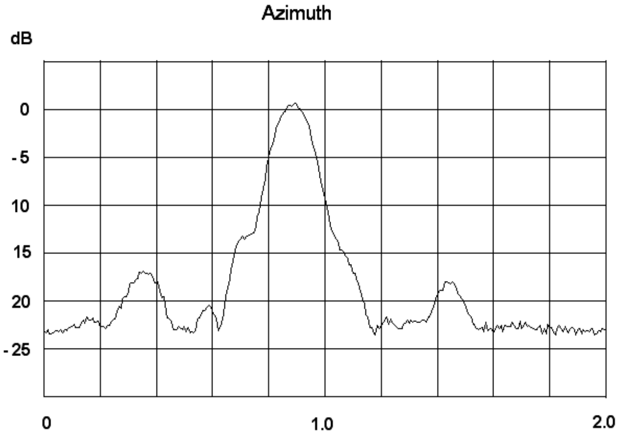
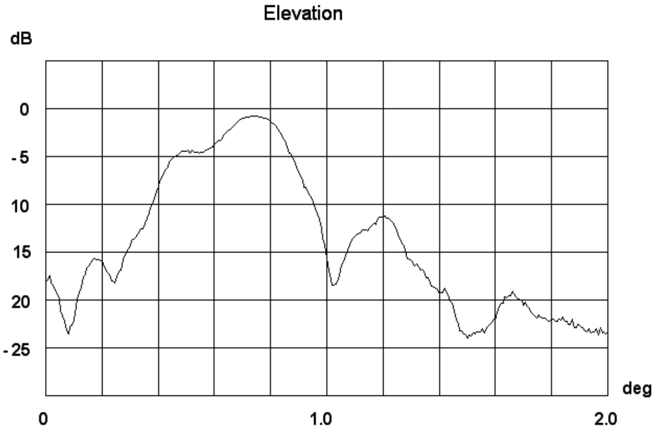
EME ANTENNA AND JUPITER NOISE ON 77 GHz
by Sergey Zhutyaev RW3BP

For EME experiments on 4mm band (77.5 GHz), I planned to use my antenna that was successfully worked on 47GHz. It is a single peace offset parabolic aluminum dish by "Supral" company. Antenna diameter is 2.4m. First antenna test on 76 GHz was made in October 2006. These were preliminary attempts to measure the Sun noise. However I actively started to work with antenna only in late 2010, after it was possible to place the beacon in 900 meters away from my house.

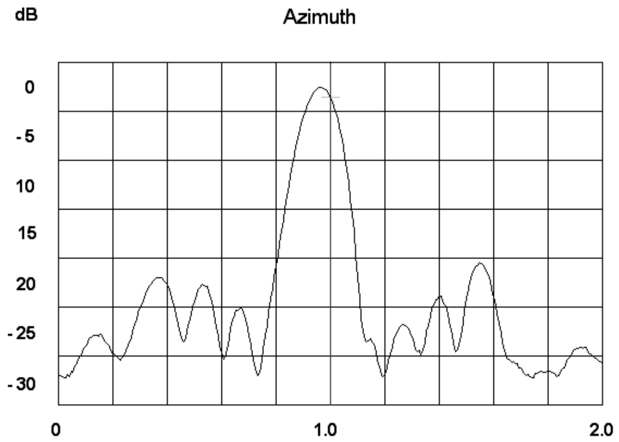
The first measurements showed that the radiation pattern is far from perfect, especially in the elevation plane.

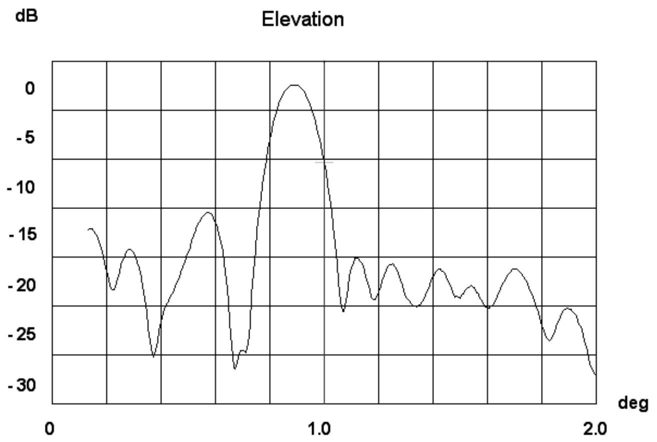




I tried to move the feed in all three directions but there was no notable improvement. It was the time to look for possible solutions. The idea was to give a try to correcting dielectric lens.

