The Detection of the NAVSPASUR Radar by passive satellite reflection in Eindhoven, The Netherlands.

2006 March 17
Rob Hardenberg, PE1ITR
pe1itr@amsat.org

This report documents how to receive passive satellite reflections from the navspasur radar over long distance. Receiving the signals intrigues very much keeping mind that the radio signals travel 20000 to 50000 km. I became very enthousiastic about it and the results need centainly some further propagation research. Maybe other amateurs are motivated by reading this document to do there own experiments. Please let me now your results.

The navspasur radar is transmitting a continues wave (cw) and operates at 216,980MHz. The location is Lake Kickapoo, USA. The receiver location is amateur radio station PE1ITR, Eindhoven, The Netherlands. The distance between the transmitter and receiver location is about 8354 km.

The main purpose of the radar is to detect satellites in earth orbit and to calculate the orbital parameters, I believe the radar is not designed to detect satellites on such a long distance as descibes in this document. Especially when the receiver is far away from the radar location. On long distance signal levels are much weaker and the reflection geometry is different. That makes the reception of the signals challenging operation.

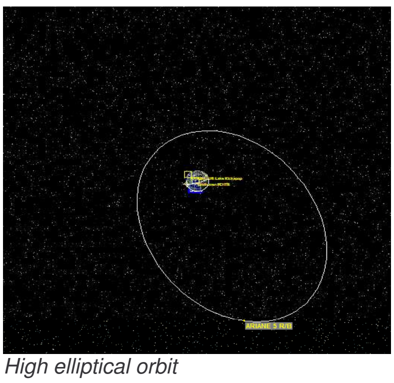
How to receive a reflection in 5 steps:

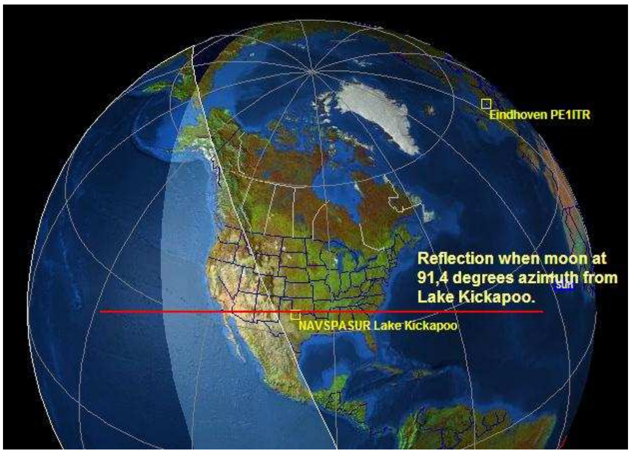
1. Radar Cross Section

To get a reflection the satellite must have a high Radar Cross Section (RCS) value and the right orbital parameters. The Radar cross section is the measure of a objects ability to reflect radar signals in the direction of the radar receiver and is expresed in m^2 . The RCS is not the real dimension of the object but a kind of virtual dimension of a object that can be viewed as a comparison of the strength of the reflected signal from a object as an perfectly smooth sphere or cross sectional area of m^2.
As example I selected in the satellite database[1] the Ariane 5 Rocket Booster, NORAD Objectnumber 25990. The Ariane 5 R/B has a high RCS of 82,2 m2 so the radio signals will have a good reflection on the surface of the object. I use the RCS to calculate the expected signal levels further explaned in step 4. Possible problem with the use of the RCS is that the receiver and transitter location are far away, so the geometry is rather extreme. But I know that and I will review that in the future as fine tuning.

2. Orbital Parameters

There are two important conditions when a satellite is selected from the database[2]. First the satellite must fly through the radar fan beam and second both the transmitter and observer must see the satellite when its flying though the fan beam.
The transmitter location has a latitude of 33° 32' 46" North. So the inclination has to be greater dan 33°. The radar fan beam is transmitting straight up and is approximally aligned east-west. The satellite must fly at 91,4° azimuth seen from the radar through the beam.


