2.4 GHz band

As the optimal dimension of reflectors we accepted the value of 3 wavelengths, which is 370 mm at 2.4 GHz. Properly built antenna has gain of about 17.9 dBi, which is a remarkable value considering the simplicity of build. In addition, this value also represents the practical maximum for this type of antenna.

The results of the simulation

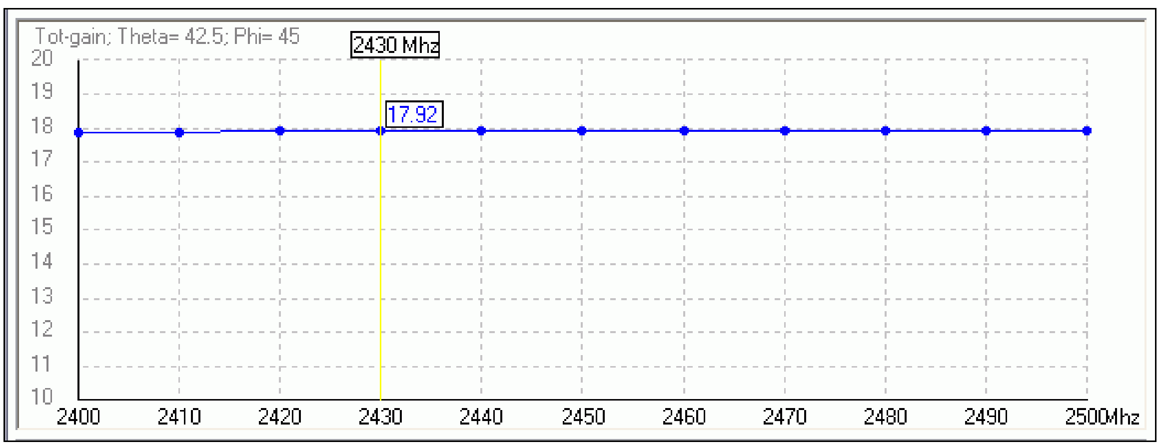

Fig. 20. Shortened 3D Corner Reflector antenna gain with 3 wavelengths reflectors length.

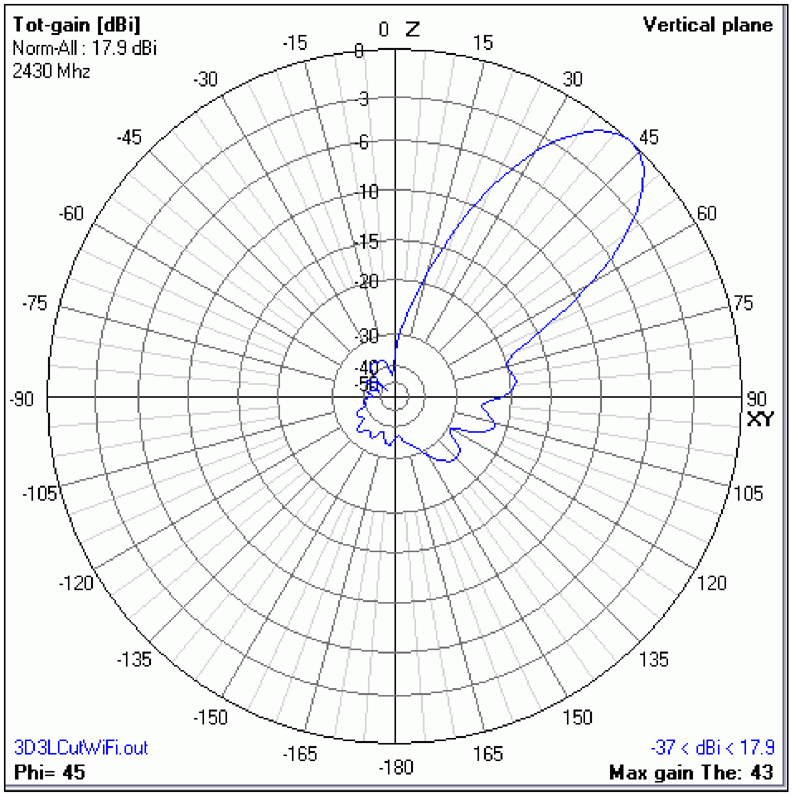

Fig. 21. Vertical diagram of shortened antenna at 2.4 GHz.

