DIY 137 MHz APT Weather satellite antenna – Or, do we need a circular polarization?

What we are listening

At the moment there are three NOAA satellites available transmitting the APT weather pictures in LRPT format. They are operating in the frequency range of 137 MHz till 138 MHz. The satellites are transmitting the RHCP (Right Hand Circular Polarized) signal on the following frequencies.

NOAA-15 137.620 MHz
NOAA-18 137.9125 MHz
NOAA-19 137.100 MHz

Beside this three NOAA satellites there is also the Russian METEOR M N2 satellite transmitting weather pictures on 137.900 MHz. The band (137-138 MHz) is crowded with the other satellite signals. Usually you can find several strong ORBCOMM signals and wideband ORBCOMM 57k6 signal on 137.560 MHz, just bellow the NOAA-15 frequency. Do not be confused with the aeronautical VDL MODE 2 signal on 136.975 MHz. This can be decoded too, but this is not the topic that I will cover in this article.

Antenna polarization

As mentioned, the satellites are transmitting circularly polarized, RHCP signals. Obviously, to get the best performance, the receiving system should comply to that using the RHCP antenna. Widely used DIY projects include the helical end-fire helical antenna (helix antenna), back-fire helical antenna (QFH helix), crossed dipoles and turnstile antenna while the rarely used are spiral antenna and the lindenblad antenna. We can produce the LHCP or the RHCP with any of the mentioned antenna. Common to all mentioned antennas is the fact that the plane of polarization is rotating making one revolution per wavelength. Such antenna will radiate energy in all planes 0-360 degrees, including vertical and horizontal polarization. The number that describe the quality of the circular polarization is axial ratio. Circularly polarized field is created from two orthogonal fields equal in magnitude. If the magnitudes are equal the axial ratio is 1 or 0db. This give us perfect circular polarization which is difficult to achieve in practice. Axial ratio better than 1db is success, and can be kept within the narrow frequency range, depending on the antenna design. DIY designs will usually result with bad axial ratio mainly producing elliptical instead of circular polarization.

Can I simply check my antenna circular polarization? Yes you can. Transmit the signal using the circular polarization antenna. Use the second linear polarization antenna (simple dipole) in the far field measuring the strength of the signal in vertical polarization. Rotate the same dipole for 90 degrees and measure again the strength with the horizontal polarization. The ratio between this two signals is the axial ratio. It is important to keep the proper distance (far field) between the antennas where the minimum Fraunhofer distance can be calculated $L= (2D)^2/ \lambda$. D is the maximum antenna dimension and the λ is the wavelength calculated from the antenna working frequency.

Cross polarization

In a few words, what is the cross polarization? As the name says, it is the polarization orthogonal to the polarization of the interest, that we are using. If we are using the vertical polarization, the cross polarization is the horizontal and vice versa. Same goes for the circular polarization, if we are using the RHCP, the cross polarization is LHCP. Why is this important for us? Simply, if you choose the wrong polarization the cross polarization will be infinite, in theory. In practice, we can not construct the antenna ideally to radiate just vertical or just the horizontal polarization hence the cross polarization will not be infinite do imperfections but will have the values of 20-30dB. You can check that easily. Try to listen some radio using the vertical whip antenna and turn the whip then horizontally. There should be difference in the signal strength at least 20dB. Same way, if you miss to wind your helix antenna in proper direction the cross-polarization will be 20-30dB and you will end up with poor signal reception.

Let's review the polarization relationship regarding the cross polarization, in practice:

X- polarization	**Vertical**	**Horizontal**	**RHCP**	**LHCP**
Vertical	0dB	-20dB	-3dB	-3dB
Horizontal	-20dB	0dB	-3dB	-3dB
RHCP	-3dB	-3dB	0dB	-20dB
LHCP	-3dB	-3dB	-20dB	0dB

What does it mean for our weather satellite reception? Mentioned earlier, the satellite transmit the RHCP signal. Ideally, this signal should be received with the RHCP antenna. If we made a mistake winding the helix in a wrong direction creating the LHCP the received signal will be lower at least 20dB if not more than it should be received using the RHCP antenna. This will result in a poor signal quality, not acceptable. If we use the linear polarization, either vertical or horizontal the received signal will be 3dB lower then using the RHCP antenna. Mentioned before, achieving axial ratio on circularly polarized antenna lower than 1dB is not a simple task making the difference 2dB. Anybody tried to build the QFH antenna knows that precise replica to calculated values is not easy. All those design imperfections and not a proper phasing may lead to degradation in performance of 1dB easily. As a result, we end up with the RHCP antenna that is only a db or two better than a simple linear polarization antenna, vertical ground plane or horizontal dipole. If you are in the weak signal communications a dB or two is not a small and marginal value but if you are dealing with the strong signals, a dB or two will not make a significant difference. As per test I have done, the required S/n ratio required for the noisy free weather picture reception is 22dB as minimum. During the satellite pass the signal reach 45dB S/n ratio hence there is a lot of signal to cover the 2dB loss due to cross polarization. Would you trade the simple linear polarization antenna design and the -2dB for the complex QFH antenna design? I already did.