High elliptical orbit



NSSS RADAR FENCE it used to be called NAVSPASUR

The NAVSPASUR transmitter is very powerfull with 767KW output. The antenna radiation pattern has the shape of a "fence" straight up and is aligned in the east-west direction. Antenna gain is 40db. See red line in the picture on the left.

Lake Kickapoo 216,980Mhz Location N33 32' 46" W98 45' 46"

The condition that both the transmitter and observer must see the satellite can be expressed in the altitude of the satellite above Earth. The altitude must greater dan 5000km. I searched the satellite database for satellites with an apogeum >5000km.
The Ariane 5 R/B (25990) has an inclination of 58,7°, Apogee height 90017,73 km and Perigee height 22617,41 km. Looking at the orbital parameters it seem a good candidate for the reflection experiment.

Here is the two line kepler set for the Ariane:

```
ARIANE 5 R/B
1 25990U 99066B   06065.58333333  .00000000  00000-0  00000+0 0  1062
2 25990 057.8427 122.9920 5375194 143.9274 358.5432 00.55301846  1451
```

3. Determine reflection time and expected doppler shift

First I make a global calulation of the reflection time. I use the Nova for Windows [3] for this and using the Listing Utility in the program for two observers. I made a listing for 30 days with the position of the Ariane 5 R/B seen at Lake Kickapoo and at PE1ITR. From this list I select the time when the Ariane 5 R/B is at 91,4° Azimuth at Lake Kickapoo and at the same time the Ariane 5 R/B is above the horizon at PE1ITR's.

To determine the exact reflection time and the doppler shift I use another program named TRAKSTAR[4]. This program has in its listing output the Range Rate. The range rate is used to calculate the doppler shift, necessary to tune the receiver. Below two tables with the output listing from TRAKSTAR.

Calculation for Ariane 5 R/B - NORAD 25990

Date	Time (UTC)	Observer	Azimuth	Elevation	Range (km)	Range Rate (km/s)
2006 Mar 08	10:23:00	NLK	90,8738	6,1695	28785,851	1,123033
2006 Mar 08	10:24:00	NLK	91,2378	5,9365	28853,58	1,133943
2006 Mar 08	10:25:00	NLK	91,6006	5,7053	28921,961	1,144737
2006 Mar 08	10:26:00	NLK	91,9623	5,4759	28990,987	1,155414
2006 Mar 08	10:27:00	NLK	92,3228	5,2482	29060,649	1,165974

NLK = The Lake Kickapoo Transmitter

Date	Time (UTC)	Observer	Azimuth	Elevation	Range (km)	Range Rate (km/s)
2006 Mar 08	10:23:00	ITR	220,9012	30,743	26365,083	1,268616
2006 Mar 08	10:24:00	ITR	220,6393	30,3354	26441,68	1,284028
2006 Mar 08	10:25:00	ITR	220,3826	29,9287	26519,196	1,299221
2006 Mar 08	10:26:00	ITR	220,1308	29,5227	26597,617	1,314195
2006 Mar 08	10:27:00	ITR	219,8838	29,1176	26676,929	1,328951

ITR = location PE1ITR

The reflection is to be expected between 10:24u and 10:25u UTC. The satellite will be just above the horizon at the radar. This is not in the peak of the radar fan beam pattern so signal levels will be low. In the second table can be seen that the satellite is above the horizon of PE1ITR. The antenna will be pointed at 220° Azimuth and 30° Elevation in the sky.
Derived from the range rate is the expected receiving frequency. The expected receiving freq is 216,9782MHz. See table below.

