MEASUREMENTS ON AN AUTONOMOUS WIRELESS PAYLOAD AT 635 KM DISTANCE USING A SENSITIVE RADIO TELESCOPE

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ABSTRACT

The Delfi-C3 spacecraft carries the first autonomous wireless payload in space. This payload is a wireless sun sensor developed by TNO in the Netherlands. The data captured by the sensor is wirelessly transported to the central computer system inside the spacecraft. Since no additional power supply is needed, this sensor is fully autonomous. The radio link is a FSK link at 915 MHz using a standard Nordic Chipset. At the Delfi C3 spacecraft two of these autonomous sun sensors are mounted. Unfortunately only one is operational. Using the Westerbork Synthesis Radio Telescope we tried to detect the 915 MHz signal from the sun sensor to the internal receiver. Before the measurements could be done, the effects of the shielding of the spacecraft case were measured using a spare spacecraft. The final obtained link budget showed a 10 dB SNR when using a 25 meter single dish telescope. Measurements were performed at the WSRT by using multiple radio telescopes placed in the orbit direction. The downlink signal of Delfi C3 was detected, but the 915 MHz signal was not as it should be. We conclude that the sun sensor is malfunctioning.

1. INTRODUCTION

Miniaturized satellites are paving the way to a completely new era of faster and far less expensive access to space. Based on COTS technology and very fast design cycles, nano-satellite drive the design of new space systems, like swarms, enable new space applications for both scientific and security purposes and initiate new markets served by new companies.

As with any emerging technology it is nearly impossible to imagine the impact nano-satellites will have on science and economy. It is certain that the classical view on the use and benefit of space systems does not apply for extremely miniaturized satellites that most likely will be operated in swarms. The discovery of the potential of these new space systems has expanded greatly in the last decade, due in large part to activity within the university satellite community, e.g. the QB50 program [1] and the OLFAR radio telescope project [2].

One of the subsystems in a satellite is the Attitude control system, including sensors for determine the position of the sun. Since a sun sensor only has to work when the sun is in the field of view, it is possible to use the sun also to generate power for the sensor. If also the data to the CPU is transported wirelessly, the complete sun sensor can be made autonomous. TNO in the Netherlands designed such an autonomous wireless sun sensor, the AWSS.

Advantages of an AWSS are:

- Weight saving
- Ease of accommodation
- Remote monitoring
- Multiple receivers possible

In Fig. 1. the AWSS is shown.

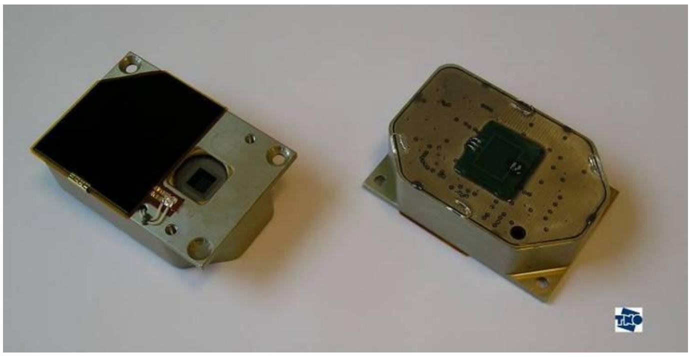

Fig.1. Autonomous Wireless Sun Sensor build by TNO in the Netherlands.

The AWSS is a quadrant detector which is installed in an aluminum package. The power of the module is generated by a Triple Junction solar cell. The data from the quadrant detector is digitized and relayed using the NORDIC nRF9E5 chipset. The Nordic nRF9E5chipset is highly integrated and low cost low power multiband sub 1 GHz RF system on chip for the 433/868/915MHz ISM (Industrial, Scientific and Medical) band. It includes a sub 1-GHz RF transceiver core, 8-bit CPU, and RAM code memory. The 915 MHz band is used in the setup. More information about the AWSS can be found in [3].

Two AWSS's are mounted on the Delfi-C3 satellite. Delfi-C3 is a triple unit Cubesat developed at the Delft University of Technology [4]. The primary mission goal of this university program was to demonstrate this technology in orbit. Two payload missions are placed on the satellite: a novel construction of thin-film solar cells developed by Dutch Space and the AWSS.

