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ONBOARD DIGITAL BLOCK FOR ELECTRIC FIELD MEASUREMENTS IN SPACE

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Abstract

The article presents a Bulgarian digital block in a Bulgarian device – Analog Measurement of Electric Fields-Wide Band (AMEF-WB). This on-board instrument with 4 sensors was developed to measure electric fields in a wide frequency range. The measurement of the electromagnetic fields and plasma parameters are in compliance with the science purpose and technical tasks of the space experiments project RESONANCE. This block is a part of a scientific satellite instrument for electric fields amplitude and frequencies measurements from quasi constant DC up to 1 MHz. The device AMEF-WB give signals in 3 different frequency bands for processing by the external receivers ELMAWAN (Czech Republic) and HFA (Poland) from the composition of the wave complex.

1. Introduction

In the field of space technologies, for the RESONANCE project [3, 5] with high-apogee satellites Fig. 3 [2], was developed a new Bulgarian device AMEF-WB [4] for measurement of parameters of space plasma. The device was designed to study electromagnetic fields and interactions of waves and particles in the inner magnetosphere of the Earth. The Earth and Jupiter are well known as radio planets that are emitting very intense and coherent radio wave emissions. The Earth's auroral radio emissions, recorded by INTERBALL-1 satellite [12], also called auroral kilometric radiation – AKR, were observed by space-borne satellites and ground-based stations [8]. Radio emissions were also recorded by the DEMETER/ICE (Instrument Champ Electrique) experiment [9, 10]. This instrument measures the electric field components of electromagnetic and electrostatic waves in the frequency range from DC to 3.25 MHz [10]. Despite the limited satellite invariant latitude (data acquisition below ~ 65°), specific events have been observed, close to the sub-aurora region, in the frequency range from 100 KHz to about 1 MHz [9, 10]. Van Allen probes A EMFISIS electric field intensity spectra 30 Hz÷500 KHz are shown during a period following the 17–18 March 2015 great storm in Plasmapause, L = 2.4÷4.4 [13].

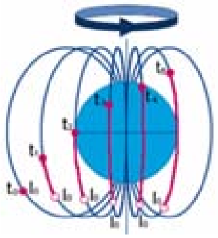

Fig. 1. Magneto-synchronous orbits of the RESONANCE project

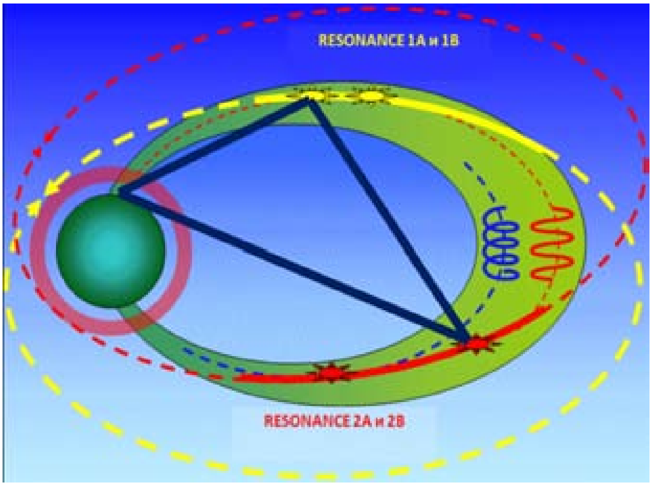

Fig. 2. Measurements with two pairs of satellites of the RESONANCE project

On Fig. 2 [2], is given the strategy for the measurements with two pairs of satellites. The dotted yellow curve is the orbit of the first pair of satellites (1A and 1B), the solid yellow line is the part of the orbit inside the selected power tube; red colored line – the same for the second pair of satellites (2A and 2B); dark blue line – the basic distance for ultra-low frequency (ULF) interferometer.