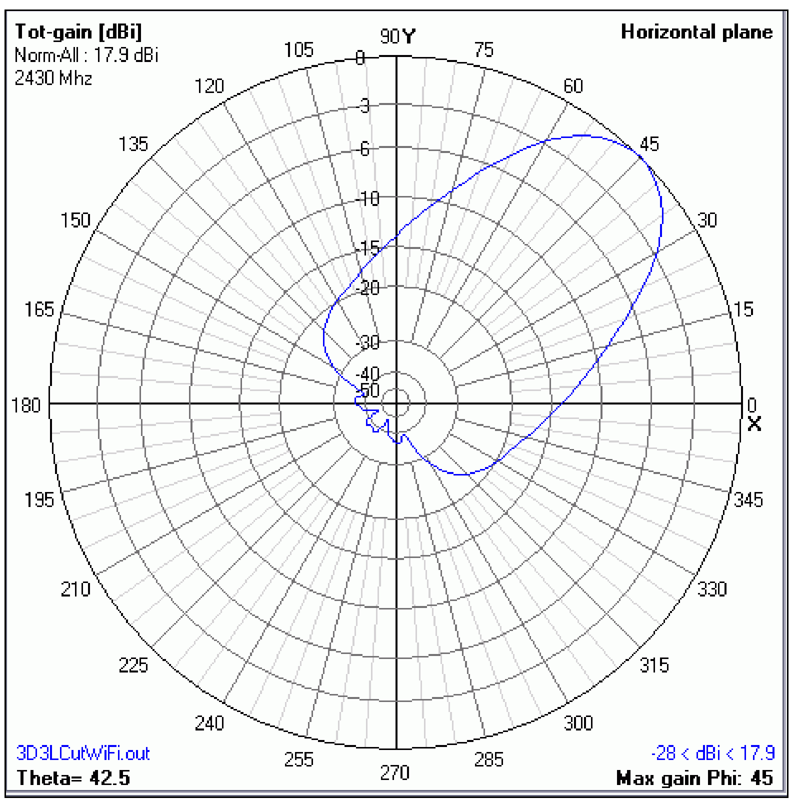

Fig. 22. Horizontal diagram of shortened antenna at 2.4 GHz.

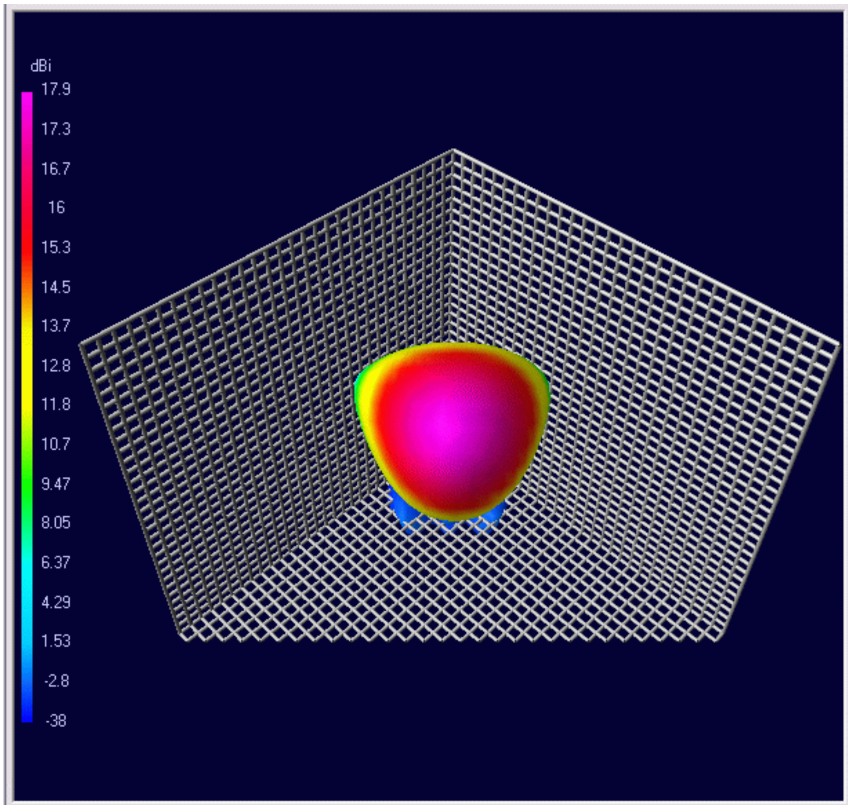

Fig. 23. Front view.