Delfi-C3 was successfully launch on April 28, 2008 from the Satish Dhawan Space Centre in India. After more than three years the satellite is still operational.

In Fig. 2 a sketch of the Delfi-C3 is shown.

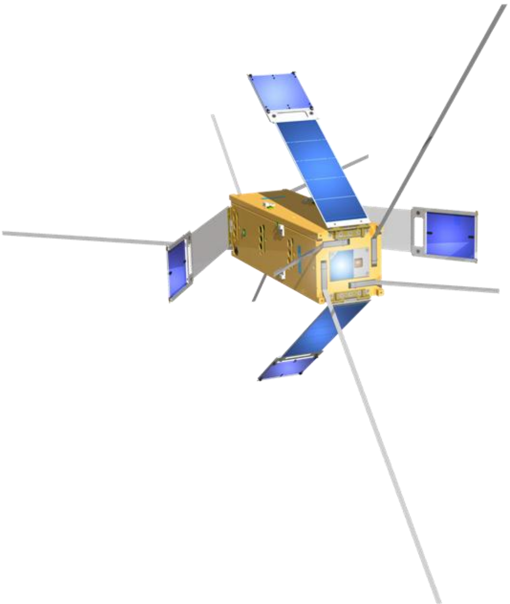

Fig.2. Delfi-C3 satellite with two AWSS mounted on both the small faces of the satellite.

Already from the first moment in orbit, only one of the two AWSS units generates data. The data of the second unit is empty and remained empty. In [3] an extensive presentation of the results of the AWSS is given.

What happened with the second unit is unknown. Is it the receiver or the AWSS? Perhaps some tuning errors occur. Analysing the data from the satellite does not give an answer to the cause of the AWSS problem. In this paper we present Earth-bound measurements to know more about the cause of the problem. The idea is to measure the signal from the AWSS directly.

The paper is structured as follows. First, in section 2, the measurement setup is presented. In section 3 the measurement results are given, followed by a discussion. The paper is concluded with the key conclusions of this research.

2. MEASURENT SETUP

The signal power of the NORDIC chipset in the AWSS is 10 mW. With a distance of (maximum) 635 kilometres, the received power on Earth is very small. Therefore a large telescope is needed to be able to receive the AWSS signal.

The idea is to use the Westerbork Synthesis Radio Telescope (WSRT) [5], (Fig.3). The WSRT is one of the most powerful radio astronomy observatories in the world. It enables astronomers to study a wide range of astrophysical problems: from pulsars to kinematics of nearby galaxies to the physics of black-holes. The WSRT consists of 14 telescopes of 25 meters in diameter each. The WSRT can observe from 120 MHz to 8.9 GHz.

Fig.3. The Westerbork Synthesis Radio Telescope.

To observe this broad frequency range, a Multi-Frequency Front-End (MFFE) is used. The MFFE has 8 receivers for different frequency bands, mounted on a feed revolver for quick selection of the requested band. All receivers use a superheterodyne architecture. The RF part is unique for every receiver. The observed frequency is band-pass filtered and mixed with a tuneable LO frequency to a common IF frequency centered at 1 GHz. The signal is band-pass filtered again to limit the instantaneous bandwidth to 160 MHz. A second mixing step converts the signal to a second IF frequency of 100   80 MHz for transportation over a coaxial cable to the WSRT building. After entering the building the signal is compensated for the frequency dependent loss in the cable by means of a cable equalizer. Then the signal can be processed further in the back-end.

For single dish observations the second IF signal is digitized with an 8-bit ADC running at 400 MHz sampling rate. The digitized signal is stored on disks for postprocessing.

There are a couple of issues to be considered. First the possibility to track the Delfi-C3 satellite with the WSRT. Delfi-C3 has an orbit duration of about 90 minutes. In order to follow Delfi-C3 along its track speeds up to 40 degrees per minute are required. Unfortunately the WSRT is not able to track so fast. To be able to see the potential AWSS signal, the telescopes will be positioned along the orbit direction.

The second issue is to check whether the telescope are positioned at the right spot. If no signal is detected, no conclusions can be drawn. Therefore we also look at the downlink frequency of 145.8-146 MHz. This signal is much stronger than the AWSS signal and should be detectable.

