Radio observation of SMART-1 in its last perilune orbit

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Abstract. The opportunity to measure SMART-1 telemetry beacon before 3rd of September 2006 was a really rare occasion. I wanted to take it, before SMART-1 impacts the surface of the moon. The ESO spacecraft SMART-1 in its last perilune orbit is in addition an ideal transmitter (telemetry beacon) to check the functionality and sensitivity of our small radio telescope which, considered by itself, is dedicated to solar radio astronomy. All measurements were successfully completed with audible sound and an acceptable SNR of up to 30dB.

Key words. S-band, beacon, doppler, noise.

1. Introduction

Observing space crafts with small radio telescopes is rather challenging since many system parameters have to be optimized in parallel. In some cases it’s very difficult to get these data ready at the right time. One has to know the exact position at a certain time in space as well the transmission frequency, the transmission power, the antenna gain, the doppler shift and at least an assumption about the bandwidth of the received signal. On September 2th 2006 our 5m telescope was equipped with a logarithmic periodic antenna 1GHz...12GHz dedicated to solar radio observations in L-band and S-band. The calibration unit exceptionally was bypassed to guarantee minimal noise figure of the focal plane unit. A critical issue was the fact that the moon was rather low in elevation. There was a real risk that during the moon observation the antenna may point to the strong sources of electromagnetic interference (nearby man made noise). Luckily, this was not the case, the noise floor away from the measured beacon signal was real noisy and not disturbed by any man made noise. Different acronyms used in labels and text are described in table 5.

2. Sensitivity estimation

As a first test, I measured the quiet sun, also at very low elevation of 5 degree (behind brushes and trees), to get an idea about pointing accuracy and system temperature $T_{sys}$ of the telescope. The result was not very promising since the signal to noise ratio or, in this case the so called Y-factor was in the order of only 2.2dB.

$$Y = \frac{V_{hot} - V_{cold}}{g} = 2.24dB \pm 0.5dB$$ (1)

Where $V_{hot} = 664mV$ was the measured voltage while pointing to the sun, $V_{cold} = 608mV$ the voltage while pointing to cold sky. Variable $g$ was the detector gradient of nominally $g = 25mV/dB$. Remark: a couple of days earlier with the sun high above horizon, I got 11dB for Y-factor. Taking into account the interpolated quiet solar flux of about $S = 60sfu$ (NOAA) on September 2th at

Fig. 1. 5m parabola with logarithmic periodic feed, focal plane unit containing a high gain low noise preamplifier. In this picture the dish is just pointing to the moon on 2006-09-02 at about 18:52UT
2235.1MHz we can estimate the system temperature $T_{sys}$ to

$$T_{sys} = \frac{SA_{eff}}{2k(Y - 1)} = 3'230\text{Kelvin}$$

(2)

where $A_{eff}$ is the effective receiving area of the parabola antenna of

$$A_{eff} = \pi r^2 \eta = 9.8m^2$$

(3)

where $r = D/2 = 2.5m$ and $\eta = 0.5$ the efficiency factor (Kraus, 1965) as a first order assumption. The system temperature of September 2th was extremely high compared to 183Kelvin when the source (sun) a few days earlier was high above the horizon.

3. Station description

A 5m radio telescope, see figure 1, was pointed to the moon in two different tracking modes [a) continuous tracking and b) on-/off source]. The incoming signals were amplified by a high gain low noise preamplifier of MITEQ company and fed via a low ohmic loss coaxial cable to our communication receiver AR5000, see figure 3. The receiver AR5000 was nominally set to 2235.100000MHz with a small offset to compensate for fast changing doppler shift of -23KHz...+12KHz. For a more detailed setup configuration, see table 3. The CW signal could be heard very clearly in the attached loudspeaker. The audio output was fed to a sound card of a standard PC and analyzed on line with the free software spectrum analyzer SpectrumLab, for details, see table 4. The weather conditions were not ideal but sufficient for radio observations, for detail, see environmental parameter table 1.