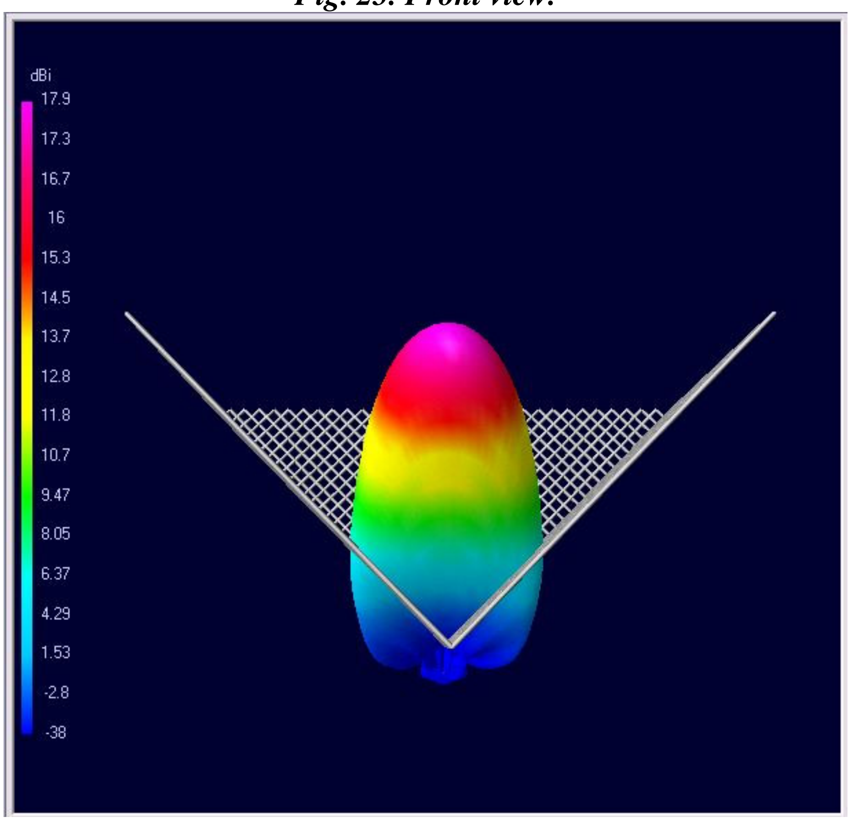

Fig. 24. Top view and horizontal diagram.

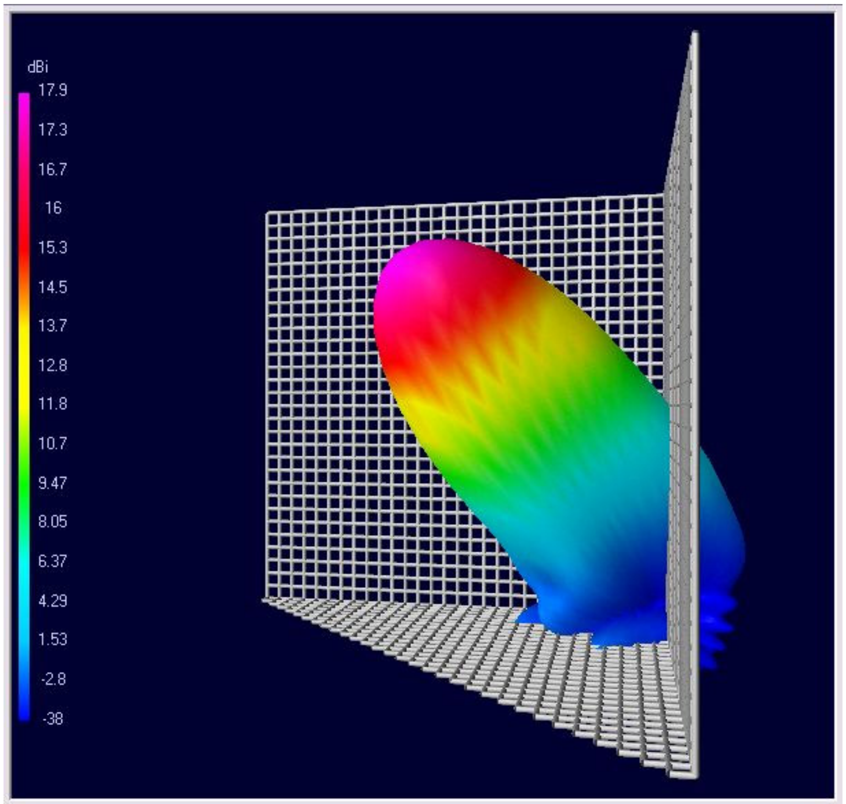

Fig. 25. Side view and vertical diagram.

