Arkadiusz Papaj (arkadiusz.papaj@gmail.com), Piotr Weszka (piotrweszka@gmail.com)

Marcin Bocheński (bochenski.marcin@outlook.com), Mateusz Michałek (mateusz.michalek@pk.edu.pl)

Pawel Karbowniczek (pkarbowniczek@pk.edu.pl), Radosław A. Kycia (kycia.radoslaw@gmail.com)
Cracow University of Technology

Andrzej Kułak (kulak@oa.uj.edu.pl)
Electronics and Telecommunications, Institute of Electronics, Faculty of Computer
Science, AGH University of Science and Technology

Agata Kołodziejczyk (maria.kolodziejczyk@esa.int)
European Space Agency, Advanced Concepts Team, Noordwijk, The Netherlands

Matt Harasymczuk (matt@harasymczuk.pl)
Warsaw University, European Space Agency, Advanced Concepts Team, Noordwijk,
The Netherlands (joanna.kuzmaa@gmail.com)

Aleksandra Ławrynowicz (olalawrynowicz@gmail.com)
Pomorski Park Naukowo-Technologiczny Gdynia

Joanna Kuźma (joanna.kuzmaa@gmail.com)
Faculty of Chemistry, Wrocław University of Science and Technology

Tomasz Brol (t.brol@ssh.gliwice.pl)

The design and the performance of stratospheric mission in the search for the Schumann resonances

Projekt i realizacja misji stratosferycznej w poszukiwaniu rezonansów Schumanna

Abstract

The technical details of a balloon stratospheric mission that is aimed at measuring the Schumann resonances are described. The gondola is designed specifically for the measuring of faint effects of ELF (Extremely Low Frequency electromagnetic waves) phenomena. The prototype met the design requirements. The ELF measuring system worked properly for entire mission; however, the level of signal amplification that was chosen taking into account ground-level measurements was too high. Movement of the gondola in the Earth magnetic field induced the signal in the antenna that saturated the measuring system. This effect will be taken into account in the planning of future missions. A large telemetry dataset was gathered during the experiment and is currently under processing. The payload consists also of biological material as well as electronic equipment that was tested under extreme conditions.

Keywords: The Schumann resonances, ELF (Extremely Low Frequencies), balloon mission

Streszczenie

W artykule opisano szczegóły techniczne misji balonowej, mającej na celu pomiar rezonansów Schumanna. Gondola została zaprojektowana do pomiaru slabych efektów ELF (fale elektromagnetyczne o skrajnie niskiej częstotliwości). Prototyp spelnił założenia projektowe. Układ do pomiaru ELF działał poprawnie przez całą misję, jednak poziom wzmocnienia sygnału, który był dobrany zgodnie z pomiarami naziemnymi, okazał się za duży. Ruch gondoli w ziemskim polu magnetycznym indukował w antenie sygnał, który wprowadzał układ pomiarowy w stan nasycenia. Ten efekt zostanie wzięty pod uwagę w planowaniu przyszłych misji. Podczas eksperymentu zebrano duży zestaw danych telemetrycznych, który jest obecnie analizowany. Ładunek zwierał również materiał biologiczny oraz sprzęt elektroniczny, który był testowany w warunkach ekstremalnych.

Słowa kluczowe: rezonanse Schumanna, ELF, misje balonowe

1. Introduction

ELF are the waves that are usually connected with natural atmospheric phenomena. They are defined to have frequency from 3 Hz to 3 kHz. Their observation can be affected by industrial activity that disturb the measurements – the most common is 50 Hz radiation of electric network and radio transmissions. Therefore, the measuring device has to be designed in the way that it can discard these strong disturbances.

