Reception of Echoes out of Space with simple means of Amateur Radio Equipment

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http://dk5ec.de/Graves-Echo.pdf

Introduction

This article describes ways how to receive echoes of space ships, satellites, meteorites and airplanes with simple means. To achieve this, simple equipment of an average radio amateur or VHF/UHF listener should be sufficient. What you need is a vhf receiver capable of SSB and a 2m yagi antenna. Big antennas owned by moon-earth-moon (EME) specialists will not be necessary, a 4-element yagi should deliver satisfactory results.

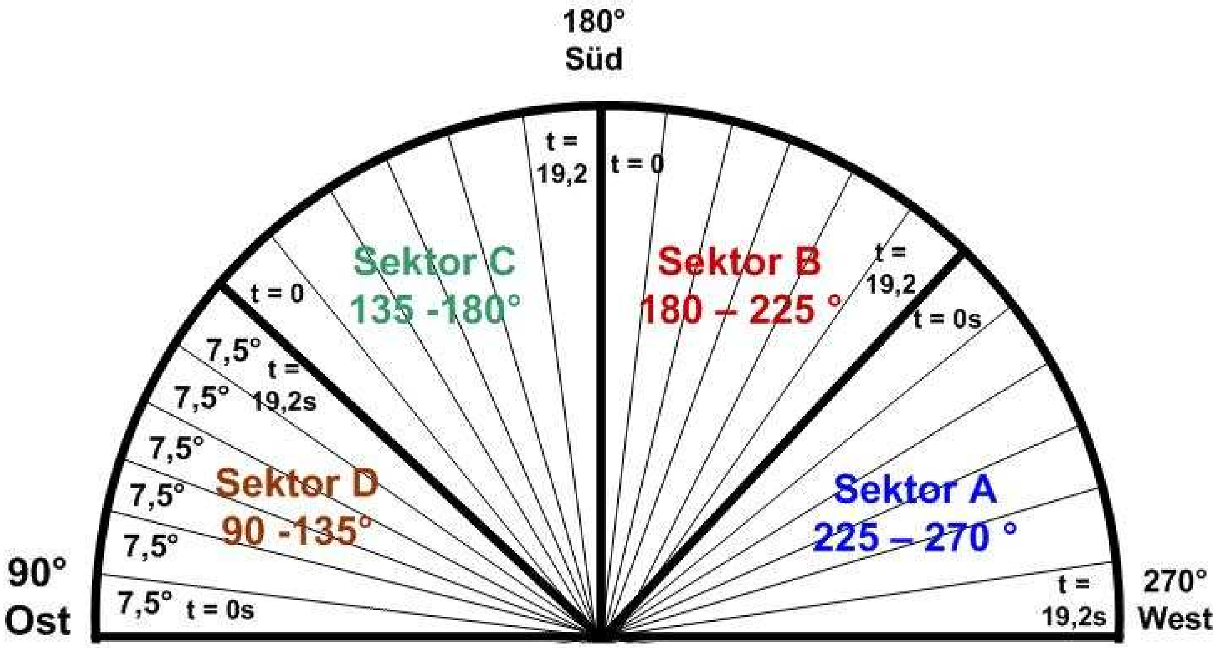
This easy reception of space echoes is possible with the help of the Graves Radar system located near Dijon/France, you should be able to hear its transmissions in most parts of Europe on the ground wave and/or tropo reflections. Echoes of this radar systems should be also heard in other continents. This radar system transmits a constant carrier at 143.050 MHz into space. A second station receives the echoes for further processing. There , the reflected signals will be evaluated, the runtime delays and Doppler shift helps the scientists to define speed and position of satellites, space ships and space junk in order to generate the precise Keppler data for these objects.

I actually got interested in receiving of the Graves echoes out of frustration about my bad results with my poor EME trials after a hint of DD0VF and PE1ITR. I always was frustrated when other radio amateurs were able to work EME stations whereas I even could not see them on the display of my WSJT waterfall. I always thought my antenna system was not working properly. Of course I know that I am a little bit under-equipped for serious EME work, having only 100 W transmission power and a low 2x17element yagi, but it was frustrating not having decoded a single EME station for days. But now thanks to Graves Radar, I can receive strong echo signals from the moon, even the ISS and many other types of “unidentified flying objects” in the sky. If you want to know about my EME experiences as a beginner, see my report at http://www.darc.de/distrikte/g/25/anleitungen/erde-mond-erde/ .

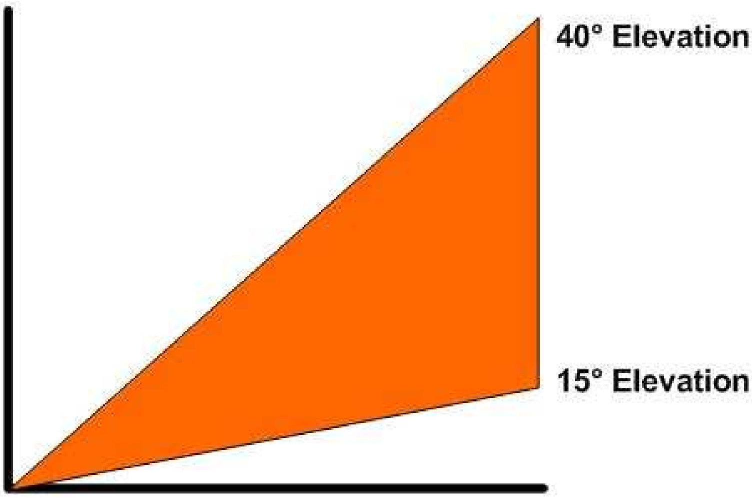
Graves Radar Functions

The Graves Radar system is located near Dijon at JN27SI. It is transmitting a constant carrier at 143.050 with several 10 kW via 4 antenna systems (fields) consisting of planar phased-array antennas. Each of the 4 antenna systems is sweeping an azimuthal (horizontal) sector of 45 ° into southern direction covering all together the direction from 90° east to 270 ° west in relation to Dijon. Each of the 4 antenna fields is divided into 6 sub sectors each having a 7,5° radiation angle, sweeping the sky by time control for 3,2 sec.
All 4 antenna fields are transmitting simultaneously, each with a 7,5° radiation angle

within its 45° sector, that is, a complete sweep is performed after 19,2 sec. and then starts anew. The vertical radiation angle stays constant between 15° and 40 ° elevation.



Graves Radar JN27SI, zeitgesteurte Abstrahlrichtung in horizontaler Ebene (Azimuth)