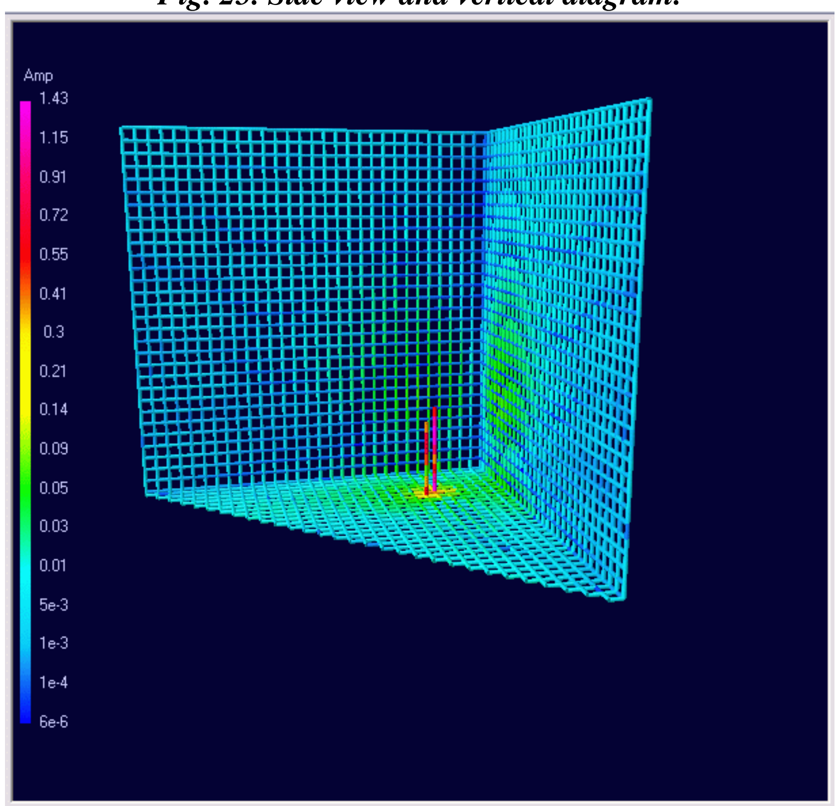

Fig. 26. Shortened antenna with element places and currents for P=100W.

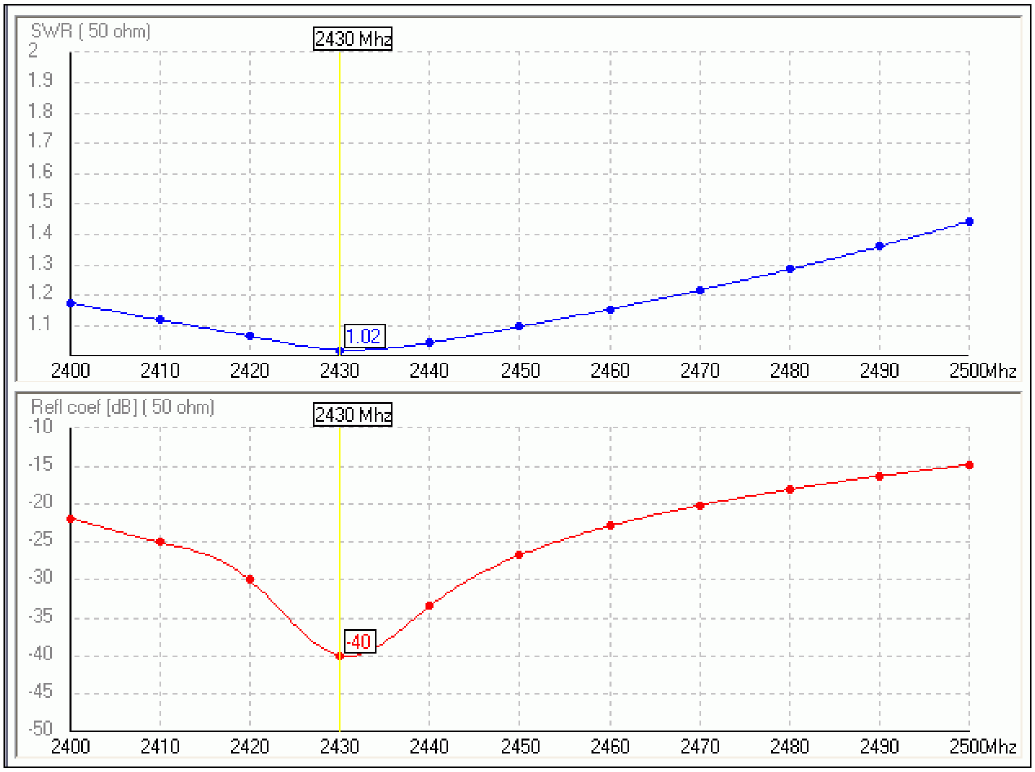

Fig. 27. Input matching and bandwidth of shortened antenna.