The third issue is the satellite body. The AWSS transmitter is positioned inside the aluminium body of the satellite. This body can function as a Faraday cage and attenuate the AWSS signal substantially. In Fig. 4. a stripped layout of the satellite is shown. The sun sensor can be seen at the top, with its antenna inside the body.

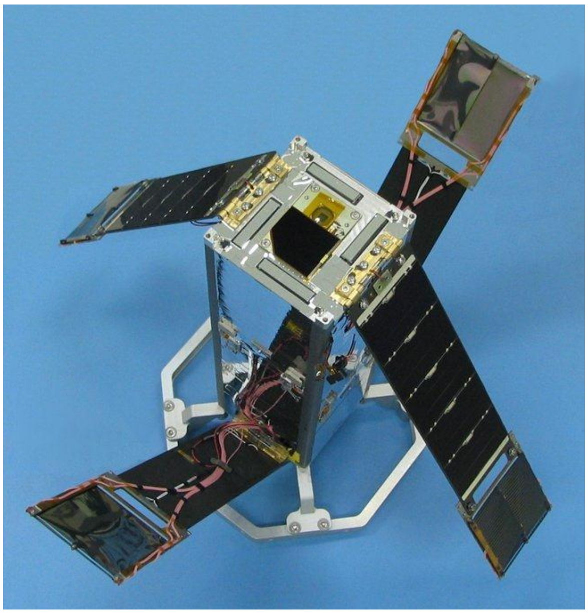

Fig. 4. Stripped layout of the Delfi-C3 satellite.

To determine the impact of the satellite body on the signals of the AWSS, we measured the attenuation using the spare Delfi-C3 unit. The measured attenuation is about 3 dB. This poor attenuation is due to the placement of the RF antennas of the spacecraft. The metal strips of the four antennas making a RFI connection between the inner side of the body and the outer side.

To calculate if it is possible to detect the AWSS signal, a link budget is made, see Table 1. The power of the AWSS transmitter is 10 mW (10 dBm). The antenna is more or less an omni-directional antenna. For the attenuation of the antenna and to account for the attenuation due to the body of the satellite we include a (modest) 20 dB. This results in an EIRP of -10 dBm.

The operating frequency of the AWSS signal is 915 MHz. With a maximum distance of 635 kilometers, the path loss is about 150 dB including atmospheric, polarization and absorption losses.

The 25 meter radio telescope gives a gain of 45 dB at 915 MHz. This results in a received power of -115 dBm. In the WSRT frontend the UHF-high system is used. The un-cooled LNA's (four in total) together with the antennas give a system temperature of about 200 K (modest value).

Link Budget		
TX power	dBm	10,00
Transmit antenna gain	dBi	0,00
Attenuation of the spacecraft (faraday cage)	dB	20,00
EIRP of the spacecraft	dBm	-10,00
Free space Path losses	dB	147,73
Atmospheric losses	dB	1,00
Polarization losses	dB	0,50
Absorption losses	dB	1,00
Path loss	dB	150,23
Pointing loss	dB	0,5
Gain receiver antenna	dB	45,37
Received power	**dBm**	**-115,36**
Receiver System Temperature	K	200,00
	dBK	23,01
Bolzmann constant	dBm/Hz/K	-198,60
Bandwidth	dBHz	50,00
Noise floor	**dB**	**-125,59**
SNR	dB	10,23

Table 1. Link budget of the AWSS signal received by the WSRT with one 25 meter telescope.

The final calculated SNR is 10 dB. Since very reasonable parameters are used, we can conclude that it is possible to detect the AWSS signal using a WSRT radio telescope.

3. MEASUREMENTS

To measure the AWSS signal, the WSRT telescopes were positioned along the orbit direction. Using a spectrum analyser at the IF of one of the telescopes we were able to detect the 145.8-146 MHz downlink signal of Delfi-C3 and confirm that the telescopes were pointed correctly.

Next step is to look at the AWSS signal. The signals from subsequent telescopes are digitized as Delfi-C3 moved from one telescope to the next. In Fig. 5 the waterfall plot from 900 to 920 MHz is shown. Clearly some signals are present.