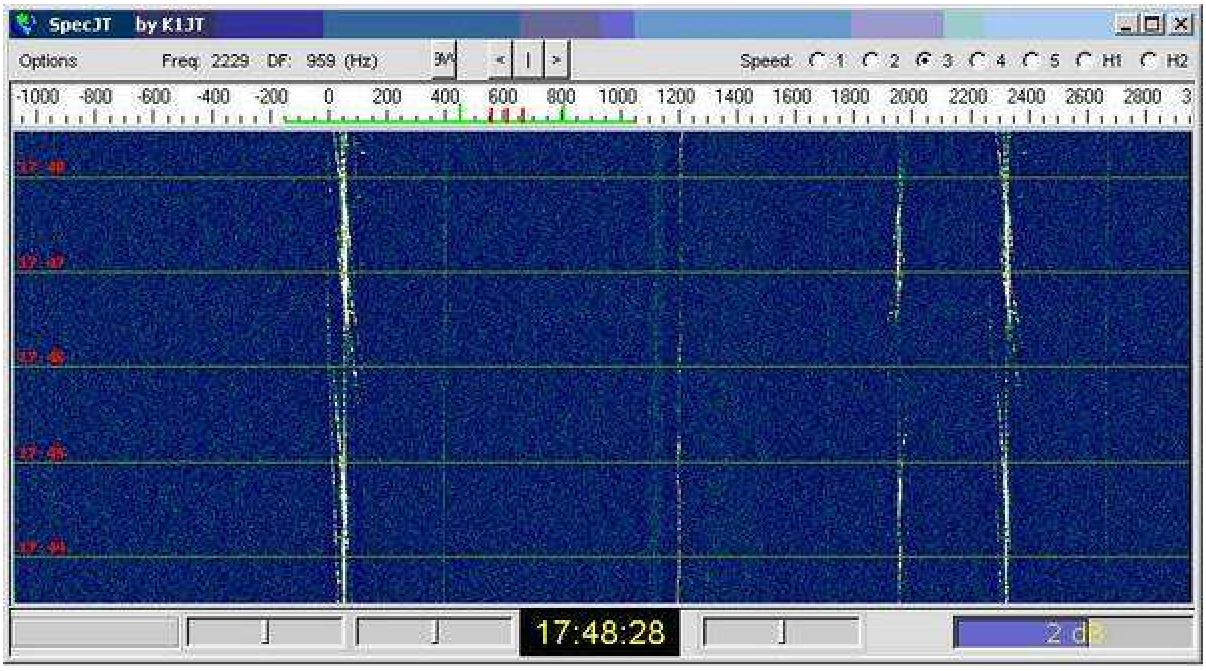
Graves Radar JN27SI, permanente Abstrahlrichtung in vertikaler Ebene (Elevation)

Picture 1: Radiation Angles of the Graves Radar

Of course, best results are received when the observed objects are located within these radiation angles. I also noticed that satisfying results can be obtained when exceeding these angles by +/- 10 °. It is important, however, that you have line of sight between your location and the objects observed. In western direction I receive the echoes starting with 20 ° elevation because a hill is blocking line of sight, whereas into southern directions I can receive the echoes as low as 3 °.

Direct terrestrial Reception of the Graves Carrier

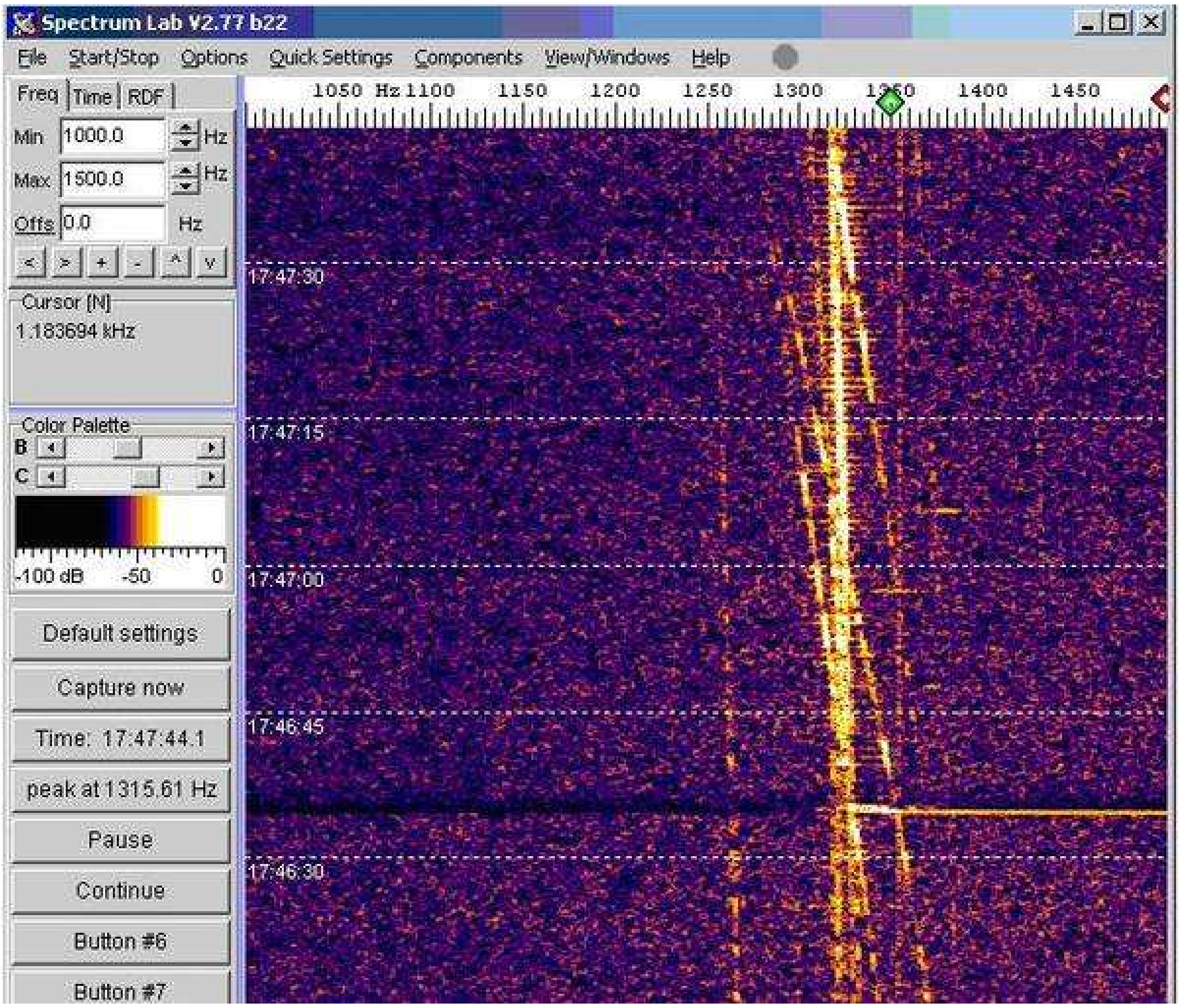
Fortunately, Graves is transmitting just below the 2m amateur radio band at 143.050 MHz. Hence, a normal amateur radio receiver as well as a 2m yagi antenna may be used without efficiency restraints. In order to hear the carrier, the receiver has to be set to 143.049 MHz SSB. For the first trial you should turn your yagi towards Dijon in order to receive the signal directly or via tropo. You can hear the carrier with alternating levels, periodically changing signal strength about every 4 seconds. When looking at the spectrogram of WSJT which is used for EME work, you mostly see a carrier of about 100 Hz bandwidth, instead of the expected single carrier. My station is located about 400 km north east of Dijon, and I am receiving the signals via tropo and airplane reflections. Sometimes the signal disappears completely into the noise level, but WSJT or the Spectrum Lab (freeware by DL4YHF) visualize the signals anyway even if the are way below the noise level.



Picture 2: Display of the Graves signal

In this picture, below the scale value 0, you can see a signal with lots of aslant lines. This is the Graves carrier received with may different reflections. The frequency deviation of the carrier which should have received with a single line, is due to reflections via airplanes departing or approaching from/to my location. These airplane reflections I will describe further down.
Attention: The signal below the scale value 400 and 1200 are so-called birdies (interfering signals), either from my own equipment or others. The signals above 2000 are misinterpretations by my own soundcard or WSJT showing the Graves signal. Please ignore everything above 300 Hz.

The same signal is also displayed by the software Spectrum Lab with a more detailed resolution, you can compare the reception times of the two programs. In this display you can recognize some interesting details. The horizontal line at 17:46:35 is most probably showing a reflection by a meteorite departing from my location with extreme high speed. Because of the less detailed resolution in WSJT you can see this “ping” only as a 2 mm wide line. The bright line at 1320 Hz represents the direct terrestrial reception of the signal from Dijon, the other aslant lines are reflections from airplanes generation a Doppler shift because of their movement to and from my location. WSJT and Spectrum Lab were running simultaneously while recording this screenshots, so you can compare the times and signals at the left side.