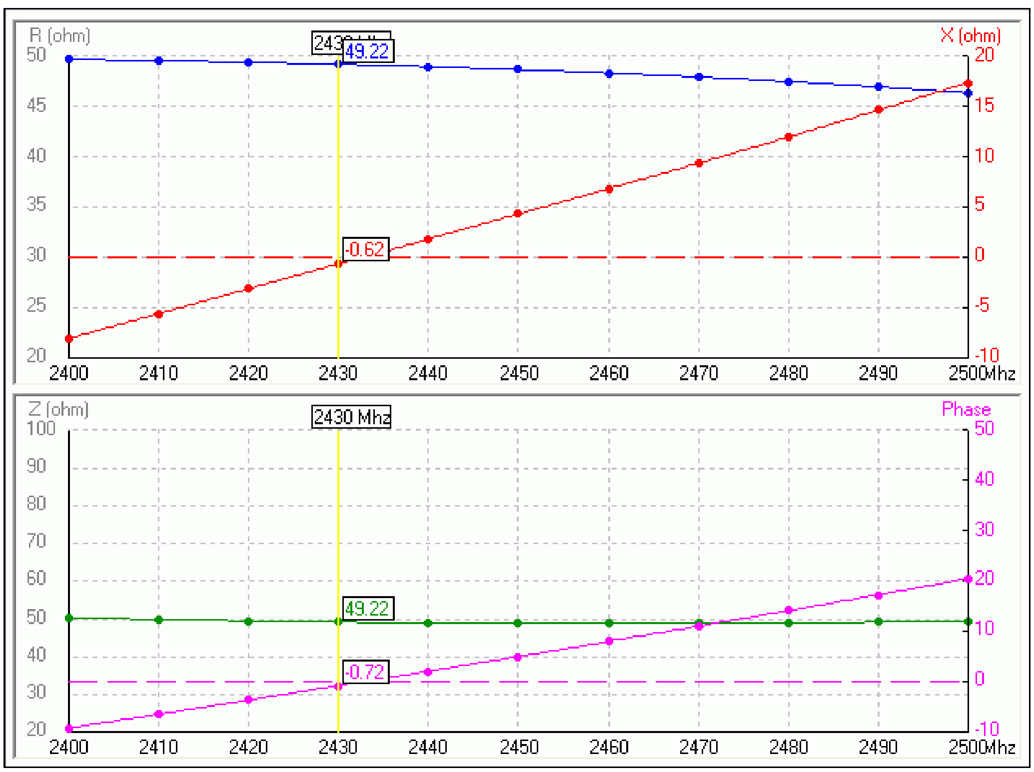

Fig. 28. Input impedance of shortened antenna.

The mechanical construction of Shortened 3D corner reflector antenna for 2.4 GHz

Antenna is made of aluminum, copper or brass (not iron or galvanized) tin. Through the bottom shortened surface, as shown in figure 30, we drill the openings for placing one female N connector and one brass screw M4-M5 (4-5 mm) with two brass screw-nuts for fixation at the length determined by calculation. To the N connector, i.e. to the small needle which is shortened to 2-3 mm, we solder copper wire or small tube with the outer diameter of 4 mm, so that its overall length with small needle of the connector to which it is soldered corresponds to the calculation of the length of the active element DR, measured from reflector surface. Brass screw is elongated by soldering to its end copper wire or small tube with the outer diameter of 4 mm, whose length is determined in such way that, with the half of the length of the screw, it gives calculated length of the adjusting element DI. The length of the passive element should be adjusted according to dimensions given in figure 31. We should make sure that the mass of the N connector and brass screw-nuts have good connection throughout the whole scope with the radiation surface. That is very important to the proper function of antenna!