Doppler shift			
C	299792,5	km/s	
F_nlk	216,9800	MHz	@NLK
V_r	1,133943	km/s	
F_r	216,9792	Mhz	@SAT
V_r	1,284028	km/s	
F_r	216,9782	Mhz	@PE1ITR

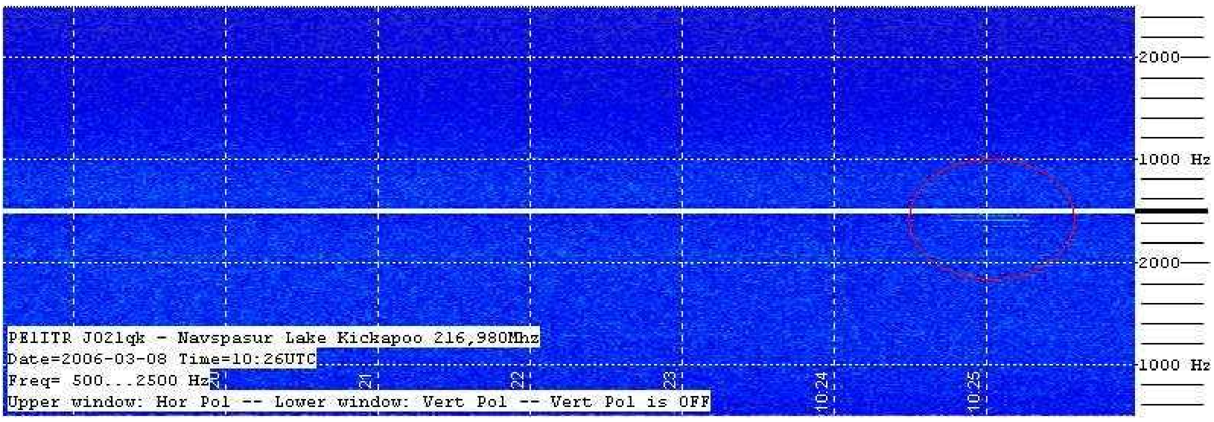
4. Calculate Expected Signal Level

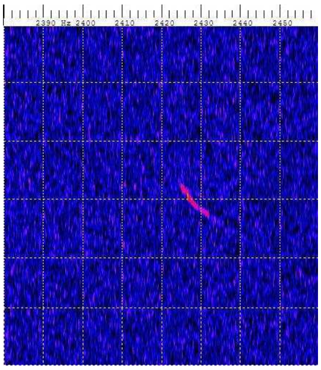
Is the expected signal level detectable by the receiver? In this step the values derived in step 1 and 3 are combined together with the tranmitter and receiver parameters.
I use a 2x14 element yagi on 217MHz. Separate receivers for each polarisation. The antenna amplifier has a noise figure of about 1 db and is mast mounted. I made in excel a spreadsheet to make the link calculation. With the receiver used I can detect signals above 175 dbm in 1 Hz bandwidth. The spreadsheet [5] shows that the signal is 7,26 db and just above the detectable level. So we give this pass a try…

Parameters			Link Calculation		
Transmitter					
Tx power	767000	W	Beacon TX level	88,85	Dbm
Tx ant gain	40	Dbi	Beacon Ant Gain	40,00	Dbi
Pathloss					
F	217	Mhz	Pathloss	170,35	Db
D	28900	Km			
Target gain factor					
RCS	82,2	m^2		27,88	Db
(Radar Cross Section)					
Return Pathloss					
	26500	Km		169,59	Db
Receiver					
Antenne gain	15,4	Dbi		15,40	Dbi
NF	1,2	Db			
Signal at preamp					
			Signal at Preamp	**-167,82**	Dbm
Conversion from NF (db) to Noise Power from Pre-amp					
Temp Preamp	92,29	K			
Temp at Sky	150,00	K			
Noise Power					
Bolzman (Joule/Kelvin)	1,38E-23	K			
Bandbreedte	1	Hz	**Noise Power**	-175,08	Dbm
Expected Signal Level					
			Signal above Noise	**7,26**	Db
			in	1	Hz

