

Finally on the air on S-band

A continuing account

Sven Grahn

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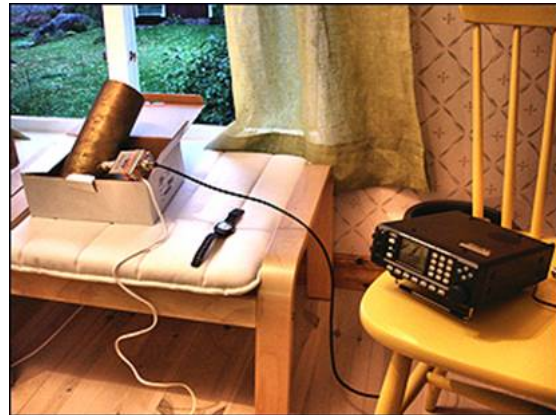
In September 2007 I finally took a deep grab into my pocketbook and bought an AR8600 Mk2 (did not have the guts to buy the AR5000) that covers everything almost from DC to 3 GHz and started to retire all my old radio gear. I had tried S-band tracking two summers ago, when I got the Okos with a WLAN dish (see ["Tracking Oko from Sweden"](#)). But that effort used a down-converter from S-band that is very prone to frequency drift and the IF receiver - an old ALINCO DJ-X10, the battery of which did not charge properly. All in all, it was a temporary effort that I did during the summer at my country cottage. I needed to do something more permanent at home in town - in Sollentuna near Stockholm.

September 16, 2007 - tracking Foton-M3

By the time I got the receiver delivered I had not yet built the 3.5-turn helix that everyone seems to use. However, at the country cottage I had an S-band horn (see [drawing](#)) made out of brass that I built many years ago from a design that I got from Dick Flagg. Over a week-end I brought the AR8600 to the country house and tried to receive the newly-launched Foton-M3, which was transmitting on 2208.163 MHz. That transmitter is part of the Telescience Support Unit (TSU), a TT&C system that serves the ESA microgravity experiments aboard the Foton. The transmitter is phase modulated with an index that leaves some power in the carrier.

My employer, the Swedish Space Corporation, has built the system and our ground station at Esrange in Kiruna was commanding and receiving it. The spacecraft would pass to the north of me, so I put the horn looking out the upstairs window to the north and at 1709-1711 UT on 16 September 2007 I was rewarded by a strong carrier with extremely strong Doppler shift. Foton-M3 was in a really low orbit. The picture below illustrates the receiving set-up - Yet another temporary rig (see picture on the right)!

The horn turned out to have a very wide beam (perhaps 90 degrees total cone angle) and I only had to move it once to catch the pass. To the east there is a high stand of fir trees and the signal was thoroughly attenuated by them. The [polar plot](#) shows the motion across the sky on the next pass. At the green dot the spacecraft passed behind the trees. The signal strength was impressive and the AR8600 S-meter climbed five or six steps up its ladder, I brought the horn to town and was able to track the Foton from our atrium.

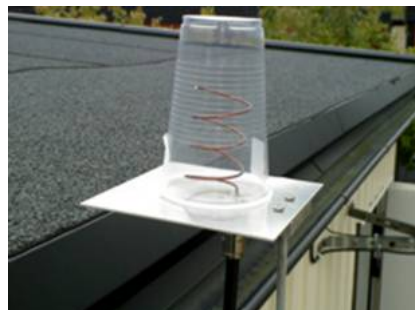


Putting up the 3.5-turn helix

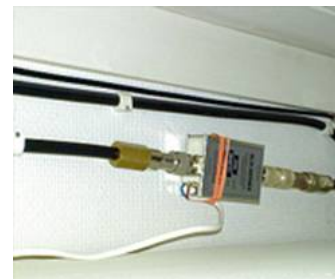
Now it was time to turn to the problem of putting up the little helix at home. I have small antenna pole on the side of our single-level house, but it is a few meters from the radio shack. However, I decided to put the helix on a little bracket as close to the shack as possible and also decided to put the pre-amp (NF=0.5 dB) just where the coax enters the shack near the ceiling. The coax between the pre-amp and the helix is 0.8 meters long adding a few tenths of a dB to the noise figure, but keeping the pre-amp warm and dry out in the open is a non-trivial task. I have decided to use this compromise for the time being. Just as an experiment I bought some plastic beer mug at the local supermarket and put on the helix as a "radome". The helix is just made according to the standard recipe but not yet checked with a network analyzer - work to be performed soon.



It is hard to make the coax shorter!