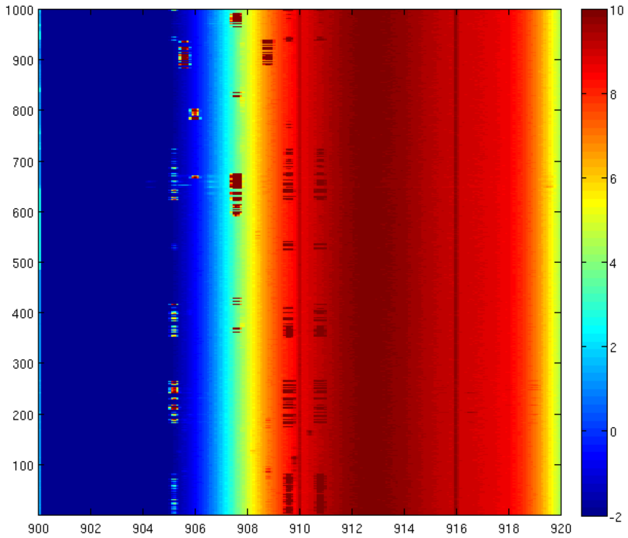

Fig.5 Waterfall plot of the one of the passes of Delfi-C3 at the WSRT with the telescopes positioned along the orbit direction.

In the measurement we observe signals which follow the line along the telescopes exactly. So, these signals were first recorded at one telescope, pop up somewhat later at the next one and disappear at the first one and so on.

This observation in first instance, confirm the reception of the AWSS signal. The timing was perfect and completely in line with the reception of the 145.8-146 MHz downlink signal. However, as can also be seen in Fig. 5., the frequency of the signals are not centered around 915 MHz, but much lower at 910-911 MHz. If the AWSS was sending its signal at this frequency, it could be a very good explanation why the radio link in Delfi-C3 is malfunctioning. However, if we look in more detail at the signal, the signal is different than we would expect for the FSK link of the NORDIC chipset. In Fig. 6 this detailed waterfall plot is given. We see two signals around 910 MHz, but not FSK modulated.

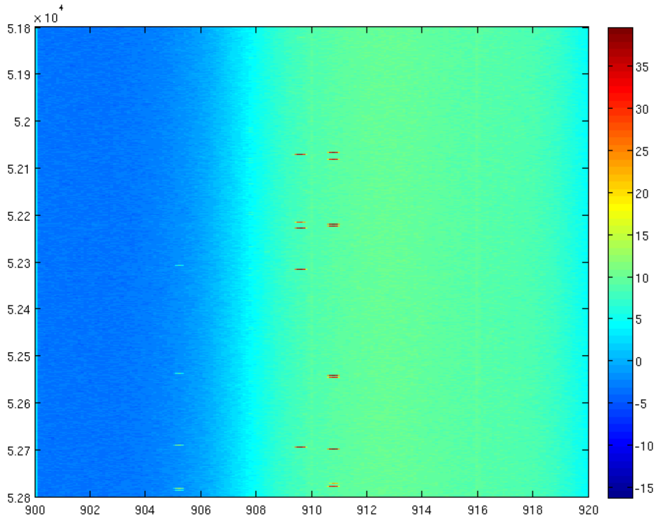

Fig 6. Detailed waterfall plot of the received signals.

Although the global timing was correct and a signal showed up at the telescopes at the correct moments, the recorded signals are not confirm the specifications of the internal AWSS radio link. Both frequency and timing of the modulated signal are not correct. What the received signal was, remains unclear.

4. CONCLUSIONS

Two autonomous sun sensors are placed on the Delfi-C3 satellite of which unfortunately only one is functional. In this paper we described a measurement method to try to determine if the problem is in the receiver unit or in the sun sensor itself. The WSRT is used to sense the transmit signal of the sun sensor. A detailed link budget analysis show that if the sun sensor is transmitting, this signal must be detectable with the setup. The 145.8-146 MHz downlink signal of Delfi C3 was detected, but the 915 MHz signal of the sun sensor was not as it should be. This concludes that it is very likely that the sun sensor is malfunctioning.

5. REFERENCES

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