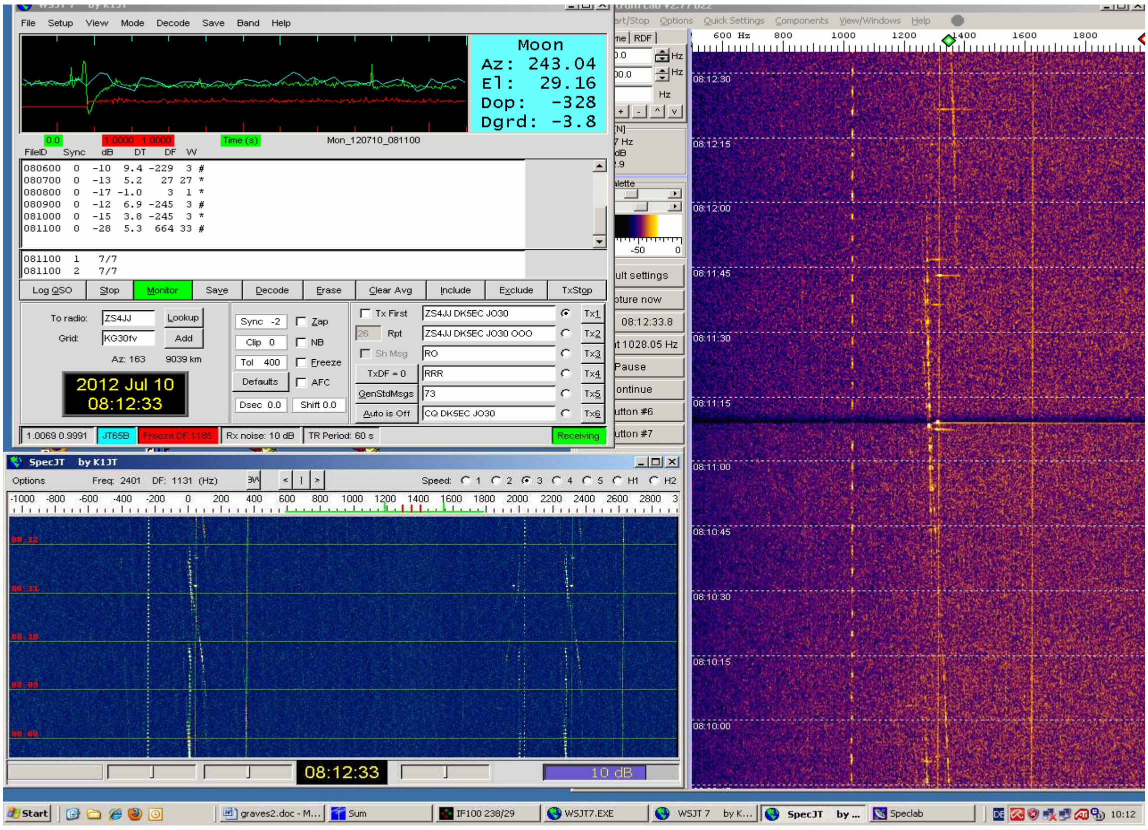


Picture 3: Reception of the terrestrial signal and airplane echos

EME-Echoes of the Graves Radars

In order to receive good echoes of the Graves signal via the moon, one should be aware of the following: Graves is mainly radiating into the southern direction, see Picture 1. Notice that the main radiation angle for elevation is 15…40 degrees. Hence you will get best results if the moon is located somewhere SE, S, SW with an elevation of 15…40 degrees. With these conditions you should be able to hear the moon echoes really loud or see them in Spectrum Lab, depending on conditions. Since the echoes come down sometimes with horizontal, sometimes with vertical polarization or anything between that, it happens that you do not see anything if you have the wrong antenna polarization. My experience is that horizontal polarization is prevailing. A yagi with turnable polarization would be really helpful. You may try a portable yagi and turn it by hand, or switch between your horizontal yagi and your monopole vertical. The polarization of moon echoes changes rather slowly and unpredictably, i.e. every 10…20 minutes.

The following screenshot was taken when the moon was positioned about 240 degrees azimuth and 30 degrees elevation seen from my location. The direct terrestrial carrier can be seen as the rather week signal below the scale value 0, accompanied by some airplane reflections. Since the moon was departing from my location, it generated a Doppler shift of about 300 Hz below the carrier frequency. The exact calculated Doppler shift is shown by WSJT with -328 Hz. As you can see, the echo signal from the moon is very clean and straight, free from other reflections because I receive this signal with line of sight. You also will notice the periodic changes of the signal strength in spite of the transmission of a constant carrier. This change is caused by the periodic change of the radiation direction of the Graves antennas.



Picture 4: Graves Moon Echo displayed by WSJT and Spectrum Lab

The right part shows the same thing with Spectrum Lab, here with higher resolution. WSJT displays the time intervals in minutes, Spectrum Lab in 15 seconds. Here you also can see several horizontal lines, representing echoes from small meteorites.
At times you can receive the EME signals with a simple vertical antenna. However, conditions must be good, and the polarization of the echo has to be vertical at this time. As mentioned before, a portable short yagi steered by hand would be the better choice.

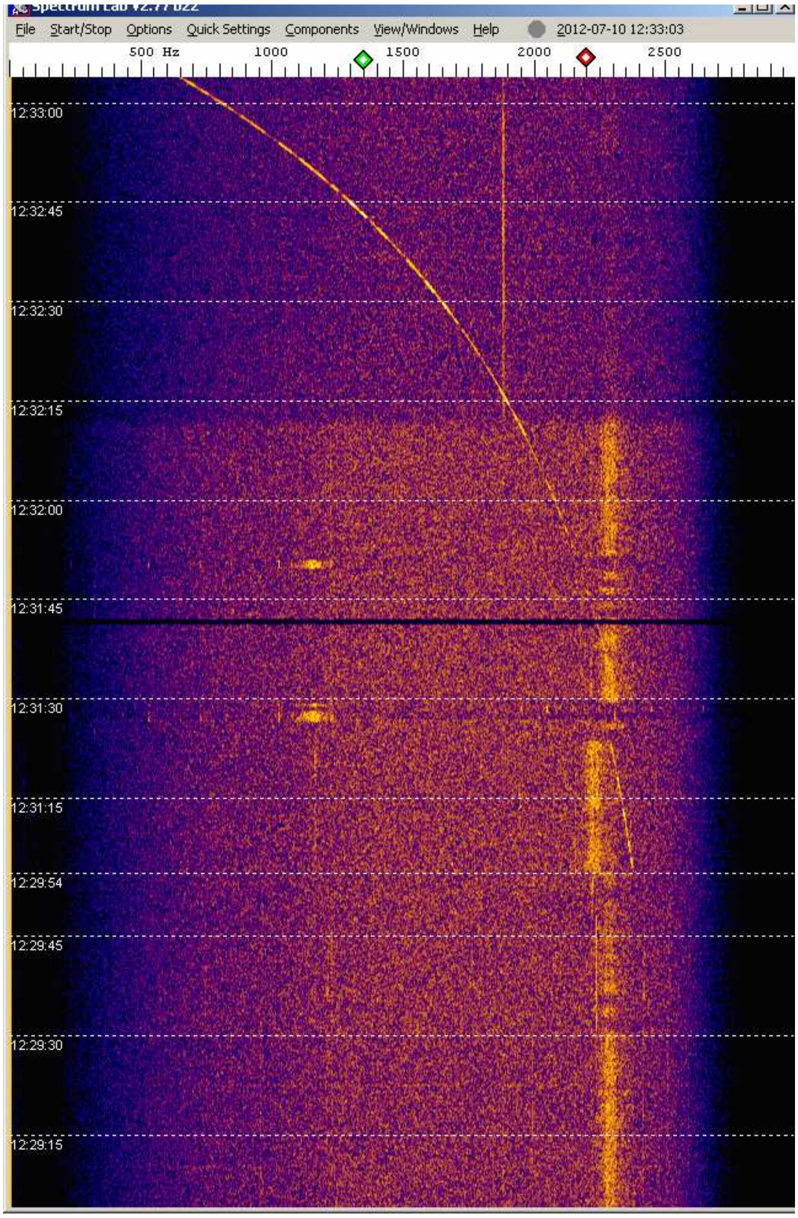
EIE signals via the Space Ship ISS (Earth-ISS-Earth)