4. SNR estimation

I wanted to have a rough value of the expected SNR. Given the transmission power $P_T$ of 5W on an isotropic helical antenna with a gain of $G > -3dBi$, $G_{typ} = 0dBi$ at a distance between moon and earth of about $r = 384'000km$,
we can calculate the power flux density $P_{FD}$ at Bleien observatory to

$$P_{FD} = \frac{P_T (G_{typ})}{4\pi r^2} = (1.3...2.7) \times 10^{-16} \text{ W/m}^2$$  (4)

And from that one may evaluate receiving antenna power $P_{SMART}$ of space craft SMART-1 at the antenna terminals to

$$P_{SMART} = P_{FD} A_{eff} p \eta = 6.4 \times 10^{-16} ... 1.3 \times 10^{-15} \text{ W}$$  (5)

where $p = 0.5$ denotes to polarization loss due to linear reception of a circularly polarized wave. To get the internal system power $P_{sys}$ we need to know the signal bandwidth $\Delta \nu$ which was measured using SpectrumLab to 12Hz ... 15Hz according to figures 4 and 5.

$$P_{sys} = k T_{sys} \Delta \nu = (5.3...6.7) \times 10^{-19} \text{ W}$$  (6)

Now we are in a position to evaluate the expected SNR for SMART-1 beacon frequency from equations 5 and 6.

$$SNR = \frac{P_{SMART}}{P_{sys}} = 30dB...34dB$$  (7)

This level was occasionally measured but the average value was much lower, in the order of 20$\pm$10dB. Sometimes the
signal even disappeared completely. I assume the reason is in the low elevation of the telescope with high level of electromagnetic interference. Or, it might be destructive addition (interference) of a direct received signal and a signal which was reflected at the moon surface (?).

5. Results

The received signals could be heard despite of high system temperature and polarization loss due to linear reception of circular waves. I got similar results expressed in SNR

$$\text{SNR measured} \approx 30\text{dB}$$

with our 7m dish were I could select both polarizations LHCP or RHCP separately. The 7m dish has a somewhat higher system temperature due to internal calibration hardware components in the FPU. Unfortunately, it was not possible to observe SMART-1 beacon with our new spectrometer ARGOS because the reception bandwidth (12.2KHz ... 60KHz) is too large compared to the signal bandwidth of just a few hertz. Using the analysis function of SpectrumLab under best conditions I got a measured signal to noise ratio of $\text{SNR measured} \approx 30\text{dB}$ which perfectly fits with the theoretical estimation $\text{SNR real} = 32.0 \pm 2\text{dB}$. All wav files were converted into fits files offline to be analyzed easier using a standard Java viewer dedicated to fits files. The doppler shifted beacon signal was then transferred into a simple EXCEL sheet and plotted as radial velocity versus time, see figure 8. Since the transfer was done manually, there is some ‘noise’ in the pixels of the velocity plot. The radial velocity was calculated by

$$v = \frac{\nu - \nu_0}{\nu_0} c$$

where $c = 3 \times 10^8 m/sec$ denotes to the speed of light in vacuum, $\nu$ is the measured frequency using sound card and SpectrumLab, while $\nu_0 = 2235.100000 MHz$ denotes to the given telemetry transmission frequency of SMART-1 space probe. The calculated velocity was a bit higher than the officially reported value of 2km/sec in daily press.

6. Conclusions

With our present hardware configuration it is quite easy to observe spacecrafts as long as all observation parameters are known. Gain, system temperature and pointing accuracy (although not perfect) are sufficient to observe satellites in L- and S-band. The present setup is ideal for further observations for students exercises because a success can almost be guaranteed. Thus, observations of Mars-Express at 8.419926GHz, Mars Global Surveyor at...
SMART-1 transmitter data and transmission schedule. I also thank L. Gurvits for additional comments during the observations at Bleien observatory.

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