One of the most important ELF phenomena are the Schumann resonances, which were predicted and measured in the 1950s (see [2]) and the references therein. They occur as the Earth-ionosphere waveguide is constantly powered by the electromagnetic waves from lightning. They interfere giving a characteristic spectrum of amplifications at frequencies 7.83 Hz and higher harmonics 14.3 Hz, 20.8 Hz etc. [1]. The frequency location of the resonances is connected with the parameters of the atmosphere; therefore, they can be used for measuring of their properties on Earth and other planets, e.g., in future missions on Mars [3, 4]. There are also some indications that the low frequency electromagnetic fields influence biological systems; however, there is no general description of this phenomenon – see review in [5].

Stratospheric balloon missions are the most versatile, in the sense of cost-results optimisation, way of performing measurements in the environment closely connected to the cosmic space or in the higher layers of the atmosphere. As the ascending and descending phases are slower than in rocket carriers the gathered datasets can be large. It is therefore natural to use this platform to measure the resonances, as was suggested in [3] in the case of Mars. The first initial results of measuring the resonance were reported in [6], therefore, it suggests that the proper design of the balloon ELF mission is of great importance in atmospheric research and future cosmic exploration.

The paper is organised as follows. In the next section the overview of the electronic antenna system and then the design of the gondola will be presented. Next, the brief description of the mission will be outlined and conclusions from the first iteration will be presented.

2. Antenna system

The Schumann resonance has two components – the electric one which is vertical and the magnetic one. The experiment was aimed at measurement of the first case.

The construction of antenna as a standard dipole [7] is unsuitable for balloon experiments due to the long wavelengths. The most appropriate choice, as the space and mass of package is constrained by the avionic law, is the short dipole active antenna of length of a few centimetres comparing to the wavelength of hundreds of kilometres of ELF waves. In the field of ELF wave it behaves like the electromotive source with negligible resistance and inductance. Therefore, it has to be connected with amplifier with large input impedance and small capacity. The most optimal length for balloon missions is 20 cm, which, based on the ground level measurements of the Schumann resonances, would generate output on the level of 90 μV, which results from the standard theory of short dipole of given length and estimated value of electric field on the ground level.

The scheme of the amplifier system is a small modification of the design from [8] called ELA 1 with passive antenna. For summary see also [9]. This design was used to observe ELFs on the ground [10, 11, 12, 13]. It was supplied with a Chebyshev filter reducing aliasing. The output was connected to the ADC described in the next section.

In the ground tests the dominating signal 50 Hz of electric power was visible, that showed the antenna system worked. In this design the induction of signal in the antenna by movement in Earth magnetic field was not taken into account as the effect depends the parameters of flight and wind.

3. Data acquisition system

The system of data acquisition consists of two computers for backup purposes:
1. RaspberryPi 3 B, 4-channel 12bit ADC converter – ADS1015, GPS and IMU (Inertial Measurement Unit) GY-801;
2. Arduino Due, 16 bit ADC converter – ADS1115 and GPS.

The systems were charged by the TP-LINK TL-PB10400 power bank with 10 400 mAh capacity. The power bank has two ports and one of them charged the RaspberryPi and Arduino computers and the second one the antenna system. There was also a second battery (Colorovo PowerBox 6800 mAh) connected to the YI Action 2 camera, which was also the device that was tested against low temperatures and extreme stratospheric conditions. The 10 400 mAh power supply was too large for a 2 h mission (as it was tested before the mission); however it was used in order to prevent the effect of low temperature on the capacity of chemical power sources. The data were saved on fast input-output transaction SD cards. The data frame format used in the first system was as follows:

```
GPS: DATA
GPS: DATA
[ACCELERATION x,y,z] [GYROSCOPE x,y,z] [MAGNETIC FIELD x,y,z]
[
'TIME', ADC,
'TIME', ADC,
...
]
...
END
```

where the first two lines are GPS data, then the data from IMU. The next part is the data from the timer and the corresponding ADC readout of 3000 samples and finally END marker. The average sampling ratio was 300 Hz, which is sufficient to detect the Schumann resonances. The clock was synchronized with GPS at startup of the system before the start.