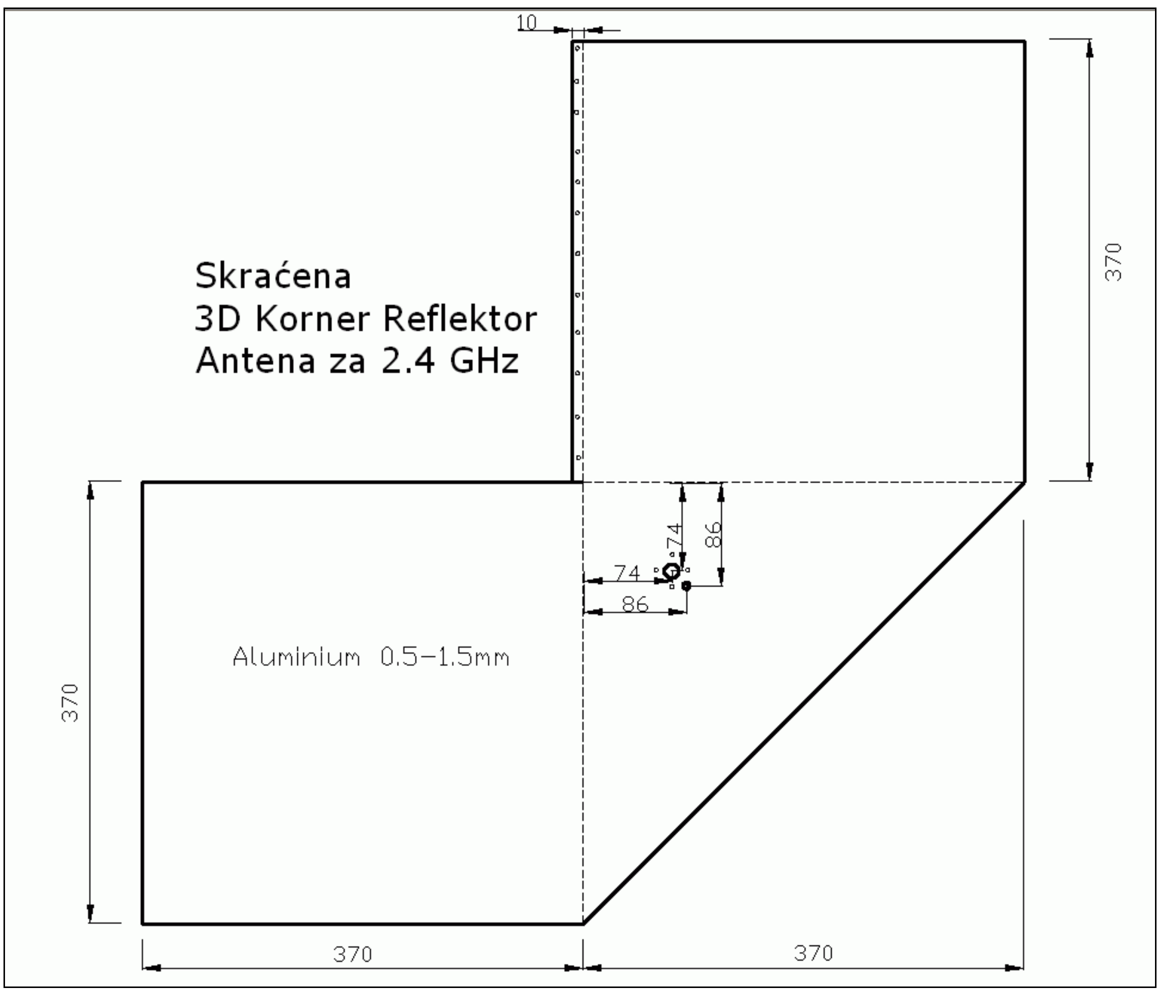

Fig. 29. Shape and dimensions of cut for shortened antenna.

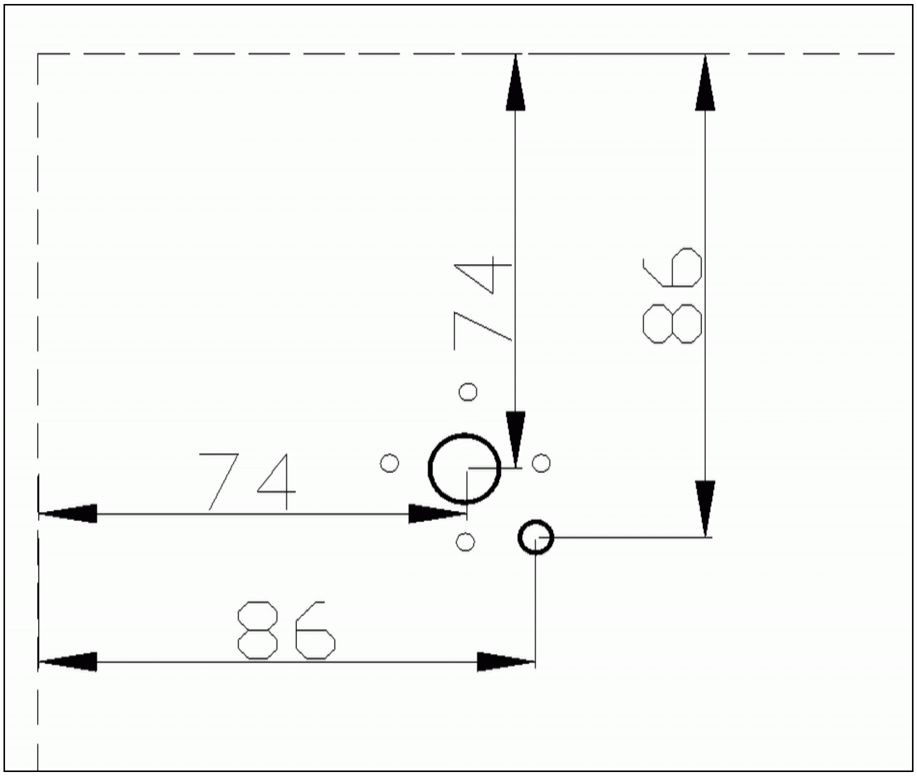

Fig. 30. Dimensions and position of holes for active and passive elements.