The "beermug radome"



The "pre-amp compromise"

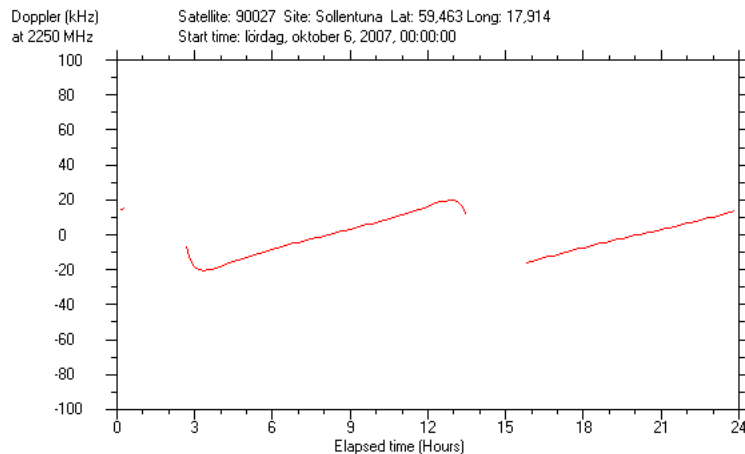
October 1, 2007 - tracking Sweden's orbital observatory Odin

Once I had the helix up I wanted to pick up Odin (cat nr 26702), a satellite the development of which I had helped start in 1990 and which I had overseen when I was the head of the Space Systems Division of the Swedish Space Corporation during the period 1993-2001. It is a great satellite of which I am immensely proud and which has made great discoveries. It carries an S-band transmitter that is supposedly on 2208.163 MHz and it is phase-modulated. The spacecraft has separate transmitters and receivers and there is no coherent transponder. The transmitter is switched on by stored commands in the spacecraft computer. The ground station usually operates automatically. Odin was easy to pick it up as it passed straight over Stockholm on 1 October 2007. I noticed immediately that the little helix has no gain whatsoever below 30 degrees elevation. The signal from the spacecraft vanished very quickly when the spacecraft passes beyond this limit. So the helix has a beam with a total width of 120 degrees. I also noticed that the doppler-shifted frequencies of the transmitter at AOS and LOS were not symmetrical around the nominal frequency 2208.163 MHz. On 2 October I made [a Doppler plot](#) and it was obvious that the Odin center frequency is near 2208.135 MHz. I called the Odin control center at Esrange to find out what they thought. The lead satellite operator pointed out that the transmitter temperature nowadays is about +40 C while the nominal frequency was measured at room temperature. That may explain the frequency difference.

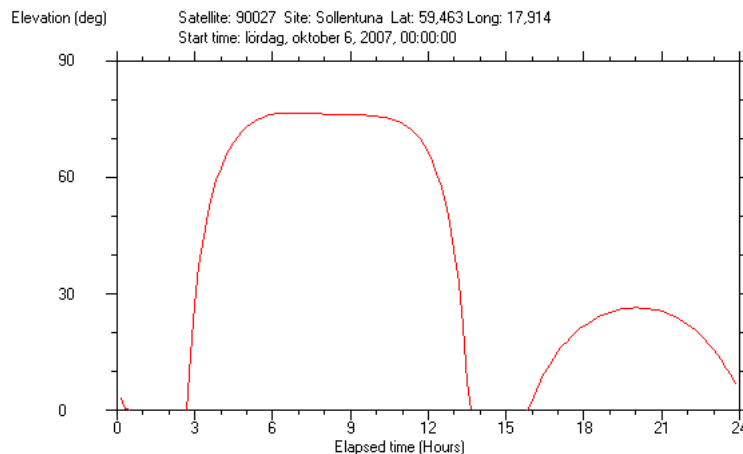
Tracking the HEOs on 2242.5 MHz

Low orbit satellites pass very quickly and are rapidly Doppler-shifted. Therefore without a spectrum monitoring system, they require much attention to catch, so for the beginner the Highly Eccentric Orbit objects that transmit on 2242.5 MHz are an easy target. The behavior of their signals is counter-intuitive after having been used to track low-orbit satellite. The first time I tuned the region around 2242.5 MHz I immediately noticed a carrier about 18 kHz below the nominal frequency and one about 20 kHz above. Soon the higher frequency carrier disappeared. The lower frequency carrier then gradually crept up in frequency during 8 hours or so until it too disappeared at about + 20 KHz when a new carrier appeared at about -18 kHz. And this is the behavior normally observed. Increasing Doppler is of course the result of the satellites ascending to apogee and then coming down. As the do this the range rate vis-à-vis me increases from a positive value to a negative value. To understand the motion of these strange U.S. spacecraft let us plot the motion of one of these satellites during 6 October 2007, in this case the object known as 900027. (1177-39170 km, i=62.8 perigee argument=270 deg),

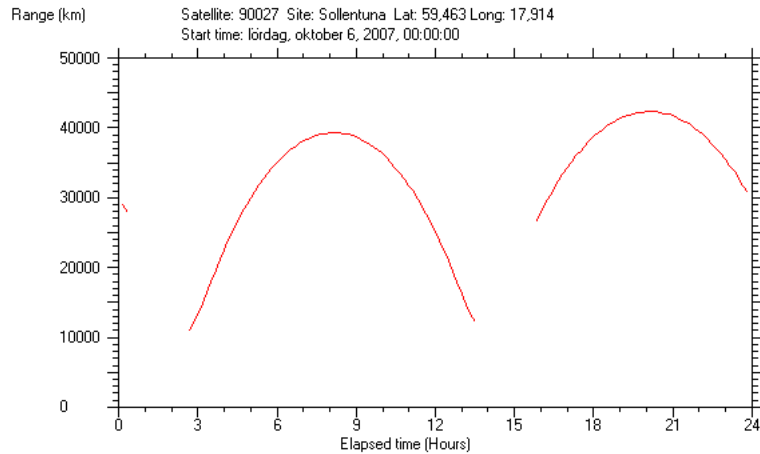
The Doppler trace with "hooks" is the one that comes more than 30 degrees above my horizon. However, the "hooks" usually appear below 30 degrees elevation, so I will not hear them.