5. Ariane 5 R/B Results

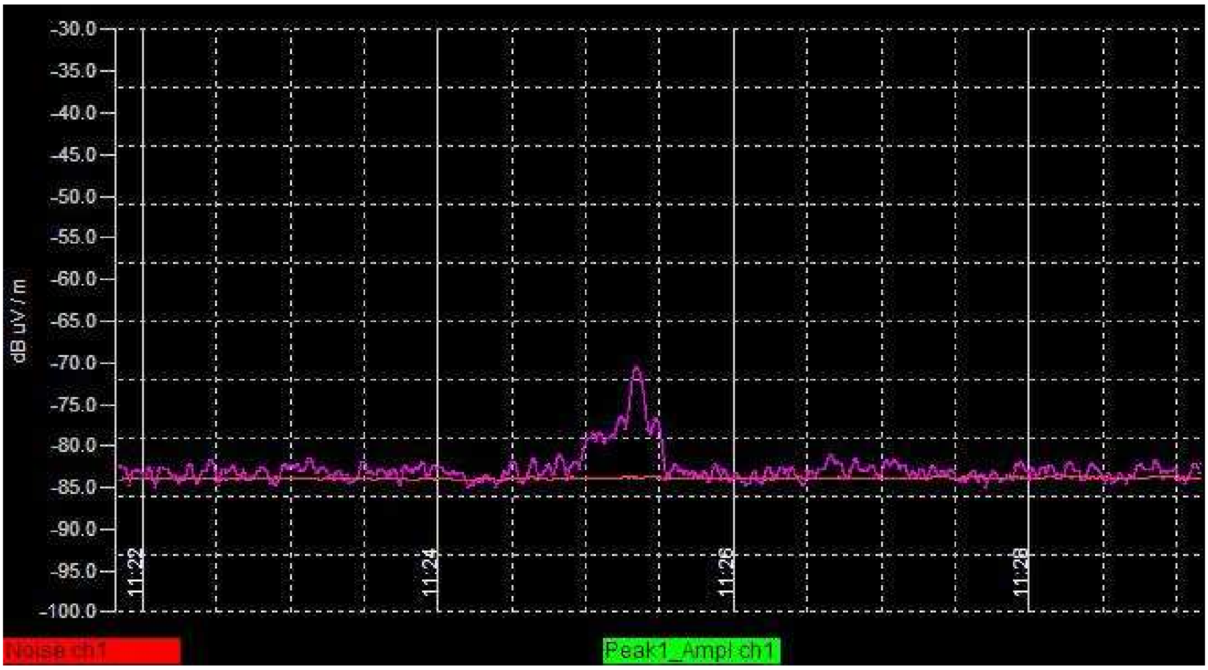
This signal levels can't be heard by ear so I used fft analyse software. Very good for this purpose is Spectrum Lab[6]. In the screenshot below is seen that a signal is appearing between 10:24:40 and10:25:15 UTC. This is in range with the calculations. Its also clear I made an error in tuning the receiver because the signal is just in the observed spectrum display. Only channel two received the refected signal (the spectrumdisplay shows channel 2 was off, but actually it was on).





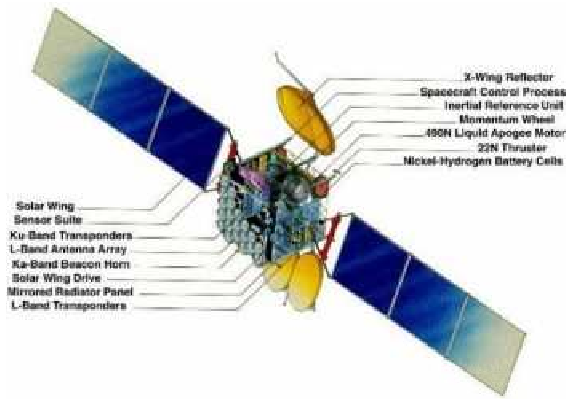
If we zoom in on the signal we get the screenshot on the left. The average doppler shift pattern is consistent with the calculation, exept the change at the upper part of the pattern. I believe that the Ariane 5 R/B is tumbling in space.