Styrofoam plate was installed between the feed and reflector for lens placement. The plate was installed in such a way that for view from the focus point to the dish it was projected onto the plate as a circle of 25cm in diameter. I start with a simple lens. It was horizontally placed dielectric strips. By selecting the width, thickness and position of strips I found a nice improvement of the radiation pattern in the elevation plane. As a result it was possible to see the main lobe and the antenna gain was a few dB more.

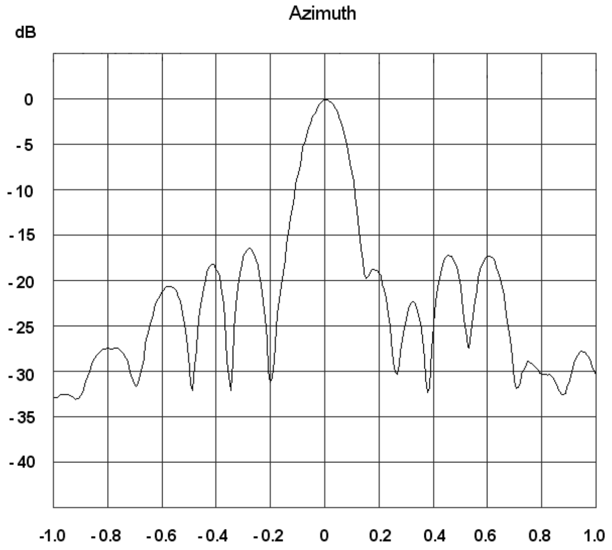


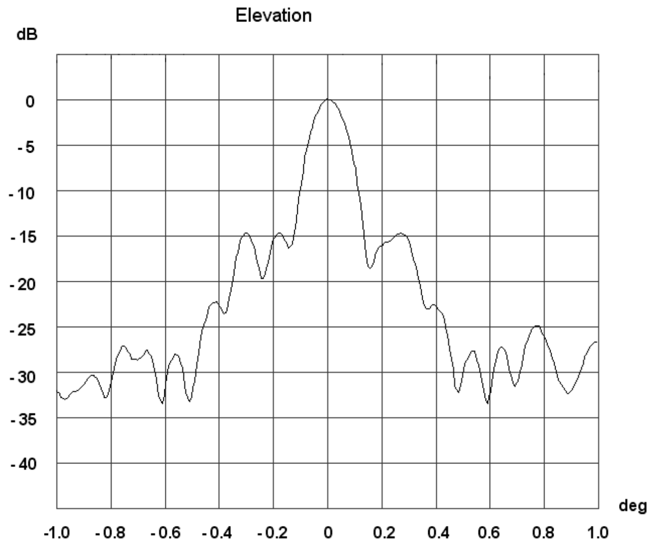


However, it became clear that to find the right lens by trial-and-error method is impossible, especially when doing it for two planes at the same time. So the next idea was to make a 3D scan of the dish and to get a map of deviations from the ideal shape and further using the obtained data for lens calculation.