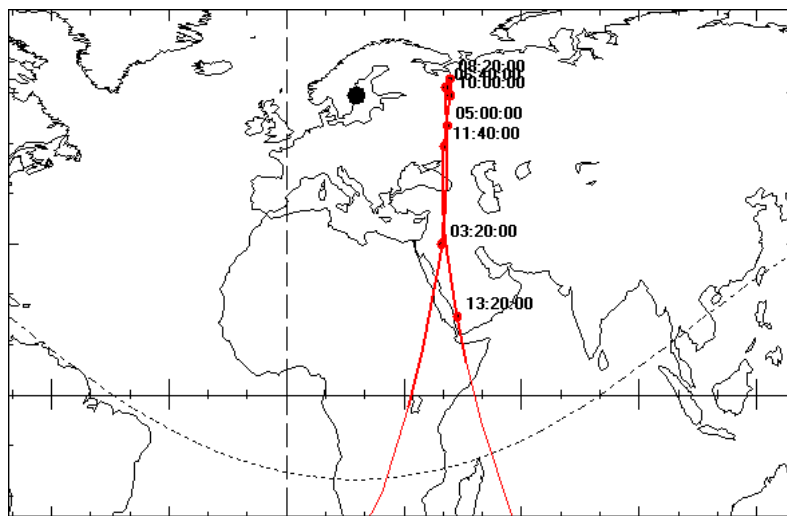
The figure below shows that on the "European Loop" the spacecraft is more than 30 degrees above my horizon for more than 10 hours!



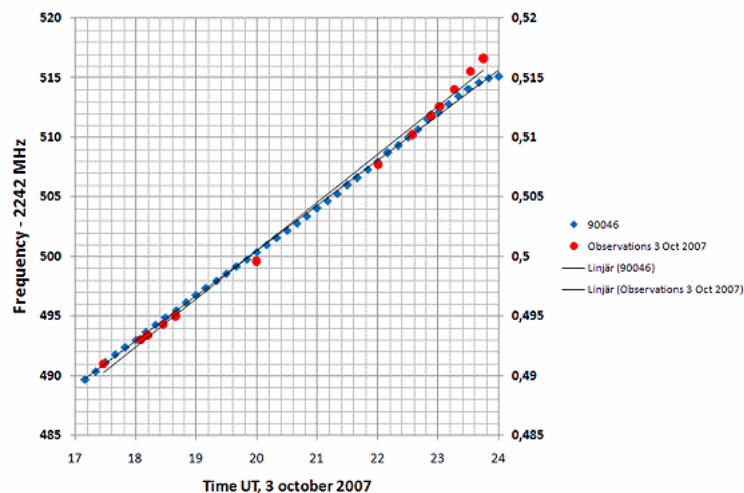
The range vs time plot reveals the reason for the Doppler plot.



The ground trace is fascinating. The spacecraft "hovers" over 41 E for more than six hours. Moscow happens to be located at almost 38 E.



I spent some time recording the Doppler frequency on 3 October 2007 and matching with simulated Doppler data from the known fleet of HEOs (90004, 90020, 90025, 90027, 90028, 90046). The match with object 90046 assuming a center frequency of 2242.498 MHz was the best – but clearly the element set for 90046 was not perfect.

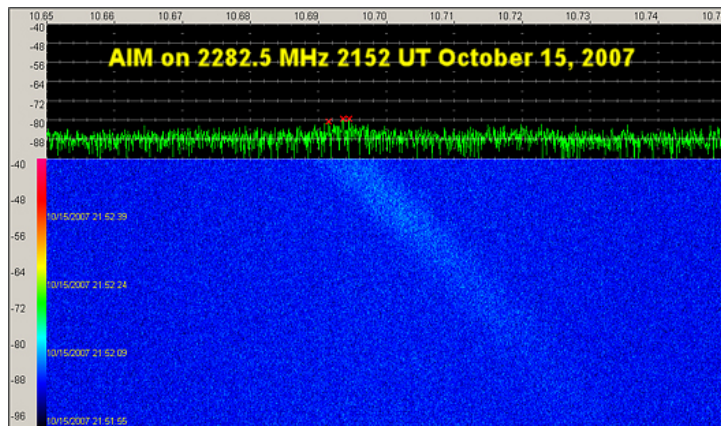


October 15, 2007 – taking the next step, ordering and taking delivery of the SDR-14

I finally gave in and decided to spend 1000 \$ on the Software Defined Receiver, SDR-14, made by RFSPACE. I sent the order by e-mail on 2 October and it arrived on 15 October. I came home in the afternoon and found it in a huge plastic box with a tight-fitting lid that I had left for FedEx to drop it in. I had the device up and running in 30 minutes with my old Dell laptop. The bewildering array of settings obviously needed experience to master, but I immediately saw the carriers of a couple of DMSP satellites on the "waterfall" display..