In the plot image below we see the peak signal level versus time. We see the signal is about 9 db above the noise level, which is like the value we calculated. In this document I show also the results from the ICO F2 satellite. Here are the signal levels for each polarisation very different in time.



6. The ICO F2 satellite Object 26857

In the next example the selected satellite is the ICO F2. This communication satellite is orbiting at a altitude of 10400 km in a nearly circulair orbit. The inclination is 44.92490000 and the RCS is 52m^2. Om the left picture a drawing I found on the internet of the satellite.



ICO F2 Object 26857 a H601 class satellite

The same way as explaned in the above descibed steps the exact time of reflection is calculated.
In the tables below is seen that the the peak reflection is expected at 7:32:40. The satellite is visible for both the transmitter and receiving observer.

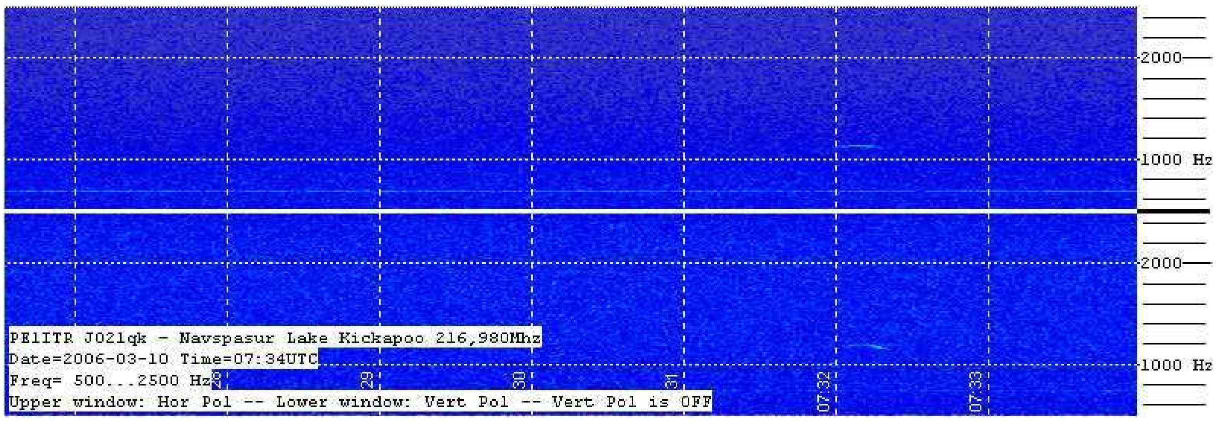
Date	Time (UTC)	Observer	Azimuth	Elevation	Range (km)	Range Rate (km/s)
2006 Mar 10	7:32:20	NLK	92,055	56,6587	11066,59	0,439885
2006 Mar 10	7:32:30	NLK	91,7289	56,5521	11071,02	0,445536
2006 Mar 10	7:32:40	NLK	91,405	56,4446	11075,5	0,451177
2006 Mar 10	7:32:50	NLK	91,0834	56,3361	11080,04	0,456809
2006 Mar 10	7:33:00	NLK	90,7641	56,2266	11084,64	0,462432