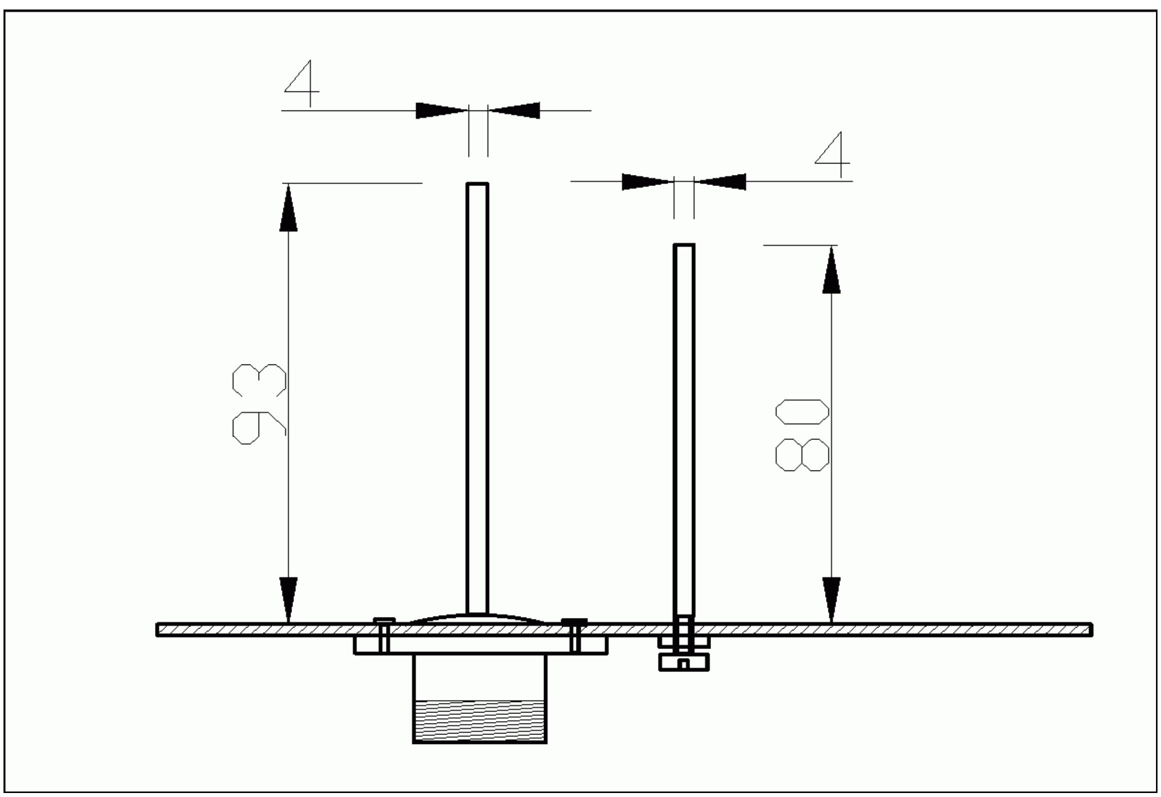

Fig. 31. Dimensions of active and passive elements of antenna.

The protection from atmospheric actions is accomplished by covering the N connector and its connection with the active element with thin layer of polyethylene, using the pistol gadget that melts polyethylene bars and deposits liquid plastic on the desired surface.
The use of acid silicone is strictly forbidden because of its very bad electric properties, great RF losses and extreme chemical aggressiveness!
Copper elements, as well as copper or brass reflector surfaces, are protected from corrosion by thin layer of varnish which is evenly deposited using spray.
The reflector surface of the antenna must be built almost as it is cast solid! That means that entire reflector surface in all three planes must behave as continuous surface with good electric contact along the whole length at connections between each reflector surfaces. Because one connection still has to exist between two planes, it is best that it is between two vertical planes. In that case, the connection line is parallel to active element so that it doesn't intersect the ways of the currents which flow parallel to the element that induces them. If the connection line is perpendicular to the active element, weak connection intersects currents which flow in reflector and the antenna works poorly! That is very important!
That's why tin needs to be cut out exactly as shown on figure 29 and folded perpendicularly along the dashed lines!
In addition to good overlap of the connecting surfaces, the number of screws or pop-rivets used in connecting the surfaces needs to be as high as possible, at least at every 10-20 mm! If the antenna is made of the brass or copper tin, it is best to solder the connection at the outer side of the antenna.