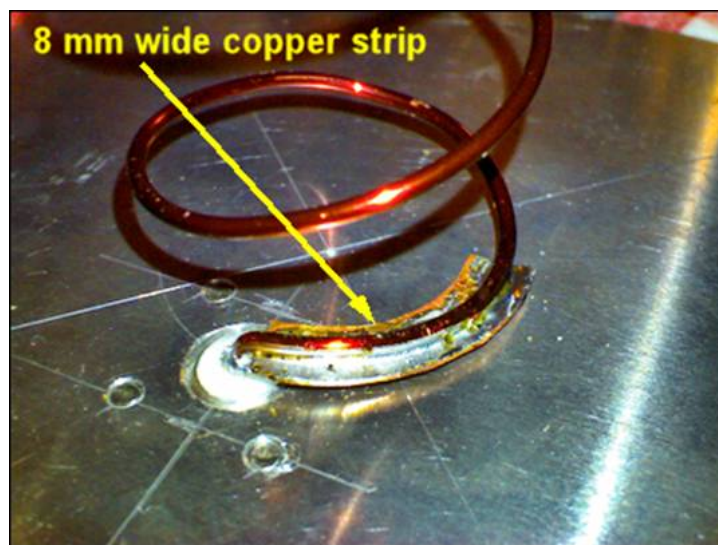
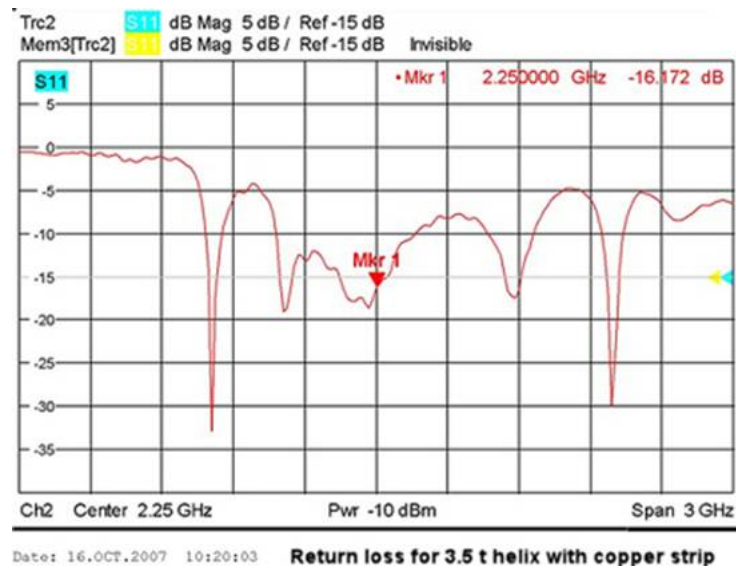
October 15, 2007 – Getting the first spectrograms and suspecting the sensitivity is not very good

I tuned around to various S-band frequencies and certainly saw signals, while from other satellites I got nothing. I particularly tried NASA's AIM satellite that puts out a nice broadband signal. I tried that frequency and watched the waterfall. At first it seemed there was nothing, but after close scrutiny of the image I could see a broadband weak noise increase doppler-shifted across the display (see below). But this looked nothing like that recorded by [PJ Marsh](#). My system clearly suffered from a sensitivity problem.



October 16, 2007 – Measuring two helix variants and the circular horn with a network analyzer

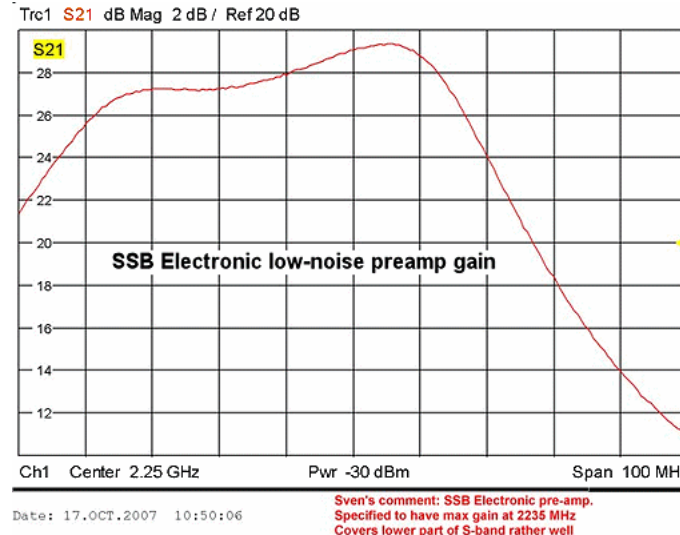
I realized that to be sure that I had a good receiving system, I needed to check out all the components and I was able to get my employer, the Swedish Space Corporation, to borrow one ([Rohde & Schwarz ZVL](#)) for a week (thanks Mikael!). I started with two helices that I have made and the horn used for Foton-M3. The helix made exactly as per the instructions ([here](#)) was not super-good. The return loss was 7 dB. I had made another one with a copper strip soldered on to the first quarter-turn of the helix. It worked much better and has about 15 dB return loss (see below).