In the RESONANCE project, the task is to carry out non-linear and non-stationary processes in magnetosphere. ELMAWAN is a multi-component low-frequency receiver in the frequency range of 20 Hz ÷ 20 KHz. But, a high frequency analyzer (HFA) task is to study an AKR. The main tasks of RESONANCE experiment are the study of choral radiation in the equatorial region and various signals in the auroral region. Measurement of density and temperature of electrons will be performed by the device based on modified Langmuir probe. Prototypes of this device, such as KM (KM-7 on the satellite of the AURORAL PROBE), was repeatedly used in the space project and worked well. The satellites for the RESONANCE project will operate in pairs in intersecting elliptical orbits of 500 km × 28 000 km at an inclination of 63.4° [1]. On Fig. 1 [2] is depicted the principle of construction of the power line magnetic field correction, together with the Earth, in different points in time (t_1, t_2, ...). The actual position of the satellite at each moment of time is marked by red circles, and the initial position is marked with white circles. It is possible to pick up parameters of an orbit so that the satellite, on the one hand, is connected together with the Earth, and, at the same time, moves along the chosen power line of a magnetic field.

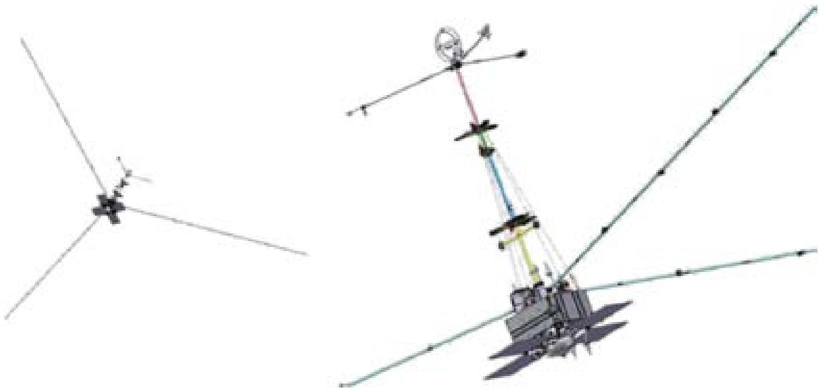

Fig. 3. A pair of satellites from RESONANCE project in flight configuration [2]

2. Materials and methods

The digital block, Fig. 5 (from device AMEF-WB, Fig. 4) consists of a galvanically separated analogue and digital part. The analogue part includes a 16-bit analog to digital converter (ADC) with 6 simultaneous inputs and a variable input range. Four of its entrances convert the electric fields with variable gain*4 through low-pass filters (LPF). Variable gain*2 of the ADC coupled with the assigned input range results in an increase in the dynamic range by 3 bits (plus 16 bits from ADC resulting in 19 bits). The data is measured 25 times in 1 s with a bandwidth from DC to 10 Hz. To control the operation of the device 16 slow values are measured: 6 temperatures and 10 supply voltages. From the measured values of the electric fields, a correction voltage DAC_{out} is calculated and output via two digital to analogue converter (DAC), which compensates for the polarization of all electric sensors (ES) [5, 6].

When shutdown protection of the central processing unit (CPU) is on (CPU stops transmitting signals) the polarizing voltage is reset to a further circuit, so that other devices using high frequency bands can continue to operate. Galvanic separation is performed through Analog Devices, Inc., iCoupler® technology integrated circuits that allow data transfer up to 10 Mb/s. The time of the measurement cycle is 40 ms, while four electrical field signals and two control signals are simultaneously measured. The collected data is collected in a total block of 224 bytes in length and sent over the communication channel by a signal from the on-board apparatus. As a backup, serial flash memory is provided in case of storage of large data for more than 4 h of measurements.