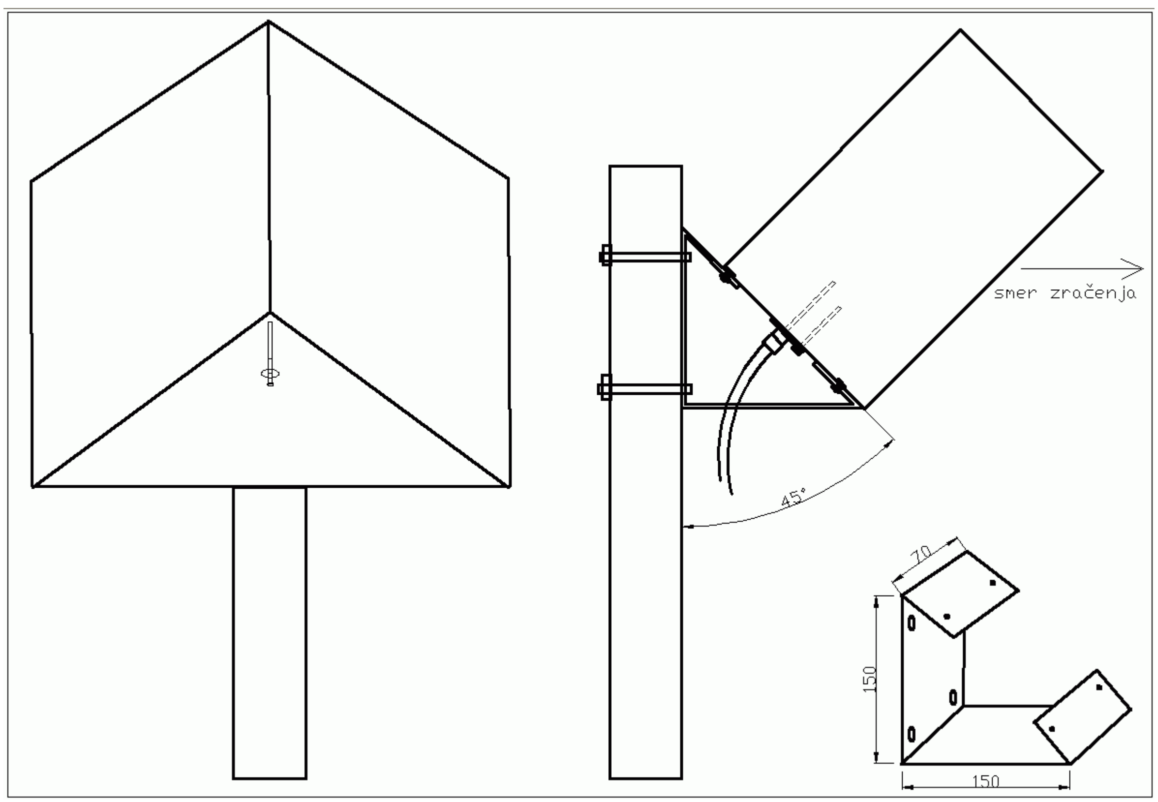

Fig. 32. Proper mounting and radiation direction of antenna.

The unusual thing while using this antenna was its aiming. There's a habit in thinking that antennas radiate along one of its geometric dimensions or perpendicularly to reflector surface. However, this is not the case with this antenna!
Its radiation diagram is under the angle of 45 degrees in relation to all three reflector surfaces and that must be taken into account during aiming! That's why it must be mounted on the stand by the carrier that will, first of all, ensure that the antenna radiates toward horizon, that is with the elevated angle of 0 degrees. In order to achieve that, the antenna needs to be mounted under the angle of 45 degrees, as in figure 32. Only then we can easily aim the antenna along azimuth towards the correspondent by rotating it around the axis of the carrier stand.
The adjustment of the impedance using the passive element is very uncritical, wide and exactly as expected. That's why it is practically possible to build the antenna, precisely measure needed dimensions and the distance between the elements and the antenna will be immediately adjusted, without any additional adjustment on the instruments that are unattainable to the most of the builders. That is yet another great advantage of this antenna.
Antenna built in this way covers whole 2.4 GHz Wireless band, i.e. all the channels from 1 to 14 and it doesn't need additional calculation for each channel separately, because antenna has exactly the same gain at all channels (figure 20). The input impedance and matching remain very good at wide frequency band, as shown in figures 27 and 28!

Calculating the Shortened 3D corner reflector antenna for other frequencies

Because of its working principle, this antenna can work at frequencies from several tens of MHz to several GHz. That's why it can easily be adjusted to work at any other frequency.
At lower frequencies, instead of tin, the wire net with the openings smaller than 0.1 wavelengths can be used. At very high frequencies, the accuracy of manufacturing active and additional elements and good connections are needed.
Dimensions of Shortened 3D Corner Reflector Antenna in wavelengths (Lambda) are:

Reflector dimensions (measured from the apex to the end):	L = 3 x 3	Lambda
Active element length (measured from reflector):	DR = 0.754	Lambda
Passive element length (measured from reflector):	DI = 0.650	Lambda
Element diameter:	FI = 0.032	Lambda
Active element position (measured from apex):	x = 0.6, y = 0.6	Lambda
Passive element position (measured from apex):	x = 0.7, y = 0.7	Lambda

The wavelength can be calculated according to the equation:
Lambda = 299.8 / freq.
The wavelength is in meters if the frequency is in MHz.

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