Selecting the right antenna

Sacrificing a few dB for the simple antenna design we can select on of the linearly polarized antenna. First we decide the polarization we prefer, vertical or horizontal. A simple vertical whip or even a ground plane vertical antenna may be a cheap and simple to build antennas.

What are the pros for the vertical antenna? Simple design, omnidirectional pattern not requiring the antenna rotator, easy to achieve 50 ohms impedance, low radiation angle that can give us good reception when the satellite is low and distant on horizon. Almost perfect antenna for our satellite reception one may say, but let se the cons for such a design. The biggest problem is coming from the fact that most of the professional radio services and networks are using the vertical polarization too. This should be not a problem if we have a descent selectivity and high dynamic range receiver. The most of the users will use the standard DVB-t dongle grade SDR receiver lacking both, the selectivity and dynamic range. This problem can be solved partially by turning the gain down a bit, with drawback through increased noise figure and reduced S/n ratio. Nearby aeronautical radio service is also using the vertical polarization on the AM. Definitely the planes are the biggest blockers. They are simply 10-12km above us and transmitting usually 25W. You may note that problem through the raised noise floor resulting with the noise strips on the received picture. A vertical antenna will have a donuts shape radiation diagram where the signals above the antenna will be attenuated a lot. At high elevations the satellites are close enough and this drawback may be compensated a bit by shorter distance.

Let's review the opposite, horizontal polarization and pros for the simple dipole antenna. Cheap and simple to build also, but there is another advantage. If we look back to the polarization relationship between the vertical and horizontal polarization we can notice the crosspolarization of 20dB. This free of charge feature will attenuate all vertically polariyed signals from the commercial radios and aeronautical service for 20dB too. We can turn back the gain on our dongle resulting the better reception and picture. The QFH antenna will not give you this advantage. Checking the same crosspolarization table, we may note the difference of only 3dB to the vertical polarization if the circularly polarized antenna is used.
So far,so good. Let's see the cons using a simple dipole for the antenna. The main drawback is the dipole radiation diagram. Horizontal dipole is not omnidirectional antenna where radiation diagram is figure 8 shaped with the deep side nulls. All signals coming perpendicularly to the dipole are going to be attenuated a lot. Rotating a dipole for the best signal is not what makes dipole a simple antenna for our needs.

Both polarization have the problems with the radiation diagram where the vertical suffer from the strong commercial signals too. Considering all, the horizontal dipole is a better option.

Improving a dipole for the NOAA birds reception

Before we continue with the practical building of the dipole antenna let's check if there is any possibility to reduce the deep side nulls in the dipole radiation diagram. As mentioned before, the theoretical radiation diagram is figure 8 shaped. In practice, the side null are not so deep and the signal coming orthogonal to the dipole can be received too, but wekaer comparing to the front coming signals. To overcome this problem we can bend the dipole in a wing shape configuration with the angle of 120 degrees between the dipole legs. Such a configuration will result with the figure 0 (zero) radiation diagram and enhanced signal level coming orthogonal to the dipole. This can be good enough for our purpose.
During the day we should have morning and evening passes for each satellite, at least three good passes. We have three satellites active and there should be at least nine good passes. A good pass will have a high elevation and will give as the reception window up to 15 minutes. The NOAA satellites are almost polar orbiting birds with a northbound or southbound passes. For such orbit it is enough to point the dipole to have the maximum radiation North and South. We do not need to track the satellite as trajectory is almost polar. If you have a clear

horizon you will be able to receive the satellite starting a very low elevations passing overhead and declining the opposite pole direction.