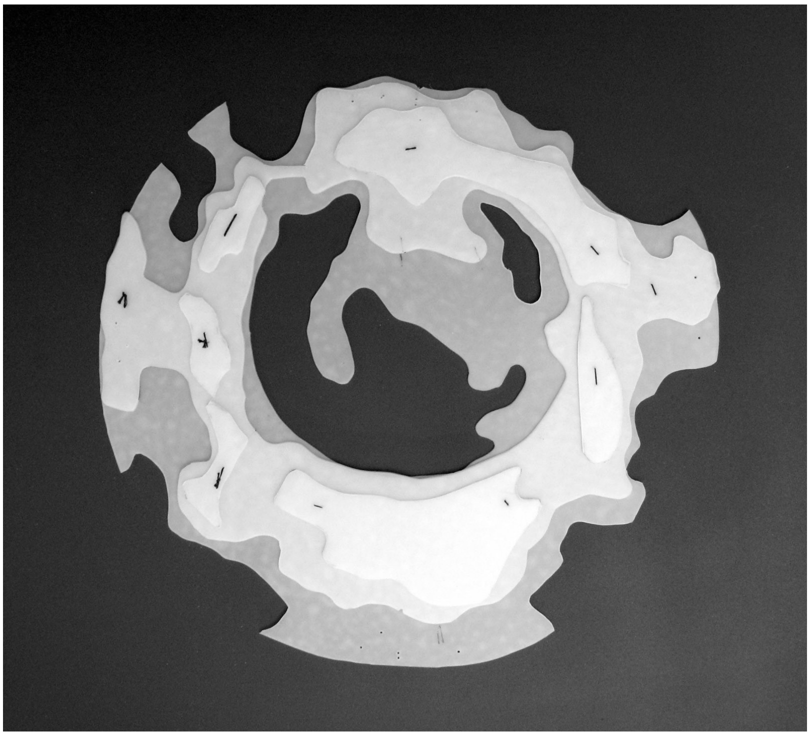
In September 2011 the 3D scanning was done with accuracy of about 0.1mm. Then I've found paraboloid closest to the actual surface and thus I found a new position of the focus point. It turned out that the feed should be moved by 11mm toward the reflector and 32mm downward!!! It became clear why I could not find a new feed position. I just could not imagine that it is necessary to move it so far.

After correction of the feed position, the radiation pattern shows significant improvement even without the lens.



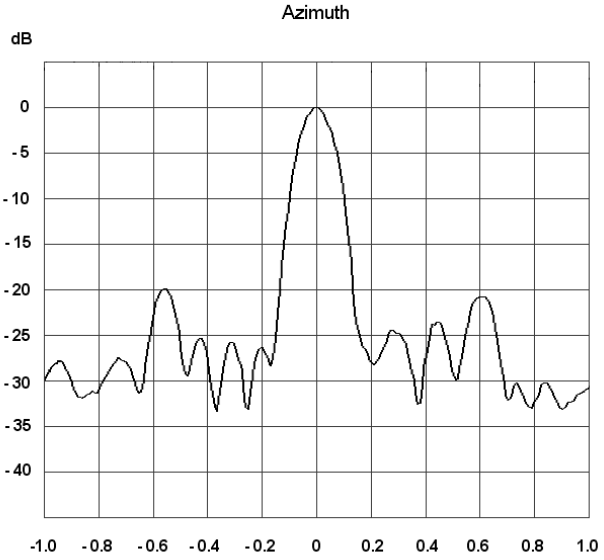


Nevertheless, I quickly calculated the lens and produced it from three 1mm Teflon layers. There was a significant improvement. The level of the first side lobe was reduced by 6 ... 7 dB. Unfortunately it was no noticeable increase in antenna gain. So I decided not to use the lens in future EME tests.