The data frame of the second system has the following format:

GPS
ADC
...
GPS
ADC
...

where GPS stands for the data from GPS and ADC denotes the data from ADC. The Arduino was not connected to the RTC (Real Time Clock), therefore it saved the ADC data until the GPS interrupted, which ended the frame – the number of ADC readouts depends on the frequency of GPS interruptions. Its average sampling rate was 600-700 Hz – the spread results from interrupt-driven design.

4. Gondola

The gondola was designed to meet standards of aviation law. Its mass was 1.69 kg. The whole gondola was made from pieces of XPS (Extruded Polyester) glued together. The outer layer was covered by aluminium foil in order to prevent electrostatic discharges which could disrupt ELF measurements. The sharp end of the antenna was protected by a piece of XPS. Figure 1 presents its cross section along the centre.
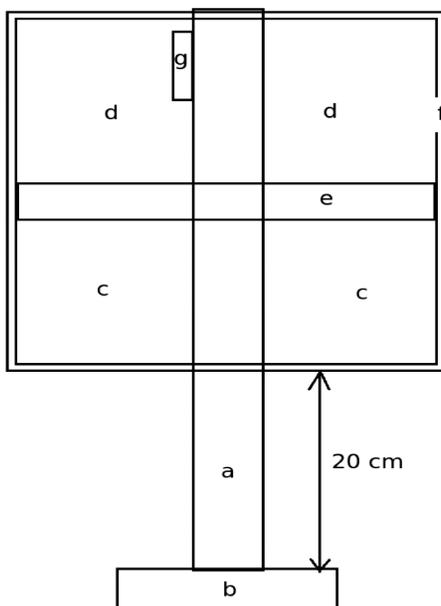
The bottom isolated compartment was occupied by the antenna system. The upper part was occupied by the acquisition systems, GPS and battery. In addition APRS (Automatic Packet Reporting System) which allowed us to localize the balloon online was also present. In the top part there was also a place for a camera, which was placed for tests in stratospheric conditions – there was a hole for the lens; see Figure 2.

Fig. 1. Schematic sketch of gondola (no real sizes):
a – antenna (plastic pipe covered by metallic foil);
b – protection of the antenna sharp end (XPS material);
c – bottom compartment (for antenna system); d – top compartment (for acquisition system, telemetry, battery and camera); e – partition wall from XPS material;
f – hole for camera; g – Inertial Measurement Unit
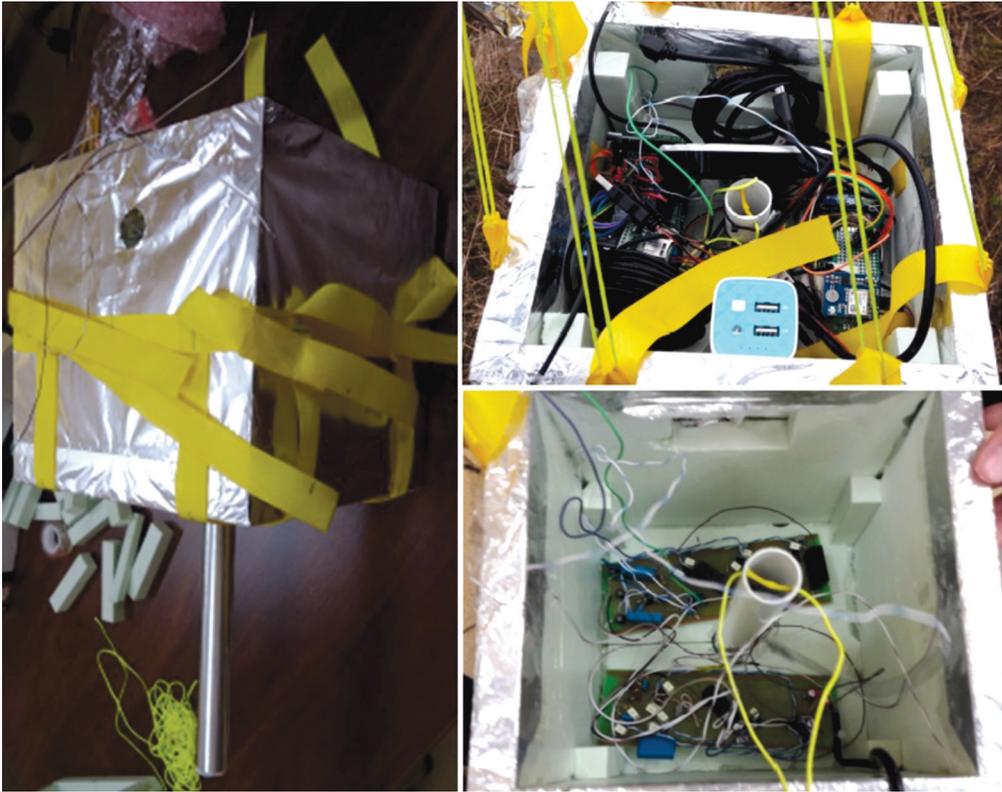
Fig. 2. Capsule view – side view, top compartment, bottom compartment