Horizontal V-dipole

Ones we know how the antenna should look like just a simple dipole antenna calculations should be applied. Using the simple formula for the ½ wavelength dipole we get the following:

L(m) = 147 / F(MHz)

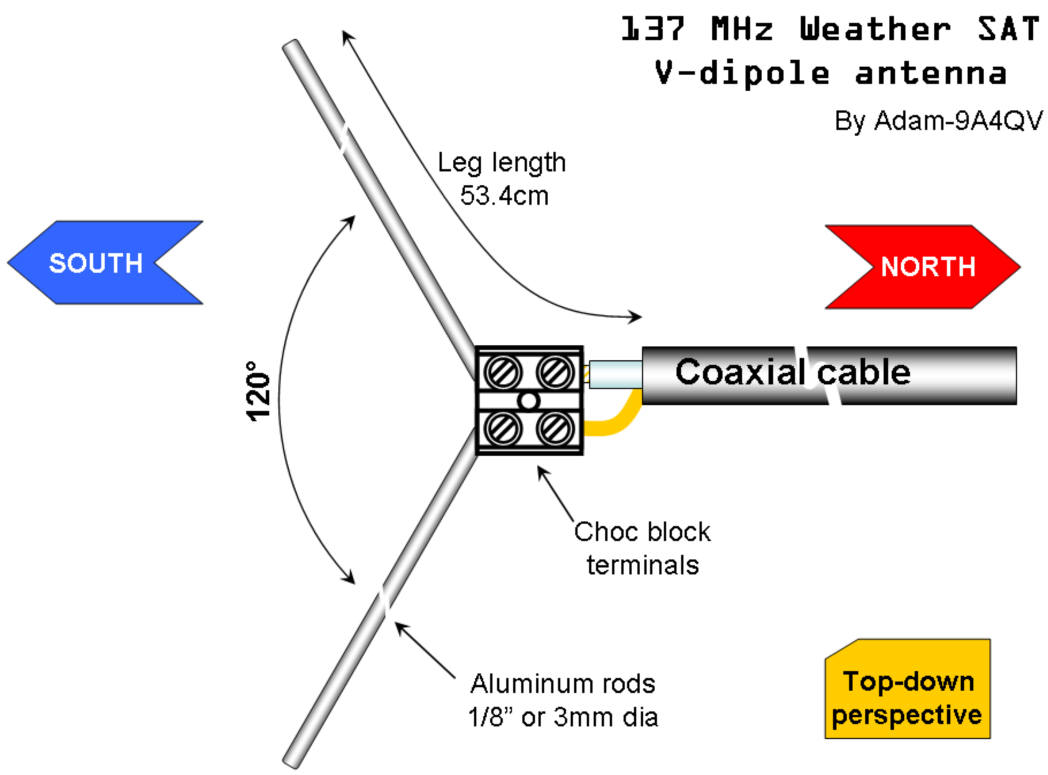
L(m) = 147 / 137.5

L = 1.068 m = 106.8cm

Each leg = 53.4 cm

Important: The length of the each leg should include the connecting wire's length up to the coaxial connector or coax. Keep this length as short as possible but it will be difficult to stay bellow 1.5 cm.

For a dipole legs I did use the 1/8“ (3.25mm) aluminum rods. Do not use a ferromagnetic materials due to increased losses caused by the skin effect. The center of the dipole is made of Choc block terminals where the aluminum rods are secured on one side and the coax from the other side of the terminal. The center hole on the Choc block is used to secure the Choc block to the /mast bracket so the antenna can be easily mounted on the mast/pole. Run the 50 or 75 ohms coaxial cable to your receiving equipment. Bend the dipole legs to create a 120 degrees angle and point the antenna to the North-South direction. You are ready for the NOAA WX sat reception.