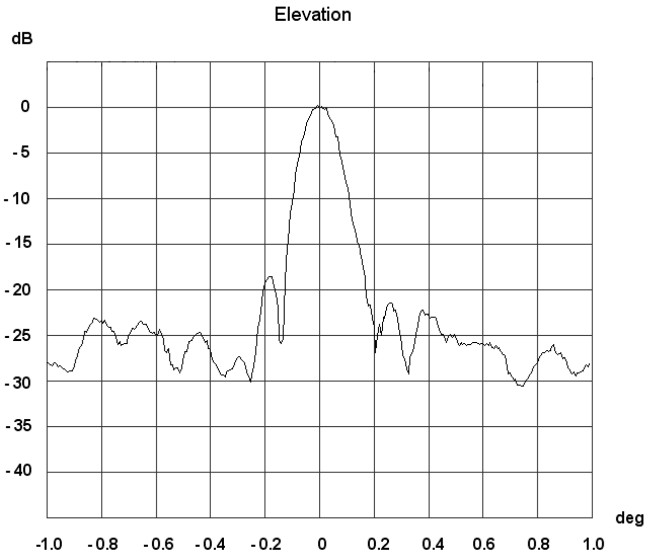


At this time I was lucky to become the owner of TWT, which in principle could work on 77 GHz. It could work but unfortunately didn’t. It took me over a year to get 60W power, enough for the first EME experiments. As a result, in February 2013 I was able to receive the first echo from the Moon, and in the summer Al W5LUA managed to copy my signals on 77 GHz.

In preparing of this report I decided to test the antenna with correction lens once again. The results obtained at the end of 2011 were confirmed.



Azimuth



Elevation

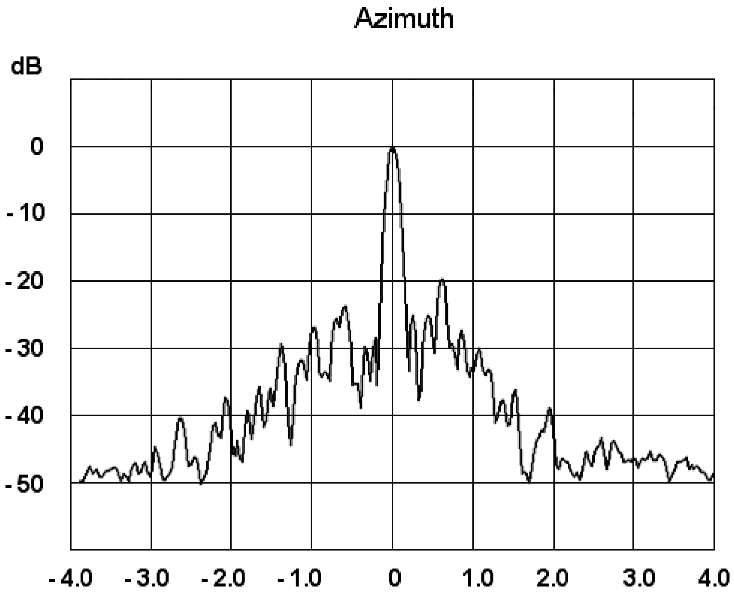
There was a significant improvement of the pattern and about 0.4 dB rise of the antenna gain. It was hard to say whether it’s high or low rise. To evaluate the effectiveness of the lens one need to know the scale of the problem. We need to know the difference in gain of my non-ideal antenna and the antenna with an ideal shape of the reflector.

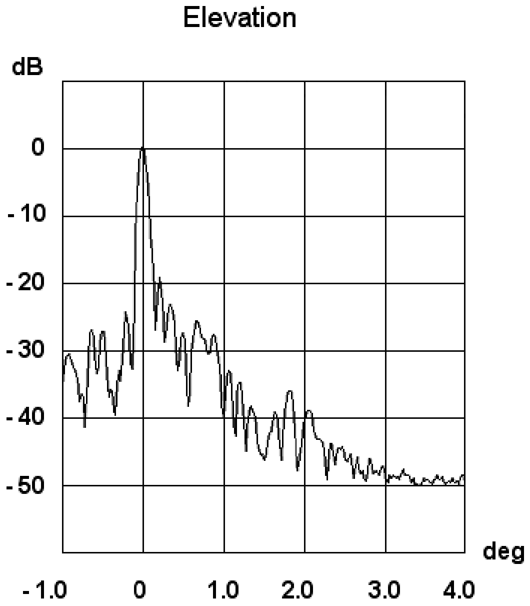
It is easy to calculate RMS deviation of the dish surface based on the 3D scan results. In my case it is 0.31mm. Ruze Equation determine the antenna gain loss by known RMS:

$L_R = -685\left(\frac{\varepsilon}{\lambda}\right)^2 (dB);$ ε - is the RMS surface error.