The circular horn also displayed about 15 dB of return loss. Not fantastic, but good enough for now. I decided to retire the original helix and put up the new one.

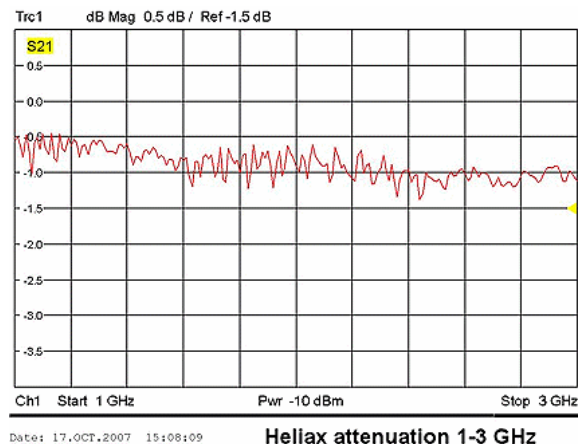
October 17, 2007 – Measuring the gain of the pre-amp, that explains some of the problems

The next step was to bring the pre-amp, the super-duper unit from SSB Electronic to SSC for analysis with the network analyzer. It showed that the amplifier performs really well for the lower part of S-band, but is really lousy for the upper 25% of the band. This, obviously is part of the explanation for the very meager signals from the AIM satellite. Its peak gain certainly agrees with the manufacturer's data, which says that peak gain is 29 dB. Apart from the fantastic noise figure (0.5 dB) the pre-amp is not perfectly suited for covering the whole band.



October 17, 2007 – Measuring the attenuation of coax cables, replacing the crucial one

The coax between the helix and the preamp was a standard RG214 with a connector inside the house that I had to solder in a very awkward position, so I feared that it was lossy. However, I had salvaged some nice coaxes (Andrews Heliax and Suhner) from a decommissioned ground station at the Swedish Space Corporation, so I brought them to the Swedish Space Corporation for measuring the loss. The network analyzer seemed to have some internal reflections, but the loss came out for both cables as 0.8 dB for the Heliax and about 1.2 dB for the Suhner cable. I put the Heliax between the helix antenna and the preamps. The Andrews Heliax connectors are very big, so I had to drill a 25 mm (1 inch) hole in the wooden wall of the house instead of a 10 mm hole!



October 23, 2007 – Sensitivity still not OK, reading the manual and finding that the system lacks gain

I was worrying that there was no noticeable increase in noise level when turning the preamps on. Could it really be that the preamps were not loud enough to exceed the noise of the AR 8600 Mk2 itself. I consulted the handbook and read to my surprise (other specs say 2.5 uV) that the receiver has a sensitivity of 10 uV at 12 dB SINAD using NFM (12 kHz at -6 dB point). Let us assume that the NFM noise bandwidth is 15 kHz. Using these data in the little calculator below you get a NF of 33.5 dB (650,000 K).

<http://www.vk1od.net/sc/RxSensitivityCalc.htm>

This may not be entirely correct, there is also the effect of the FM demodulator, but anyhow the noise temperature at the input is very high. What kind of preamp gain is needed to exceed that? If the receiver NF is 30 dB then it is wonder it is hard to beat the receiver noise! Dick Flagg commented on these numbers:

"... The effect of preamp gain is then very, very important. I did a few calculations as follows for a system like yours with a 0.5 dB cable in front of a 0.5 dB NF preamp driving a 1 dB cable to a receiver with a 30 dB noise figure. I varied the gain of the preamp and calculated the receiving system noise figure and temperature referenced to the terminals of the antenna.

G = 10 dB, NF = 21 dB, T = 41000
G = 20 dB, NF = 12 dB, T = 4168
G = 30 dB, NF = 4.26 dB, T = 484
G = 40 dB, NF = 1.46 dB, T = 116

As you can see you really need lots of gain to come anywhere near getting the benefit of that very low preamp noise figure. Even more gain than 40 dB would help. But I worry about so much gain without bandpass filtering. Particularly with that MiniKits preamp which is probably broad as a barn. It may be necessary to put a bandpass filter between the good preamp and the line driver MiniKit..."

October 25, 2007 – Getting an extra amplifier

I realized that I need an extra amplifier with about 20 dB gain, so I ordered an assembled MiniKits EME103 pre-amp, but being a bit impatient I hit upon another idea. I asked the an engineers at the Swedish Space Corporation if he had any S-band amplifiers laying about. And, in a "electronics candy box", Anders found two MiniCircuits amplifiers (ZEL-1724LN), one used and one unopened in the original antistatic plastic shipping bag. I got the used one on "loan" from the "candy box". It is a remarkable piece of hardware (1700-2400 MHz, Gain=23 dB, NF=1.3 dB) but at a remarkable price (\$275). Thanks for the help, Anders.