The additional payload of biological samples was attached to the side walls of the gondola as well as to the long string and hang below the gondola.

The gondola was attached to the parachute by nylon strings and the parachute was connected with a balloon in such a way that in case it popped it automatically opens during the fall.

For the experiment abHwoyee HY-1200 balloon model was selected as it is sufficient to reach 30 km with a payload of 2 kg when filled with hydrogen gas.

In the next section the mission will be described.

5. Mission

The mission started on 27 November 2016 at 9:18 am of CET, i.e. GMT (+1 h) when the balloon was released near Gliwice, Poland, see Figure 3. The decision of the start was preceded by a simulation of the trajectory using wind predictions at [14]. The prediction for the balloon trajectory shortly after the start of the balloon is presented in Figure 4 and the path of flight from GPS data is presented in Figure 5.

Fig. 3. Start of the balloon
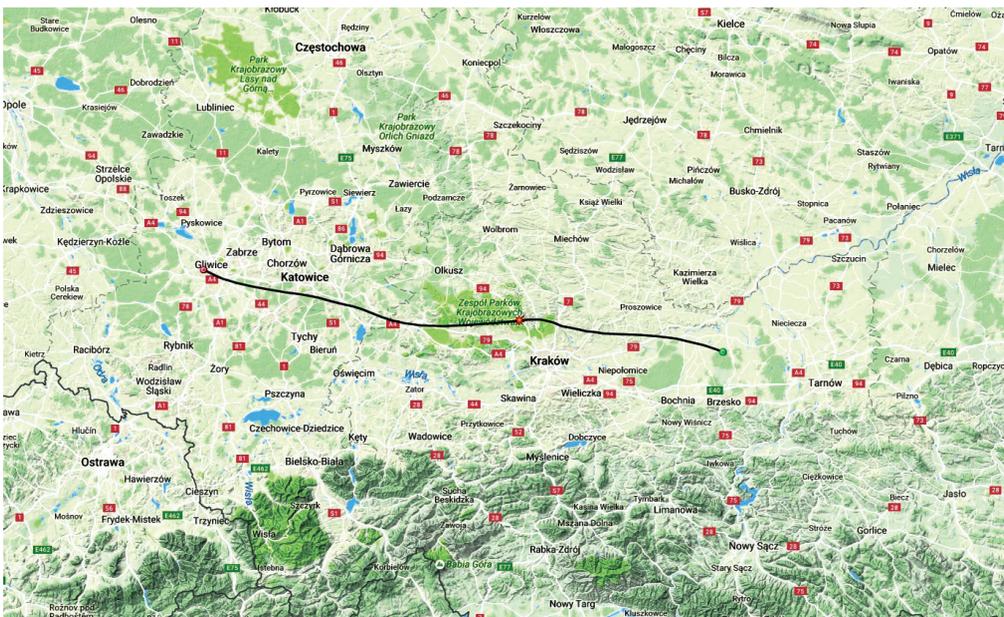
Fig. 4. Trajectory of the balloon predicted according to the wind simulation on 24th of November from [14]

The comparison of Figure 5 with the simulation made on 24 of November on Figure 4 indicates that the simulation quite well agrees with the real path.