For my case L = - 685 $(0.31/3.9)^2$ = - 4.3 dB.

This is discouraging loss and 0.4 dB lens improvement is too low for it. But further experience showed that the actual loss is not so bad. In the case of smoothly varying deviations, as in my case, the Ruze Equation gives an overestimate. So we need to look for other ways to define the real loss of the antenna gain. One way is to analyze directional pattern recorded in a broader range of angles and with maximum possible for my beacon power dynamic range of 50 dB. For example there is pattern for my antenna with the correction lens.

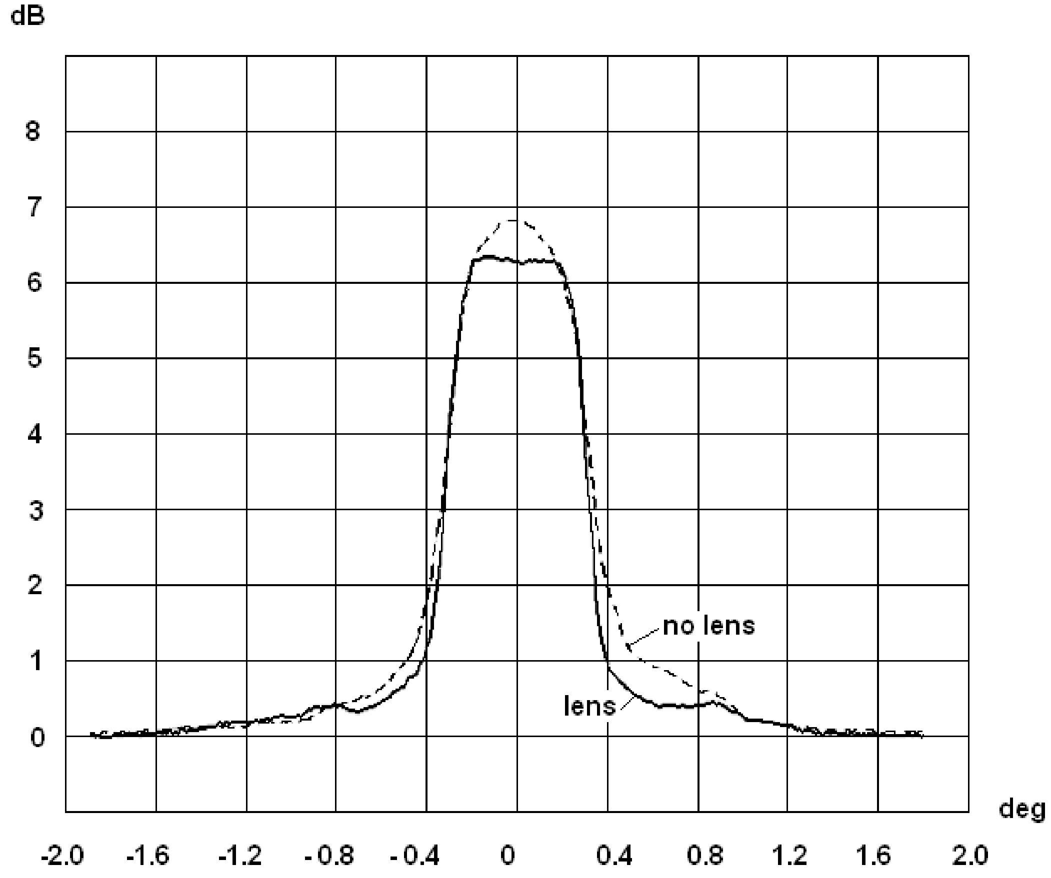

Azimuth


Elevation

So, we have the data to analyze a part of the radiation pattern, adjacent to the main lobe. From the most common considerations it is clear that smooth deviations from the ideal shape of the dish affecting only this part of the pattern. Based on these diagrams the three-dimensional pattern of the antenna was built for two cases - with and without the lens. The integration of 3D pattern gives the following results.