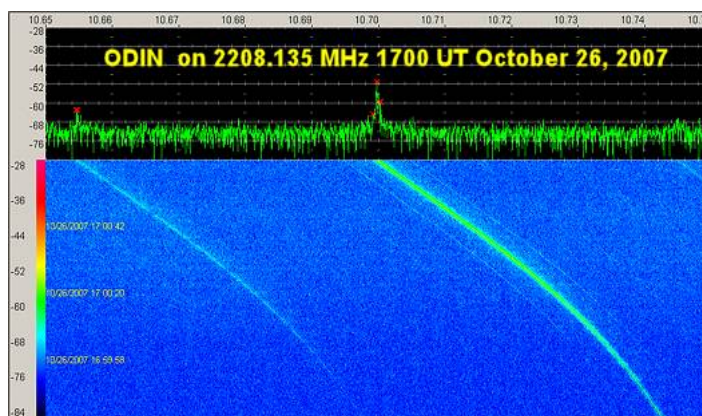


I hooked the new preamp up directly after the SSB Electronic preamp (see below) and now a distinct increase in noise could be noticed when turning on both preamps.

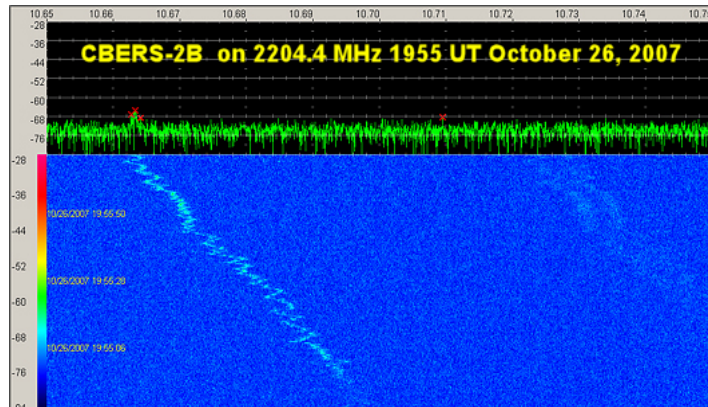


October 26, 2007 – Trying the new system, getting much better results

Here are a few examples of what 20 dB extra gain would do. For example, the Swedish Odin satellite had just looked like a single line across the waterfall. Now there was more detail.



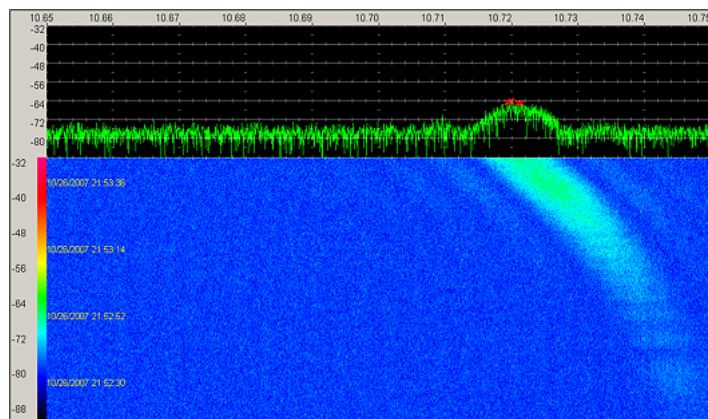
I also tried some other birds, like CBERS-2B that PJ Marsh has shown to have a badly fluctuating carrier. Is it broken? This is what I found:



I also was able to pick up satellites on 2230.0 MHz that I had not succeeded with before. **Cosmo-Skymed 1** was visible on the waterfall at 1725.30-1734.55 UT, **almost 10 minutes!** At AOS the elevation was 6 degrees and a LOS the elevation angle was 9.6 degrees. What happened to my rule that nothing is received below 30 degrees elevation? Well, this satellite certainly punched through that limit. Also saw Metop-1 on 2230 MHz, but it was much weaker than Cosmo-Skymed 1. Envisat on 2225.0 MHz also visible, but it is a weak signal too.

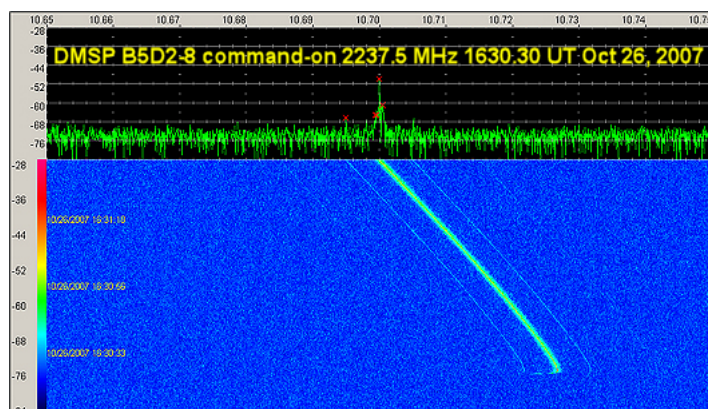
October 26, 2007 – Tuning the AIM

In the evening of 26 October I finally got the chance to see how good the improved system really was and a few minutes before midnight local time I finally received the AIM spacecraft. A marked improvement over the spectrogram from 15 October could be seen (see below).