Now starts the real interesting part. The radio amateurs equipped for satellite operation have some advantage, but with some manual effort you can manage without. A horizontal dipole might be sufficient, a hand operated small yagi outside would be perfect.
As mentioned before, the Graves radar is used for determining the position of satellites, space ships and space junk. The larger the space object, the stronger are the echoes coming back. Because of the relatively small distance between the earth and of the ISS you may not only see the echoes in Spectrum Lab, but can here them with good signal strength. The echoes from the ISS are considerably stronger than from the more distant moon.

When trying to receive the ISS echoes I used my tracking program SatPC32 for automatic antenna control and Doppler shift compensation. But here I had to learn that a normal satellite tracking program for the Doppler shift compensation was useless. I found out that the Doppler shift of ISS echoes is double the value compared to the one at normal ISS operation, i.e. with packet repeater. This is caused by the addition of the Doppler shift between the Graves radar and the ISS and the additional Doppler shift between the ISS and my ground station.

Because I had to cover now a bandwidth of more then 12 kHz, but having only a SSB bandwidth of 0.3 … 2.7 KHz, I had to find a manual way to change frequency several times during one ISS pass. Since the frequency is moving rather fast, I programmed 7 memory channels of my transceiver in the range of 143.042 … 143.054 MHz, separated by 2 kHz from each other. If I set my transceiver to 143.054 MHz, I can cover the range of 143.054,3 … 143.056,7 MHz to make the signal audible or visible in Spectrum Lab. The same goes for the other 6 channels, that is, the audible range is the shown dial frequency + 0,3…2,7 kHz. The audible tone of a ISS pass will turn always lower coming from west and going to east.
If the echo tone frequency is approaching the lower end of the audible range of 300 Hz , I switch to the next lower memory channel. Here I hear the same signal, but about 2 kHz higher. I can follow in the display of Spectrum Lab how the tone moves from the upper frequency range (right side) to the lower frequency range (left side). This game is repeated as long the ISS will disappear in the east.

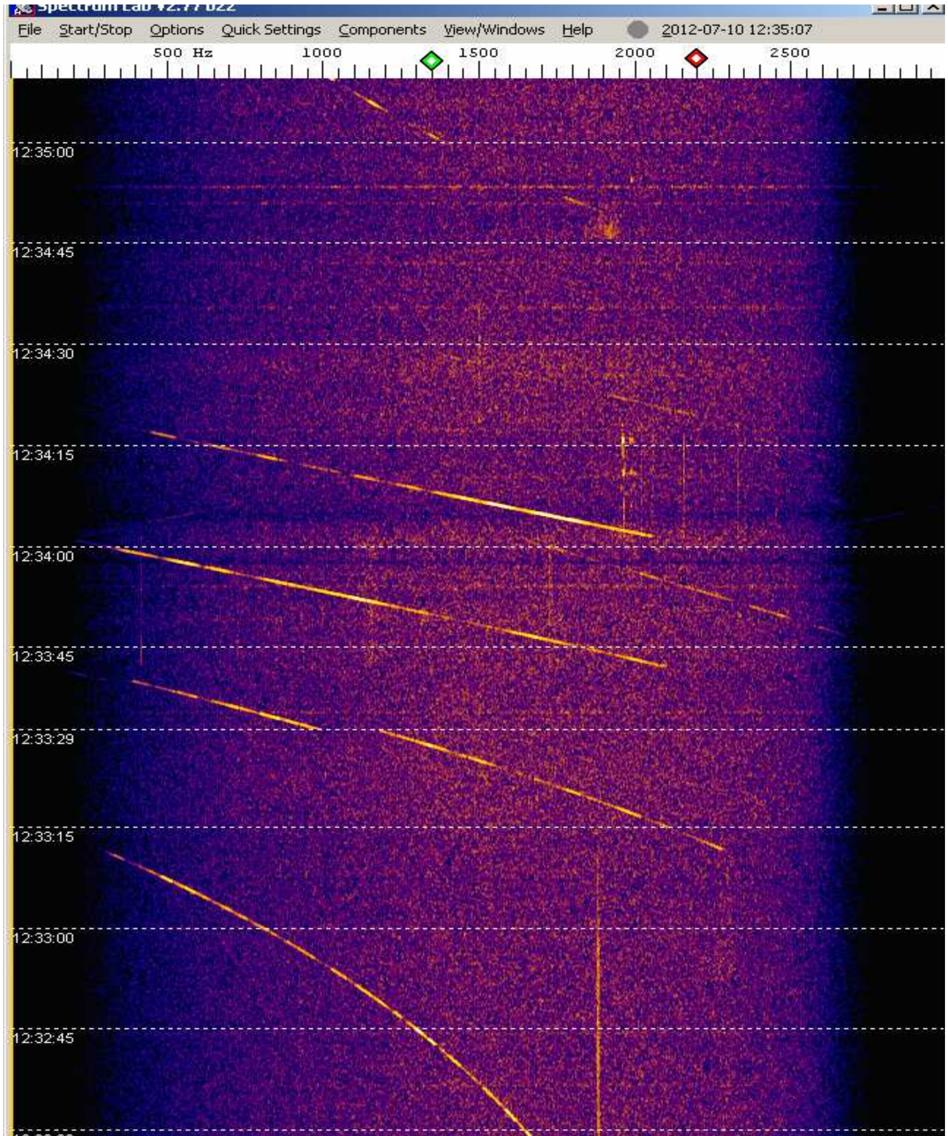
The picture below shows the following:
The display of my transceiver shows 143.054 MHz. The first audible tone, that is the Graves echo, appears at 12:29:30h at ca. 2400 Hz (see frequency scale upper part of display), ending at ca. 650 Hz at 12:33:10h. Hence, I received the first signal of the ISS echo at 143,056.4 MHz.
Remark: Both lines at 1900 and 2300 Hz are birdies (interfering signals) appearing with different signal strengths depending on the antenna direction. At 12:31:25 and :50 you can see meteorites pings.
The steepness of the curves corresponds to the Doppler shift change. In the beginning it changes slowly (nearly vertical), and changes rather fast (nearly horizontal) when coming and going nearer to/from my position.



Picture 5: Echo Frequency of the ascending ISS in the West

The following screenshot is showing the multiple change of channels during one pass of the ISS. The lower curve at 12:32:15h, is showing the change at a dial frequency 143,054 MHz. It is the continuation of the same curve of the previous picture. The two curves above correspond to the dial frequencies 143,052 and 143.050 MHz. The weaker curve in the middle of the picture right of 12:33:45 to 12:34:00h does not fit into the pattern of the other lines, and most probably is a Graves echo of another satellite of space junk passing this moment.