Antenna without lenses – $\varepsilon_M = 0.63$. Antenna with lens - $\varepsilon_M = 0.69$. If we estimate the additional losses on minor side lobes and back lobes of 5%, we obtain for the case without lens $\varepsilon_M = 0.60$, and in the case of the lens $\varepsilon_M = 0.66$. The benefit from the lens is approximately equal to 0.4 dB, which is close to the results of my measurements. Here ε_M is the main beam efficiency (ratio shows the power radiated by the main lobe of the total power radiated by the antenna). For fixed type of the feed the aperture efficiency ε_{ap} of antenna is changing in proportion to ε_M ; $\varepsilon_{ap} = k\ \varepsilon_M$; For my feed this coefficient is approximately equal to 0.8 .

Sun noise measurement



As an example, here are the results of measurements made with the lens and without correction lens. Without the lens it is a high level of the first side lobes and flat top (solar disk) is not visible. However, the maximum level without the lens is higher than with the lens, although the antenna gain without the lens is less. This is due to the fact that the first side lobes in the absence of the lens partially fall on the solar disk and give additional increase of noise level. This is an example of how sun noise measurements may show the false improvement of the receiving system.

Now let’s come back to the previous problem, and try to define beam efficiency by sun noise measurements. We proceed from the following considerations:

1 - With the lens contribution of side lobes on the solar disk does not exceed 2%;

2 - Noise temperature of the Sun on 77 GHz T_{SUN} = 7000K;

3 - The apparent temperature of the Sun is reduced in proportion to losses in the atmosphere – L_{atm}.

4 - The apparent temperature of the Sun is proportional to ε_M . Only main lobe is directed to the Sun (see item 1). Minor lobes are directed mainly at cold sky;

5 - Sky noise is mainly determined by atmospheric noise T_{atm} .

We can write the equation:

$$Y_{sun} = \frac{T_{sun} L_{atm} \ \varepsilon_M + T_{atm} + T_{rx}}{T_{atm} + T_{rx}}$$

Here the numerator is the noise level in the case the antenna is directed to the center of the Sun. The denominator is the noise level in case the antenna is directed on the cold sky. Y_{SUN} - the ratio of these levels that we can measure, T_{rx} - receiver noise temperature.

We need to find the value of ε_M , so transform the equation:

$$\varepsilon_M = \frac{(T_{atm} + T_{rx})(Y_{sun} - 1)}{T_{sun} L_{atm}}$$

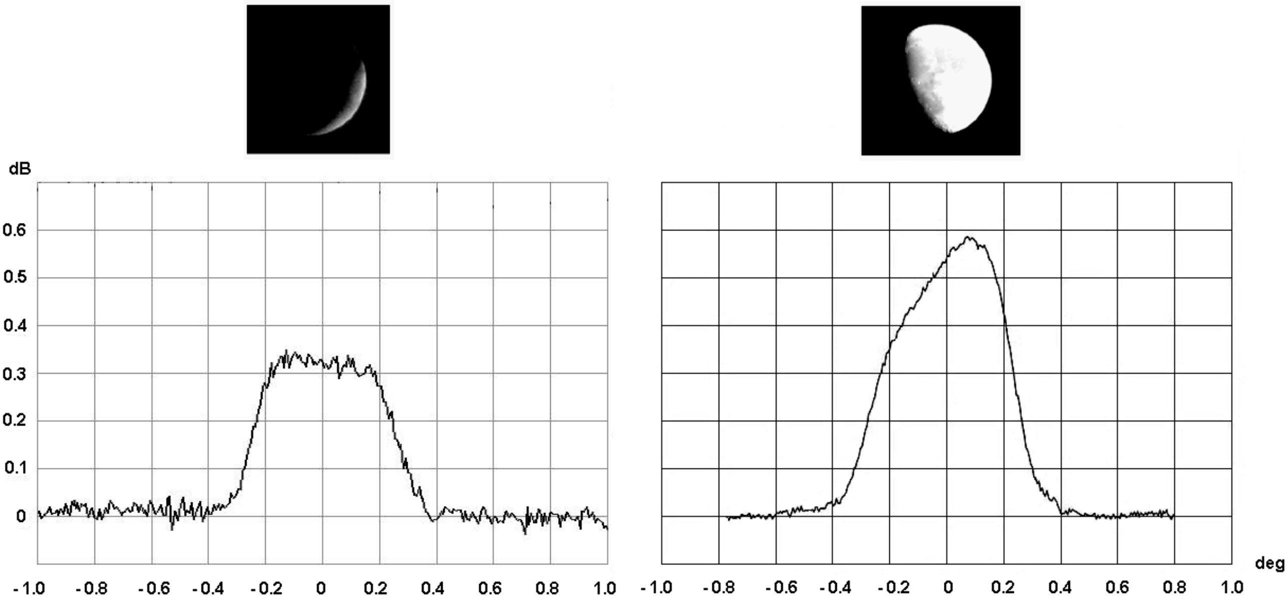
We have the following inputs:

T_{atm} = 70K and = 0.77 for 27C, 38% humidity and 55 degrees elevation.

T_{rx} = 1030K, T_{SUN} = 7000K, Y_{SUN} = 4.3 (6.3dB).

By calculations we get ε_M = 0.67. This is very close to the result obtained above. Keep in mind that the accuracy of the calculations depends on the accuracy of the input data on the noise temperature of the Sun. Let T_{SUN} = 7500K, then ε_M = 0.62. Even in this case it is much better then ε_M = 0.3 calculated under Ruze Equation result.

Moon noise measurement



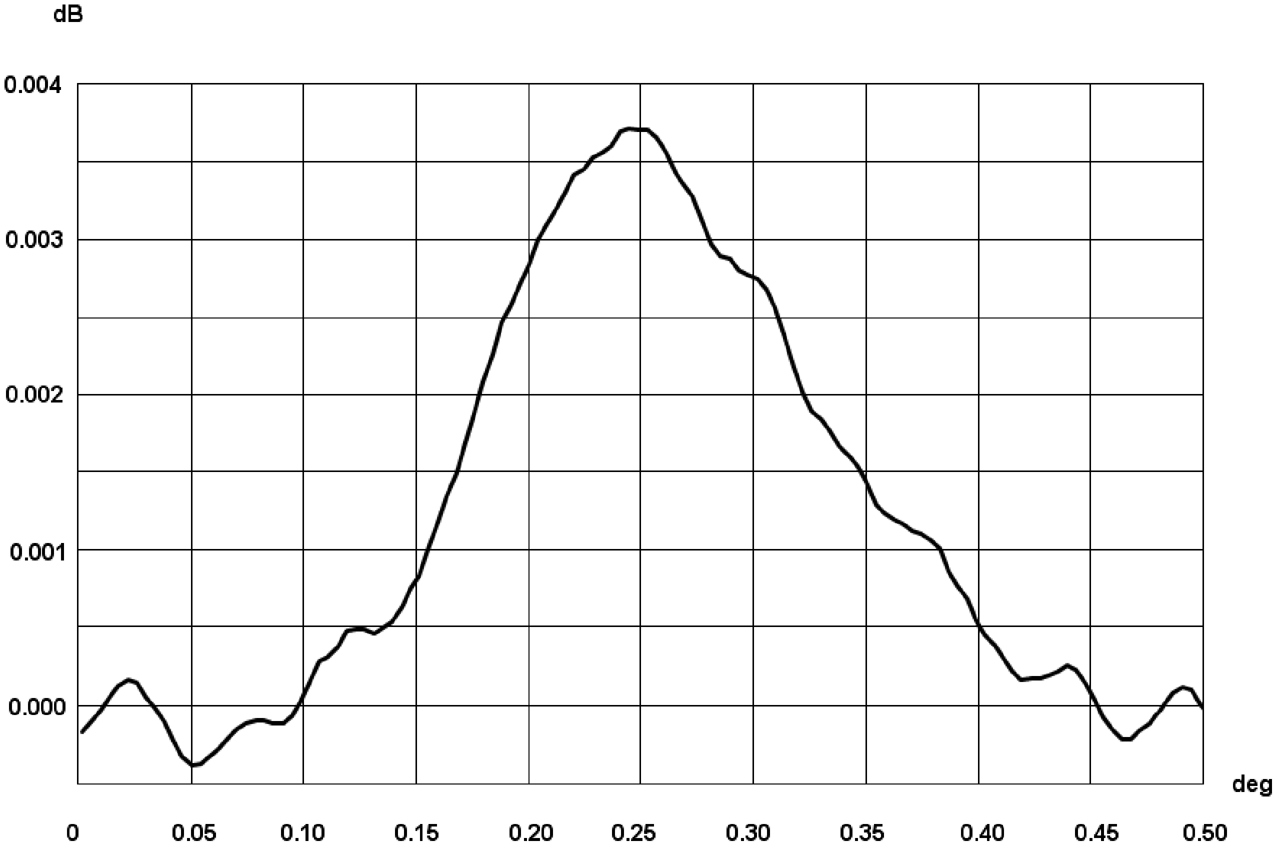
Moon noise on 77 GHz is strongly depends on the phase of the Moon. The noise level of the full Moon is about two times higher than of the new Moon. In contrast to the lower frequency bands, you cannot find the center of the moon by the noise maximum, and need to be guided by the edge of the lunar disk.