October 26, 2007 – DMSP B5D2-8 command-on

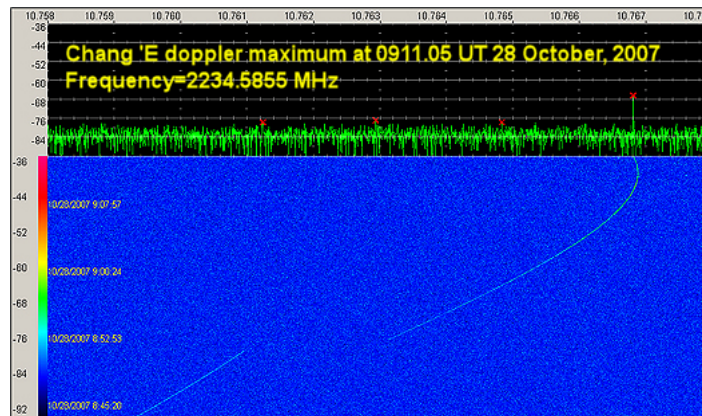
While tuning around at random I kept the receive for a while on the DMSP housekeeping channel 2237.5 MHz. When I looked at it again I saw the strange shape below. The transmitter was commanded on and it is possible to see how the transmitter frequency quickly stabilized. But who commanded it on? Was it a ground station or the spacecraft computer? It turned out that the spacecraft was DMSP B5D2-8.



October 27 and 28, 2007 – Tracking Chang'E

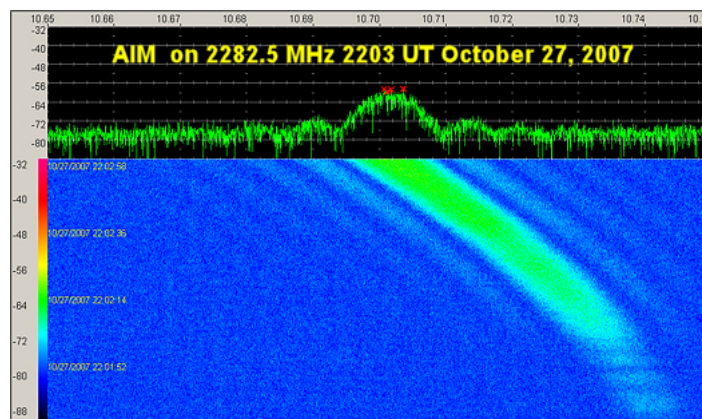
When I switched on the receiving system in the morning (local time) on 27 October 2007 I had little hope of picking up anything from the Chinese lunar probe Chang'E. The elevation above my horizon would barely touch the 30 degree lower limit of my helix coverage. But I immediately picked up a weak carrier and set the SDR-14 to move really slowly so that I could get a good overview of the Doppler curve. I had to do gardening work (cutting a high hedge) during the hours before noon, but when I came into the house at 0920 UT after finishing the hedge work I saw that there had been a frequency shift, a Doppler maximum and Loss-Of-Signal. I had run predictions for Doppler shift and elevation angle using the original element set for Chang'E (actually a secondary object but it had roughly the same orbit as the moon probe) and those predictions showed no Doppler maximum or setting below my horizon before 1000 UT. Clearly, if this was Chang'E, the orbit must have changed. I logged into Space-Track and found that this was indeed so. A

simulation with the new orbital elements confirmed that I had indeed seen Chang'E (read more [here](#)). The spectrogram below shows the Doppler maximum on 28 October 2007.

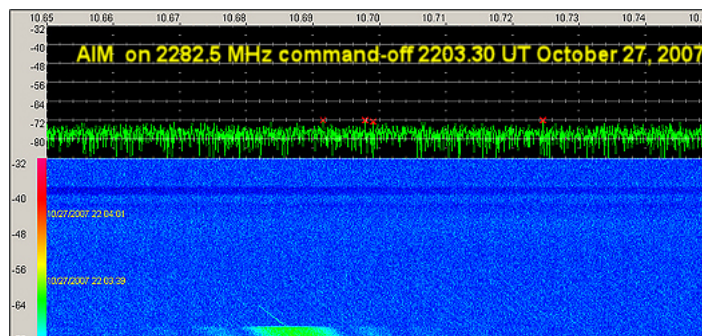


October 28, 2007 – Another go at the AIM satellite

I tried AIM again at midnight 27/28 October 2007 and I received a really nice spectrogram (see below) from AIM then restarted the waterfall, only to hear the noise from the AR 8600 go up (the AIM signal silenced the AR 8600 wideband FM detector) and saw the signal on the computer screen vanish (see second spectrogram below) – sort of. The downlink was commanded off, but from where?