The curve above, starting at the right at 12:32:02, is recorded with the dial frequency 143.048 MHz. Within this frequency range the direct reception of the carrier signal is possible which is seen here of course at 2000 Hz rather weakly, until the next channel change. The line above, dial frequency 143.046 MHz is hardly visible here since my antenna rotor reached its end and started moving 360 degrees, hence loosing the ISS for about 45 seconds



Picture 6: Doppler shifts while changing dial frequeny by + 2 kHz

The following picture shows the continuation of the previous pictures and time intervals, the lower long curve corresponds to a dial frequency 143.050 and the upper curve to 143.042 MHz. When approaching the loss of sight (LOS) in the east, the change of Doppler shift is getting lower and lower. Again for better understanding: the left end of a curve is identical to the right end of a next higher curve.

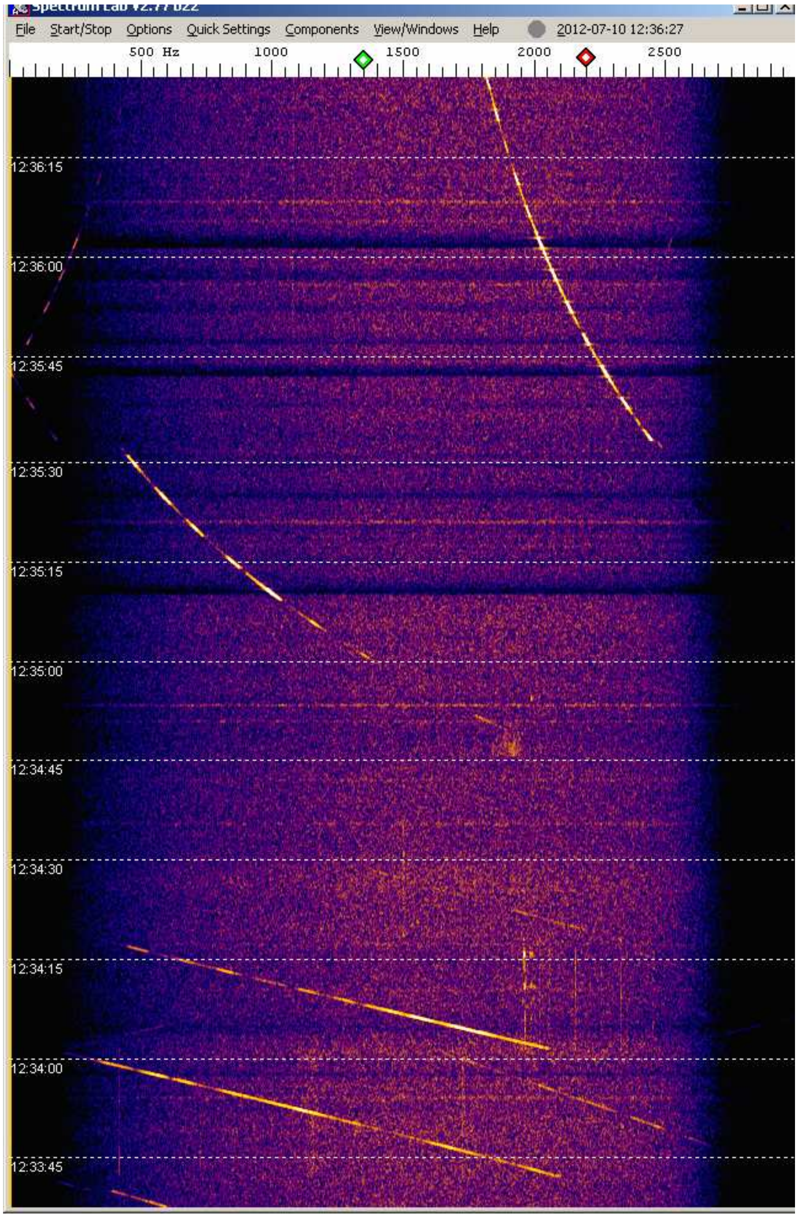
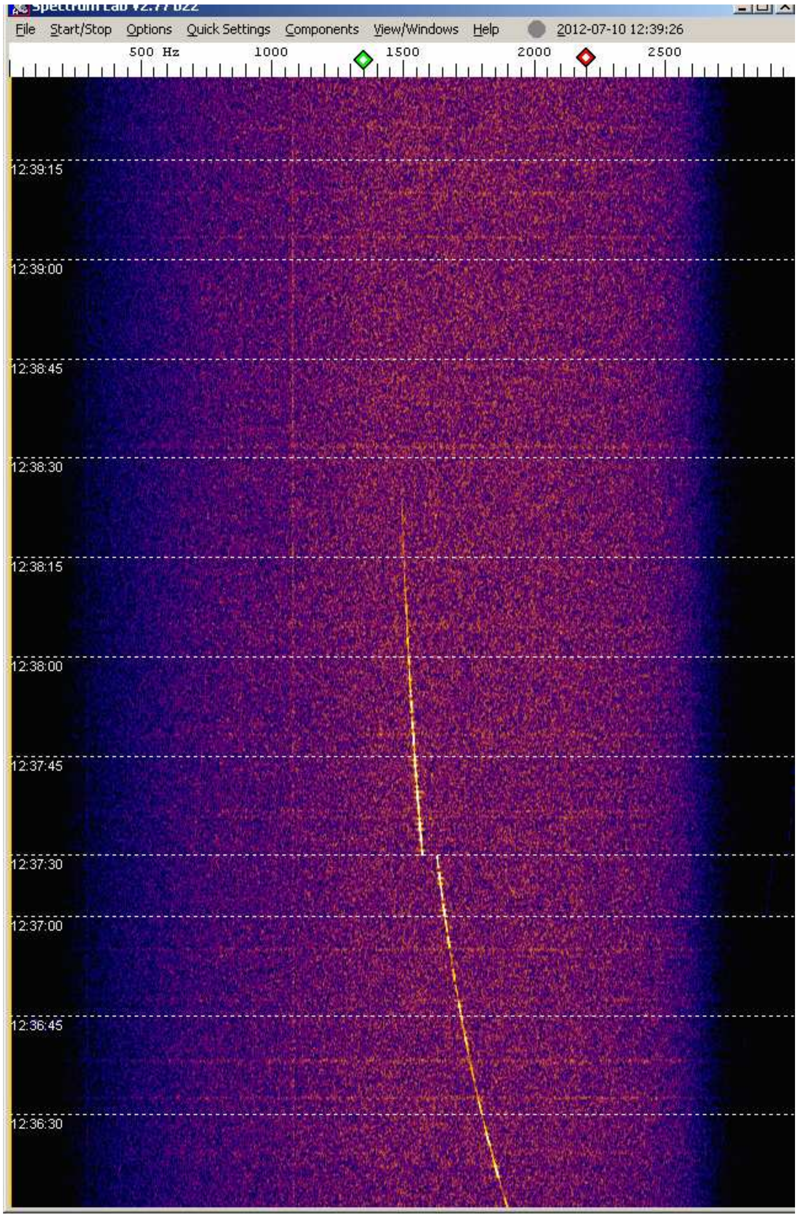