In addition the height profile of the path of the balloon from APRS data are presented in Figure 6. The height plot for the data from GPS is presented in Figure 7. It can be seen that the balloon had constant vertical speed during ascending (line); however, after it popped its vertical velocity was large (almost horizontal part of the trajectory) until it started to decelerate when the parachute was slowly opening. A more detailed analysis of the flight can describe the dynamics of the atmosphere and the gondola-balloon system and this will be presented in a separate paper. The balloon popped at an attitude of 30 km above sea level and during the descent the parachute opened as can be seen in Figure 8.

The flight lasted 2 hours. The gondola travelled 135 km from the starting to the landing point and the lowest temperature it was exposed to was −55°C.

Additional information from the mission, including photos, are available on [18].

The preliminary results of the experiment will be described in the next section.

6. Preliminary results

Preliminary analysis of the data from the Schumann resonances measurement system indicated that the system was saturated for the entire mission as is presented in Figure 9.
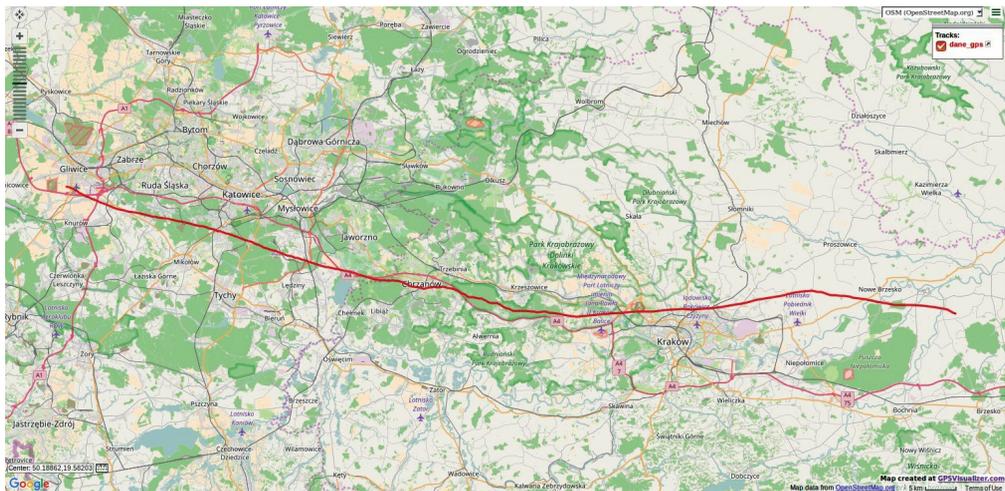
Fig. 5. Trajectory of the balloon generated from GPS data from [16]

This indicates that the level of amplification was too high. Therefore the redesign of this part of the system is required before the next mission. The excitement was caused by the movement in the Earth's magnetic field as it was tested after the mission in ground tests.