Jupiter noise measurement

I had an idea to use Jupiter for general test of the receiving system and to measure its quality G / T. For this test we need a point source of known intensity. My antenna stand is not precise enough to point the antenna with high accuracy. I have to calibrate it from time to time by video camera. So we need a point source visible in the optical band and Jupiter is the best choice for Northern hemisphere.

The next step is to calculate the expected Jupiter noise level. The easiest way is to rely on my moon noise measurement results. We consider the noise temperature of the new moon and of the Jupiter is about the same (140 - 150K). On the new moon I have the noise level a little more than 0.3 dB. The angular size of Jupiter (44”) is about 9 times smaller than the width of the main lobe of my antenna (400”). There is 80 times difference for solid angles. Accordingly the noise signal from Jupiter must be 80 times less than that of the moon. This means that the noise signal will have a level of 0.0037 dB. For all its simplicity, this estimate is accurate enough and allows us to define the necessary technical means. Just at this moment there was information from Luis CT1DMK about his new radiometer. I did not do it myself, and ordered it from Luis (with 40 MHz bandwidth). Measurements were done in clear frosty nights with maximum transparency of the atmosphere for millimeter waves. Even in good conditions, the task was very difficult.

During each measurement antenna was motionless and Jupiter crossed the main lobe due to the rotation of the Earth. One measurement takes a little more than a hundred seconds. During this time Jupiter moved across the sky 0.5 degrees. The first measurements showed that one such track is not enough to check Jupiter noise. I start to do it again and again for future averaging. Unfortunately even averaging of 10 or 15 recordings did not give a reliable result. I have already started to lose hope, especially as the weather began to be worse. And suddenly on February 1 I got quite good noise signal with level close to calculated.



You can see the result of 10 recordings averaging. I have no reliable explanation for this effect. It seems that much depends on the state of the atmosphere. On February 1 the temperature rose and the state of the atmosphere obviously changed compared with previous frosty nights. Perhaps the atmosphere became quieter and it reduced the signal fluctuations. In any case I plan to do it again next winter to understand the problem.

Conclusion

1 - For 77 GHz band you need antenna with extremely high accuracy of the reflector surface. However, the size of the antenna for EME communications must be at least 2.4m (maybe 1.8m).

2 - Antennas of this quality are not easily accessible to amateur radio and are very expensive. It is possible to use lower-quality antennas but it is necessary to check up radiation pattern.

3 - It is possible to compensate surface deviation by dielectric lens. In my case gain loss was reduced to -1.4 dB (-30%). Antenna gain now is approximately 62.5 dBi.

4 - The Sun is most informative and easy to use celestial source.