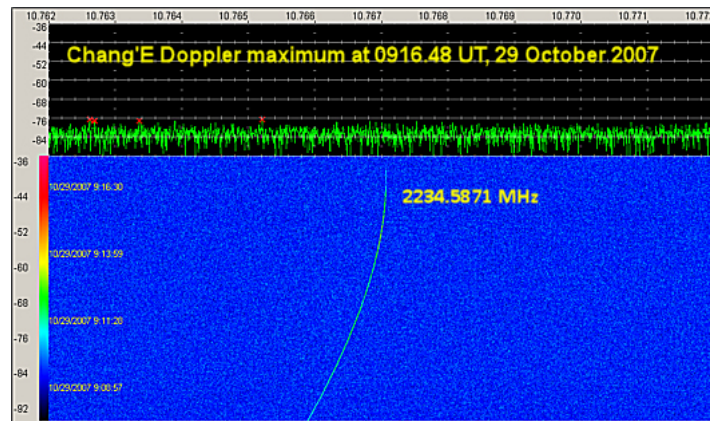
below is the command-off. Strange to see that there was a carrier a while after the wideband signal disappeared and there is some residual weak wideband stuff even after the carrier had disappeared. I tried tuning around to see if there had been a change in operating mode or uplink station. No sign of the satellite!



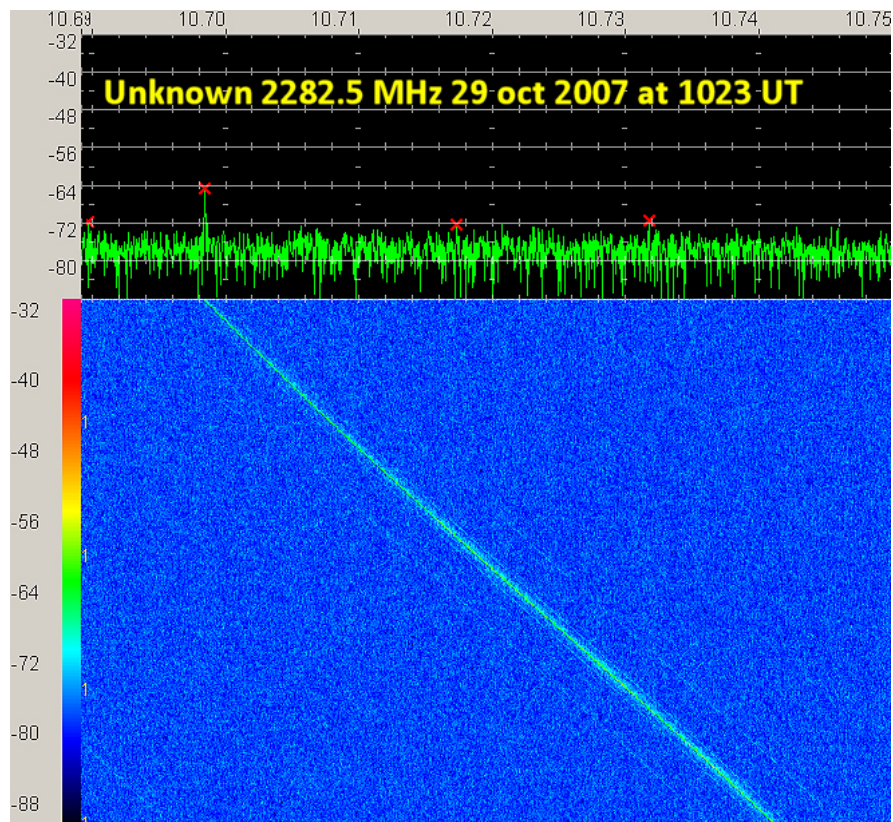
So, it seems my receiving system is getting better, but I still cannot pick up the Japanese SELENE, even when the elevation angle comes near my magic limit 30 degrees. Why? Well, we shall see what new preamplifier and antenna experiments will yield.

October 29, 2007 – Chang'E picked up just before another raising of the apogee and picked up an unknown

I switched on the tracking gear as soon as I had finished breakfast. The signal from Chang'E was there at 0652 UT but extremely weak. It kept fading in and out but finally near 0900 UT the signal strength improved and the Doppler curve showed signs of approaching a maximum. The maximum occurred at 0916.48 UT at the frequency 2234.5871 MHz, about 6 minutes later than the day before. The signal rapidly faded after that at disappeared at 0917.30 UT, almost exactly as the day before. Chinese media announced that a maneuver to a 48-hr orbit with apogee at 120000 km was planned and it was reported to have occurred at 1001 UT, 43 minutes after I lost the signal. Will I be able to pick it up when it comes back to earth in two days?



I also picked up an unknown spacecraft on 2282.5 MHz while just waiting for AIM at 1020.30-1027.10 UT. See picture below:



Well, this is as far as I have come up to now. The story continues. [Here](#) are a few more spectrograms.

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