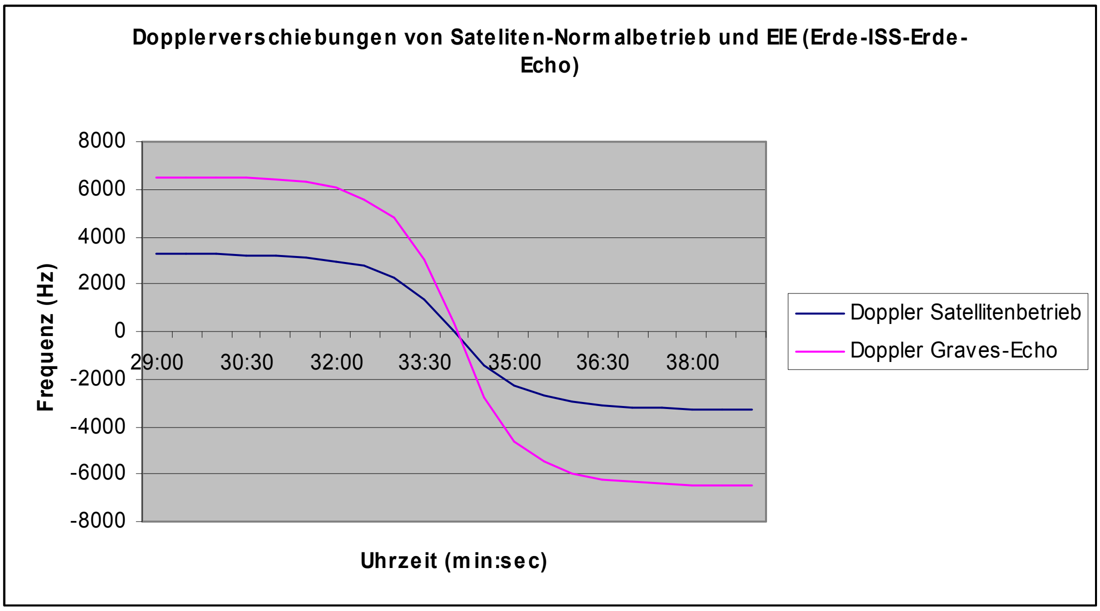
Bild 8: The ISS is approaching the Loss of Sight (LOS) at the east

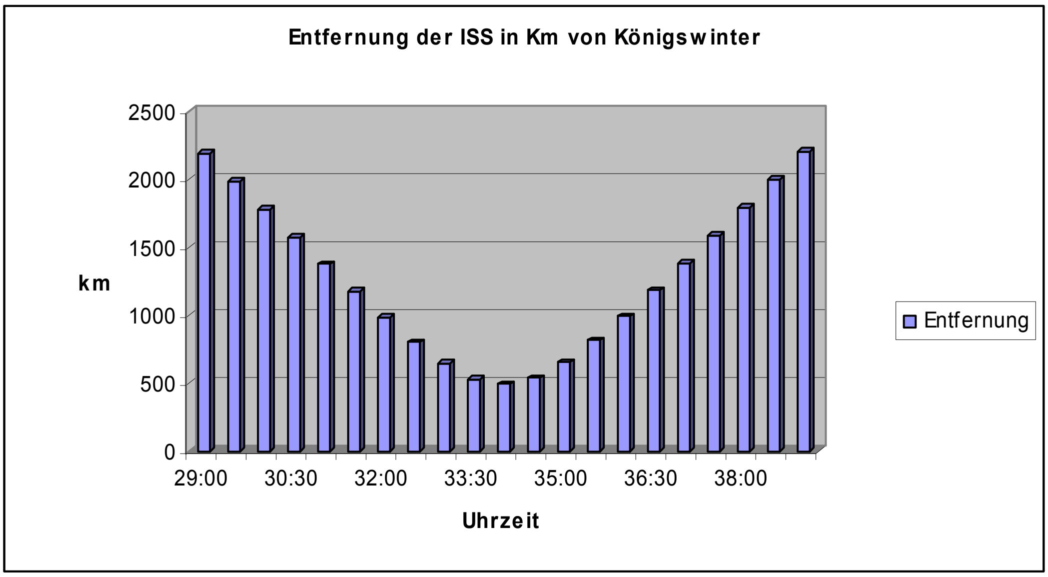
The following picture shows the echo when reaching the loss of sight (LOS) of the ISS in eastern direction. Hence, we could “see” the ISS until a carrier frequency 143.043.5 MHz including Doppler shift.

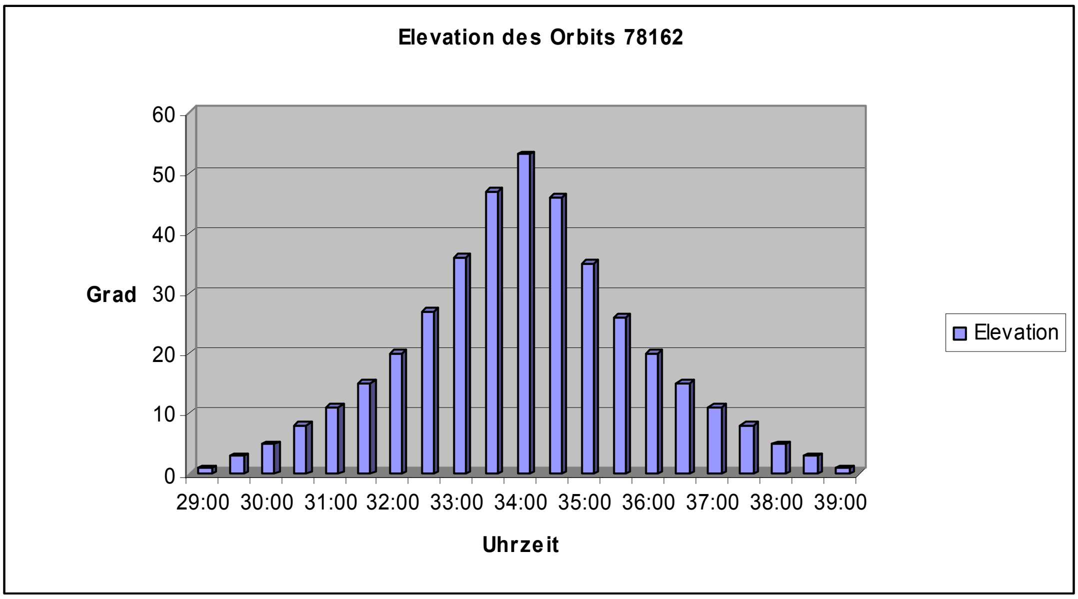


Picture 8: Echo signal of the ISS at around 143.043,5 MHz before LOS

In the following I present my above observations as an oversight in form of diagrams and tables. I did not count on the double values of the Doppler shift compared with normal satellite operation. When making my first measurements I always missed the echoes near the AOS time because I used the tracking program values, and I suspected having the wrong Keppler data. The diagrams show nicely that the Doppler shift approaches 0 Hz when passing by my observing station in Königswinter.