NLK = The Lake Kickapoo Transmitter

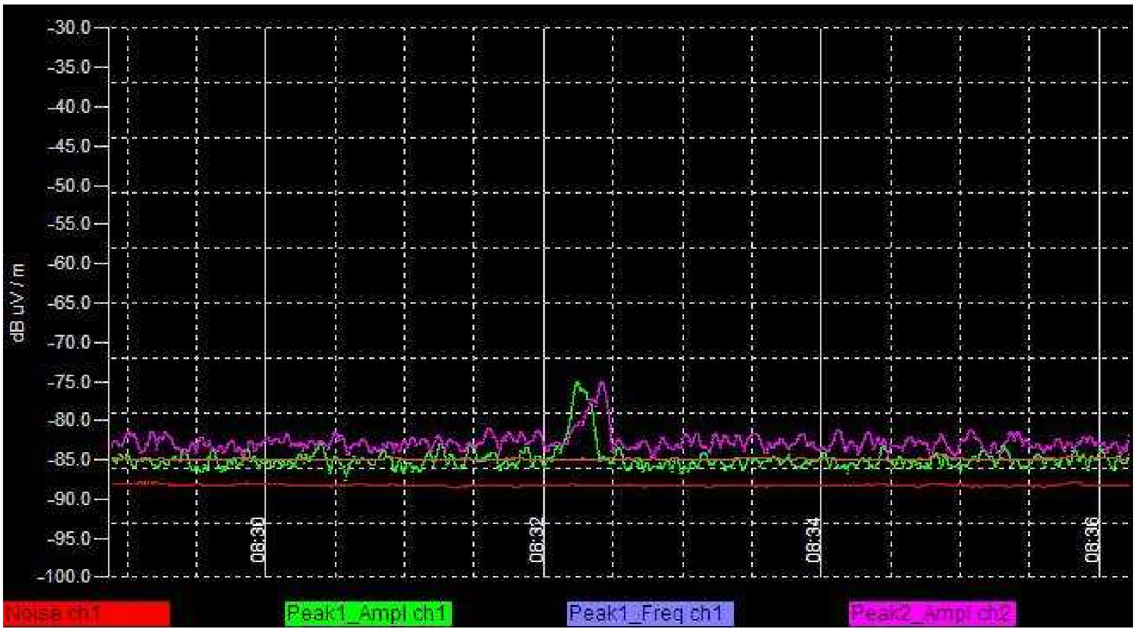
Date	Time (UTC)	Observer	Azimuth	Elevation	Range (km)	Range Rate (km/s)
2006 Mar 10	7:32:20	ITR	282,6121	7,5406	14707,22	-1,52988
2006 Mar 10	7:32:30	ITR	282,6076	7,6851	14691,93	-1,52924
2006 Mar 10	7:32:40	ITR	282,6029	7,8298	14676,64	-1,52858
2006 Mar 10	7:32:50	ITR	282,598	7,9747	14661,35	-1,52791
2006 Mar 10	7:33:00	ITR	282,593	8,1198	14646,08	-1,52723

ITR = location PE1ITR

In the waterfall display below there is plot of the actual received reflection on both polarisation channels. The reflection according to the plot is between 07:32:00 ~ 07:32:20UTC.



To see more about the signal amplitude levels I plotted the peak signal amplitude versus time. Both polarisations are in one plot. Interesting to see is that the peak reflection time is different for both polarisation channels.



7. The receiver

The receiver system used in the reflection experiment is 2x14 element crossed yagi home made by the dl6wu design. The antenna has azimuth andFor each polarisation there is a separate receiver. The receiver is a Yaesu FRG9600 communication receiver with USB demodulation. Each channel has a homemade pre-amp with a 3sk183 GaAs FET. The estimated Noise Figure of the preamp is around 1 db.


2x 14 elements 4 wl yagi antenna


2 x pre-amp with 3sk183 GaAs-FET

The audio from the receivers is feeded to the AWE64 gold soundcard on an old 100MHz pentium computer. De audio is recorded on a wav file and then afterwards analysed. Software used is Spectrum Lab.

[1] The RCS value from a satellite: Space Track, http://www.space-track.org

[2] Orbital Kepler Elements: Celestrak, http://www.celestrak.com

[3] Nova for Windows by Northern Lights Software Associates: http://www.nlsa.com

[4] TrakStar Version 2.65 Satellite Tracking Software by T.S. Kelso: http://www.celestrak.com/software/

[5] navspasur satellite reflections.xls by R. Hardenberg, PE1ITR: http://www.itr-datanet.com/~pe1itr/navspasur.html

[6] DL4YHF's Amateur Radio Software: Audio Spectrum Analyzer ("Spectrum Lab") http://people.freenet.de/dl4yhf/spectra1.html