The analysis of data from the GPS and accelerometer indicates that it is possible to make a dynamical model of the gondola-balloon system and atmospheric dynamics. The analysis deserves another publication which is currently under development.
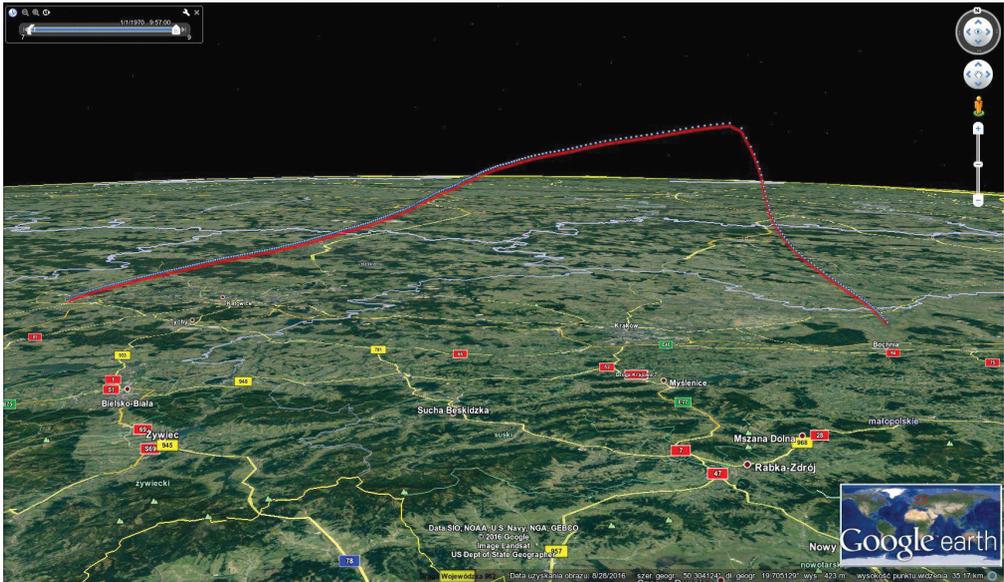
Fig. 6. The path of the balloon from APRS data visualized in Google Earth service [15]
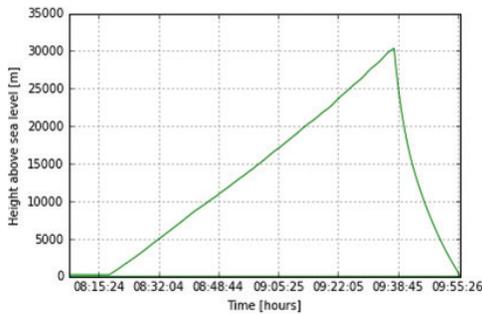
Fig. 7. Height profile for GPS data. Time is given with
the respect to GMT
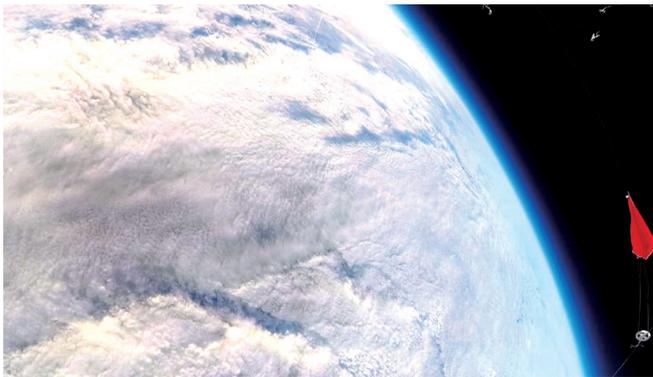
Fig. 8. Balloon popping. The opening of the parachute (red) and the remnants of the balloon are visible. The large
cloud cover and the atmosphere layer that gradually passes to the space can be noticed
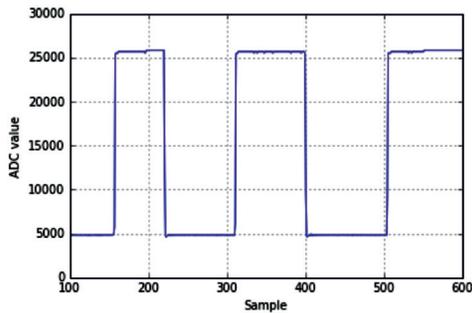
Fig. 9. Saturation of the ELF system. The system oscillates between low and high state

The analysis of the biological part of the experiment is currently in progress; however, no living bacteria and fungi were detected.

The camera was tested under stratospheric conditions. It worked after the landing and the film from the mission is available at [17].

7. Conclusions

The experiment described in the paper was intended as a proof of concept for stratospheric ELF missions. Although no Schumann resonance was registered the analysis of the results enables the system to be redesigned for future missions. Additional data including telemetry and biological samples were gathered and the equipment was tested under extreme conditions. The concepts used in this experiment can be adapted to future similar balloon missions on Mars.

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