Dopplerverschiebungen von Sateliten-Normalbetrieb und EIE (Erde-ISS-Erde-Echo)
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
Frequenz (Hz)
29:00
30:30
32:00
33:30
35:00
36:30
38:00
Uhrzeit (min:sec)
Doppler Satellitenbetrieb
Doppler Graves-Echo


Entfernung der ISS in Km von Königswinter
2500
2000
1500
1000
500
0
km
29:00
30:30
32:00
33:30
35:00
36:30
38:00
Uhrzeit
Entfernung


Elevation des Orbits 78162
60
50
40
30
20
10
0
Grad
29:00
30:00
31:00
32:00
33:00
34:00
35:00
36:00
37:00
38:00
39:00
Uhrzeit
Elevation

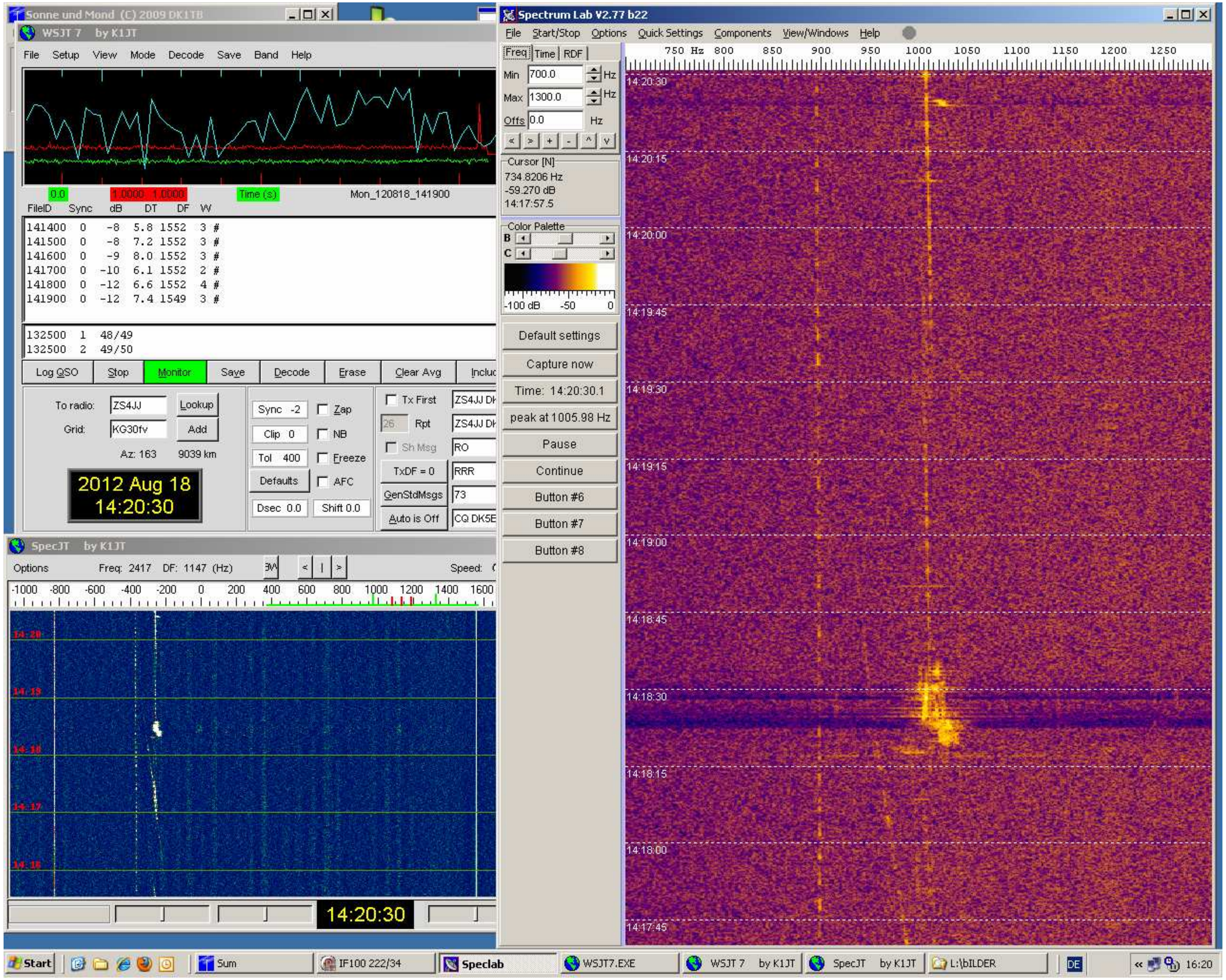
Time 12:29.:00 UTC	29:00	29:30	30:00	30:30	31:00	31:30	32:00	32:30	33:00	33:30	34:00	34:30	35:00	35:30	36:00	36:30	37:00	37:30	38:00	38:30	39:00
time [s] AOS to LOS	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8	8,5	9	9,5	10
Elevation	1,4	3,3	5,5	8,1	11,2	15,1	20,1	26,7	35,9	47,1	53,5	46,6	35,3	26,3	19,7	14,8	11	7,9	5,3	3,1	1,2
Azimuth	285	284	283	282	280	278	274	269	259	239	202	165	146	137	131	128	126	124	123	122	121
Doppler satellite operation	3287	3277	3258	3228	3179	3098	2916	2243	2243	1353	0	-1395	-2266	-2726	-2968	-3103	-3182	-3231	-3261	-3279	-3289
Doppler Graves echo			6.500	6.450	6.400	6.300	6.100	5.600	4.800	3.000	300	-2.800	-4.600	-5.500	-6.000	-6.200	-6.300	-6.400	-6.500		
Distance	2187	1981	1776	1572	1372	1173	982	803	646	532	490	538	657	816	996	1187	1385	1587	1791	1997	2203

Measurements and Data of Orbit 78162, 10.7.2012, AOS 12:29:00, LOS =12:39:00 UTC

Remark: Depending of the direction of the AOS of the ISS I have received the echoes above 15 degrees elevation, because my antenna shows into the direction of the neighbouring houses, hence attenuating the ISS echoes.

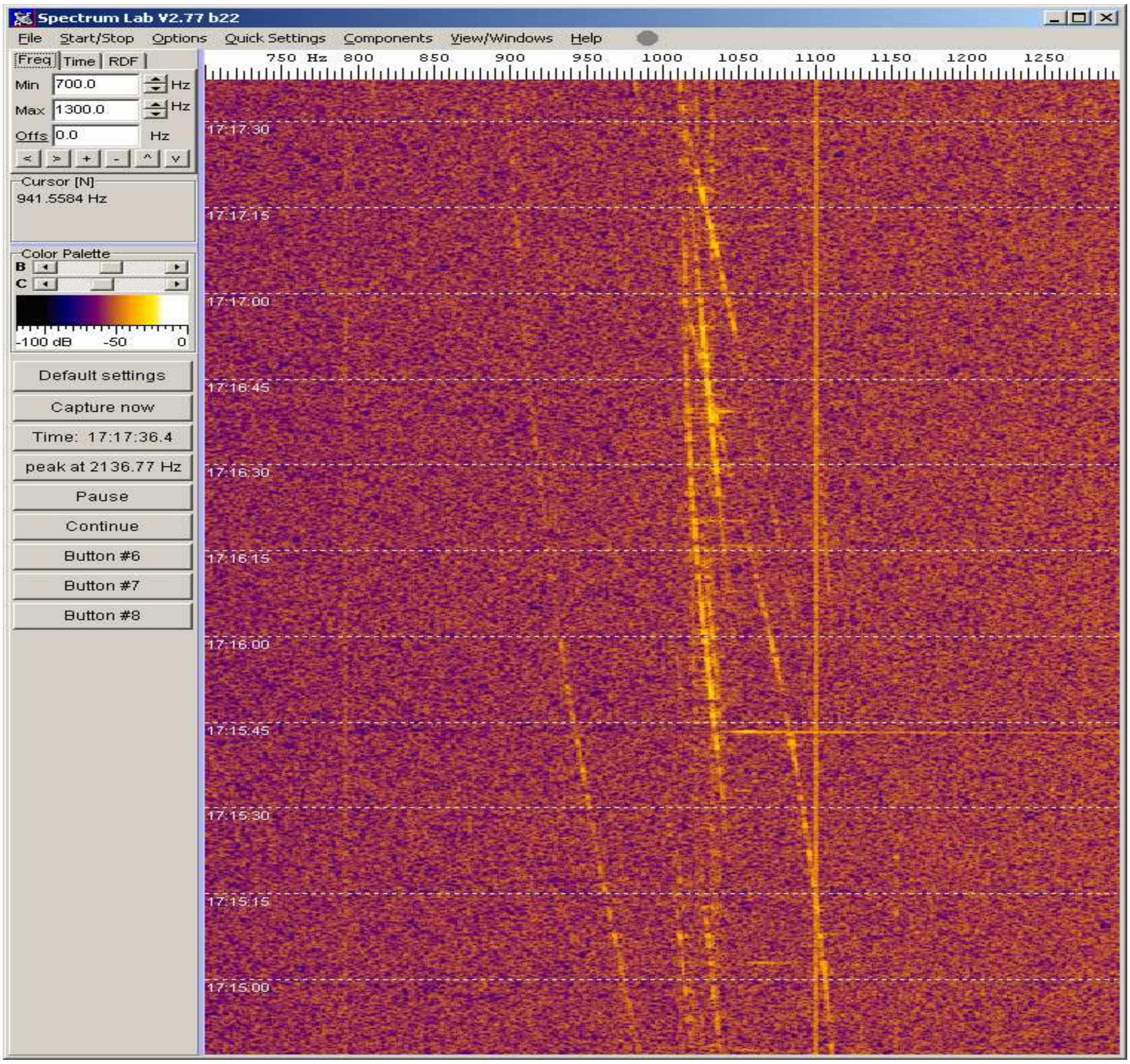
Observations of other “Unidentified” Flying Objects (UFOs)