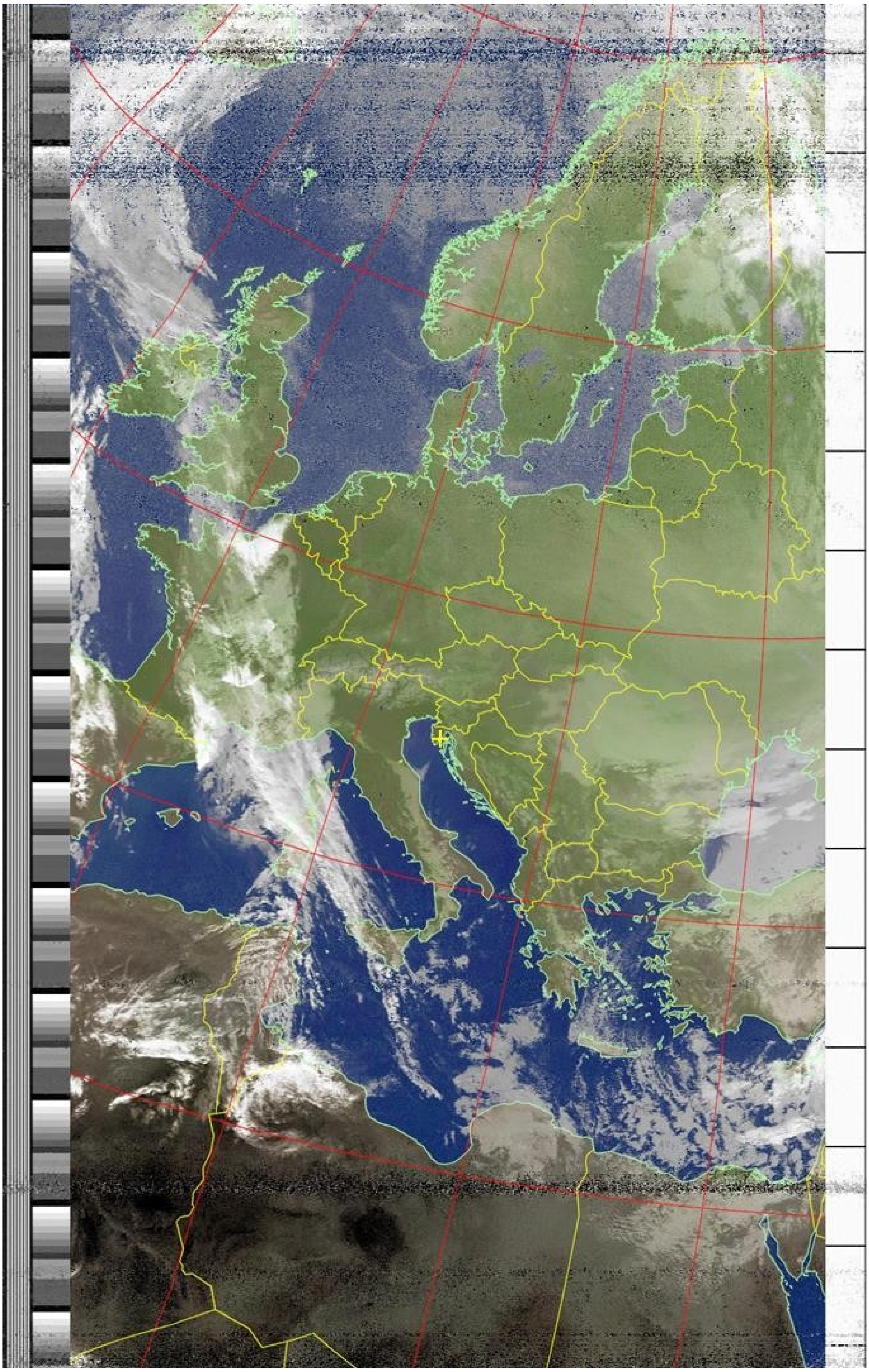


The results

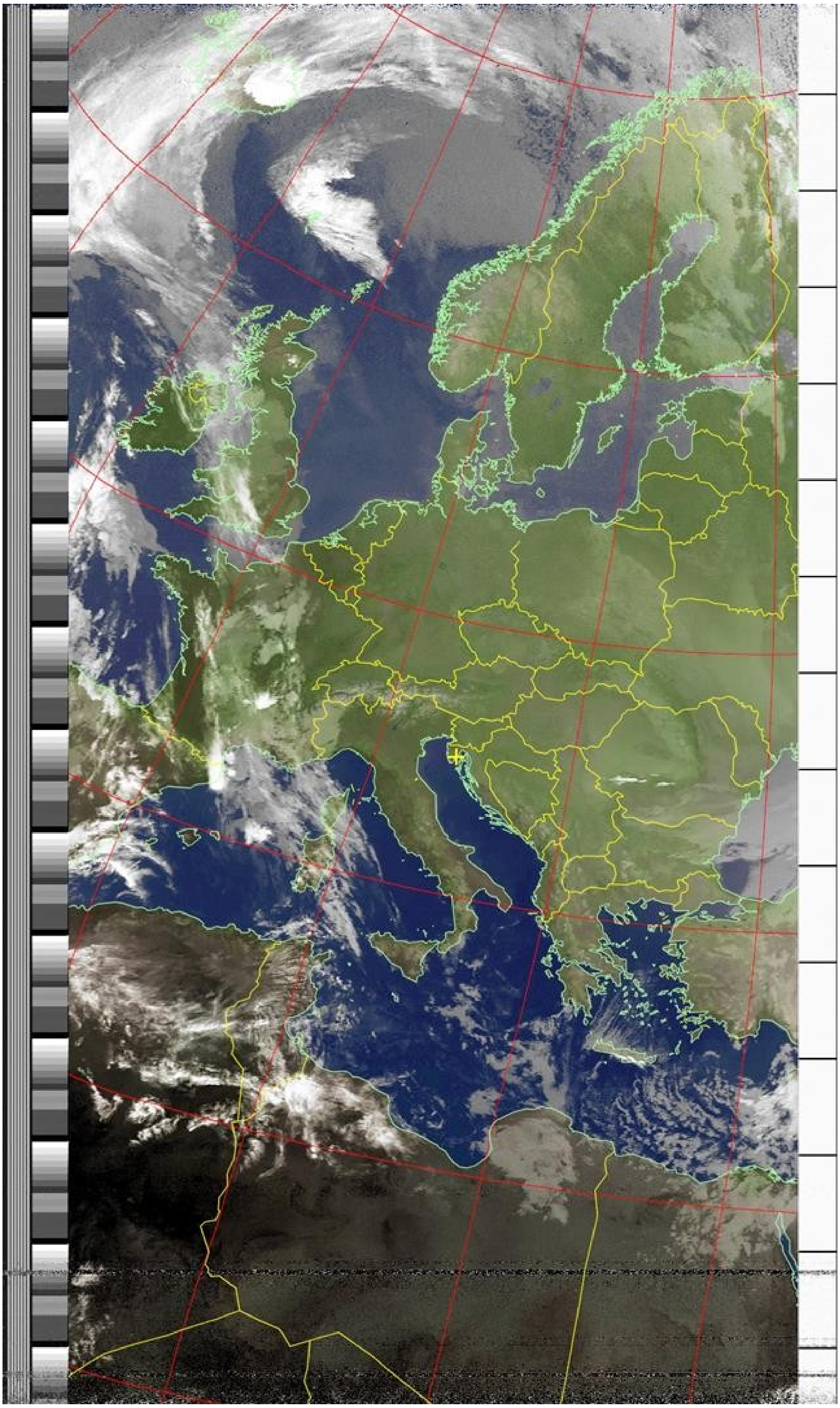
My location is not a perfect but still very good for the satellite reception. I have a clear horizon to the North but hills and a high voltage power lines to the South limiting my south elevation to 7 degrees. The antenna is fixed on the roof antenna pole, 8 meters above the ground.

First test made was including the barefoot setup, usually used by the beginners looking to have fun and quickly receive the weather sat pictures. Starting from the antenna (V-dipole) there was 2 mtrs of RG-213 cable / N connector followed by N/N adapter and 12 mtrs of H-2000 cable. Another N/N adapter followed by 10 mtrs of RG-214 cable with another N/PL259 adapter. Finally, there was 1mtr of flexible but lossy RG-58 cable and BNC/SMA adapter to match the RTL.SDR dongle connector. All together, there was 25 mtrs of the mixed quality cables and 4 coaxial adapters. On the dongle side there was also SMA/SMA DC block used to isolate the DC from the dongle bias-t.
I was really pleased with the received picture quality despite the mentioned limitations. There is a noise in the picture present close to the horizon due to obstacles in the South and a weaker signals on the North. These are really remote parts of the World and the air masses from that areas are not affecting the weather where I am living. I found out that the Signal to

noise ratio (S/n) required for the noise free picture is close to 22dB. Bellow that, the picture start to be noisy, resulting a black strips across the received picture.
First test conclusion, a simple DVB-T dongle and a 20 meters of the SAT-TV grade coaxial cable using the horizontal V-dipole can deliver quality and good enough picture.



Second test was made using the advanced setup. V-dipole antenna and an FM-notch filter with the LNA4ALL with a Bias-t and ESD protection modification on the antenna. The same coaxial length and the RTL.SDR v.2 dongle.



WXtoIMG was setup for 0 to 0 degrees elevation reception to get the complete pass and evaluate the location regarding the blind elevation spots. Performance and received picture was much better, mainly towards the North direction where the picture was received down to 0 degrees elevation. Towards the South, the problem with the hill and the power line is still present but less visible than using a barefoot setup. Another advantage is that the signal to noise is higher and the degradation in the picture caused by strong airplane signals in 137Mhz band is not visible as the S/n is still high, over 22dB to meet the requirements for the noise free reception. The top-notch setup should include the 137Mhz steep bandpass filter and the LNA on the antenna.

Presented V-dipole horizontal plane antenna is a simple DIY project that will deliver good results in receiving the 137 MHz weather satellite transmissions. All performed test delivered very good and excellent pictures despite using a home depot cheap materials and hand tools. This can be a beginner antenna project for all RTL dongle users where the success is guarantied.