During my observations I noticed some echo signals with a similar shape as the echoes coming from the ISS, see Picture 5 at 14:33:50h, the shorter curve at the right, not fitting into the pattern of the ISS curves. I assume, these were echoes from other low orbiting satellites with bigger volumes. I downloaded the Keppler data of some NOAA and Iridium satellites, sometimes being visible at dawn, and was tracking them with my automatic antenna system. But I was not very successful, and I could not reliably reproduce the echoes as I could when following the ISS and moon. The Iridium satellites are less in volume and 4 times the distance compared to the ISS, hence the echoes having to bridge the 8-fold distance. Hence the expected signal strength of these objects is by far less.
In the mean time I got to know that the Graves radar often is used by the fans of the meteorite shower and sporadic-E observers since many years. Picture 10 is showing such echoes. At 14:20:25, 14:20:10 und 14:18:50 I recorded some pings of single small meteorites which sounded like “piuuu” in the loudspeaker. You can hear these sounds practically every minute or more. At 14.18:30h I could hear a complete meteorite shower. The field strength of the echoes was so strong causing the AGC of my transceiver to change, and the background noise disappeared completely.
I made further interesting observations when turning my antenna into the direction of the busy Frankfurt airport located 120 km south of my home. Here I could even follow the 2 minute landing/starting cycle of the airplanes, showing the curves periodically every 2 minutes at Spectrum Lab starting and stopping near the carrier frequency. The aslant curve between 14:17:00h (Picture 10 at bottom) and 14:19:00h shows that the airplane started around 14:16:50h and moving away somewhere into southern direction until it disappeared at 14:19:00h from the screen, that is, I lost line of sight because the bird disappeared behind the horizon. In Picture 3 you can also observe some airplane movements. In Picture 12 I displayed he different airplane movements with a drawing and further explanations.
Just to be complete: According to Picture 10 the carrier frequency of the Graves radar is audible at 1000 Hz, and the moon echo is visible with a Doppler shift of -110 Hz. However, the WSJT program showed a Doppler shift of +30 Hz. The difference of two values is most probably caused by the circumstance that the moon was moving away from my location, but approaching Dijon. WSJT apparently shows the correct value if the locations of the transmitter and receiver are identical.



Picture 10: Echoes of the 4 „UFOs“ terrestrial carrier frequency (1000), moon (900), airplane and meteorite shower (14:18:30h)

Picture 11 shows with high probability which runways were used for landing and starting. The shorter curves nearer to the carrier frequency at 1010 Hz most probably were starts and landings at the east-west runway. The Doppler shift is less here because the planes are moving relatively slower from/to my observation point in Königswinter. The longer curve at the right side of the screenshot ending at about 17:17:30h, is caused by an airplane coming from south into my direction landing at the south-north runway. That is, this plane was approaching me relatively faster than the planes using the east-west runway. The long curve at the left side of screenshot starting below 17:15:00h appears to be a plane starting at the north-south runway and moving away from me into southern direction. Of course all planes are using actually about the same landing and starting speed independent of the runway direction, but in relation to my observer location in Königswinter these speeds appear differently when using the east-west direction or the north-south direction.
Remark: the carrier at 800 Hz and 1100 Hz are interfering signals



Picture 11: flight movements at the different Frankfurt runways north-south and east-west

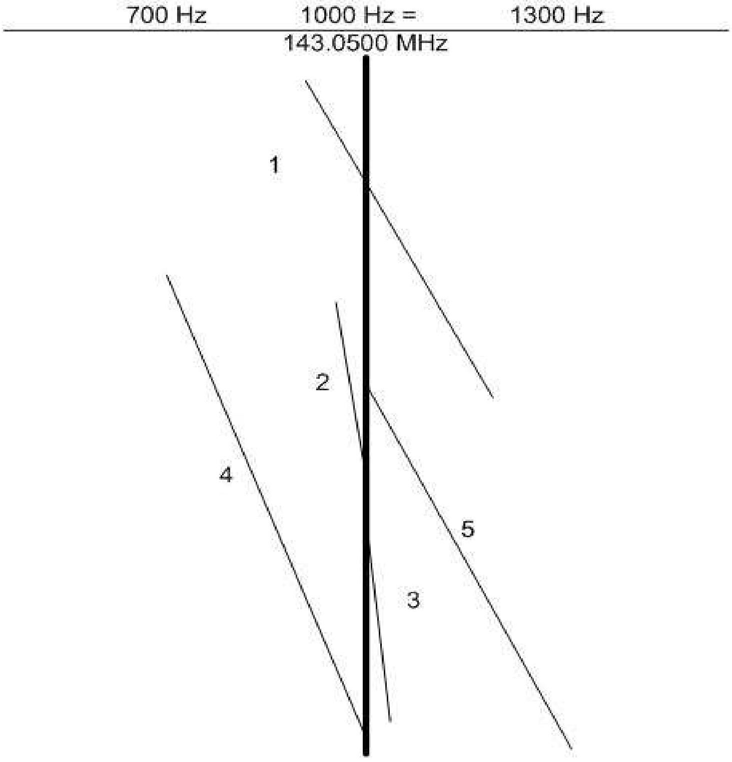


Bild 12: Schematische Darstellungen der Flugbewegungen

The curves of Picture 12 represent the following movements:

1. a plane is moving towards me and then moving away (no landing) of starting
2. a plane starts in Frankfurt (east-west runway) and moving away from me
3. a plane is moving towards me and lands in Frankfurt (east-west runway)
4. a plane starts in Frankfurt (north-south runway) and moves towards south
5. a plane is moving towards me from south and lands at south-north runway

Epilogue

With the help of the Graves Radar System we can receive strong echoes from space objects with simple means, especially from the moon and the ISS. The moon echo (EME) could be received with good signal strength parallel to the terrestrial carrier frequency with a Doppler shift of 320 Hz.
With some tricks the echo signals could be monitored during a complete pass of the ISS, starting after rise (AOS) in the west at 12:29:30h at a frequency of 143,056.4, dawn (LOS) east at 143,043.5 MHz at 12:38:30h.
With the recording of meteorites including showers and airplane movements, very interesting observations could be recorded.

Lots of success with your own tries to receive echoes from space!

73, Karl, DK5EC
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