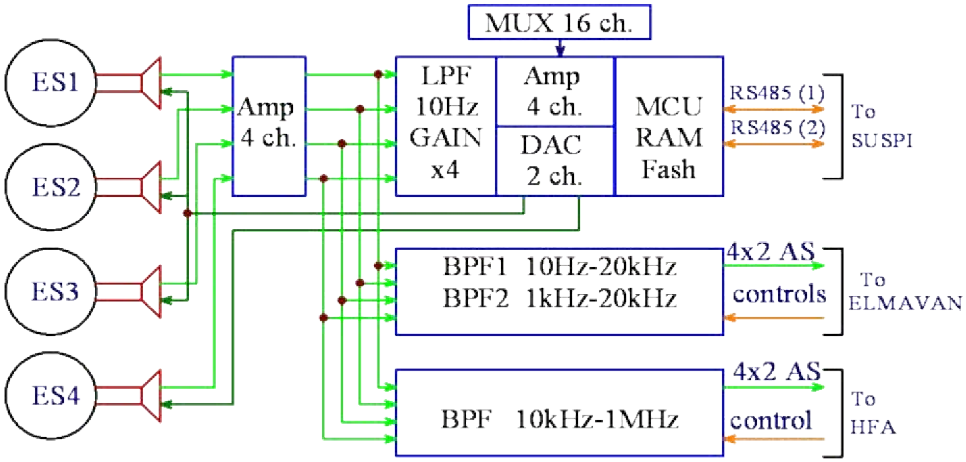

Fig. 4. Device AMEF-WB from RESONANCE project

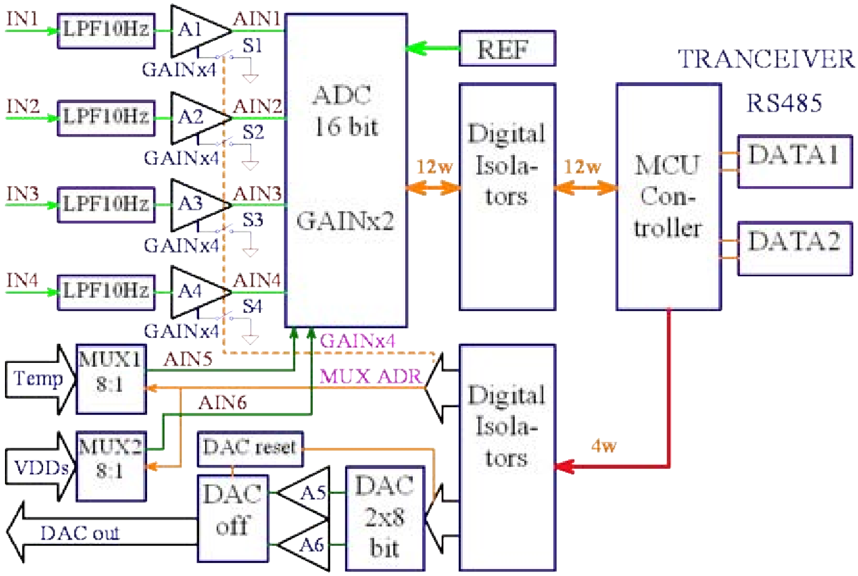

Fig. 5. Digital block from device AMEF-WB from RESONANCE project

2.1. Analogue part

For 16-bit ADC is used a chip with simultaneous converting bipolar inputs, manufactured by Analog Devices, Fig. 5. This allows at the same time measurement of the 4 wave inputs from the ES. The other two inputs measure 8 multiple values via MUX1 and MUX2. Through them is measured 6 temperatures: 4 from ES1, ES2, ES3, and ES4; 1 from the power supply unit and 1 from the digital unit. Power supplies are also measured. The ADC has a variable input gain*2, which extends the dynamic range of the input value conversion. The measurements are controlled by CPU. They are transmitted through a serial synchronous interface (SPI) [7].

The four analog signal inputs have one filter LPF-10 Hz which limits the input bandwidth to 10 Hz to ensure proper waveform measurement. The variables amplifiers with gain*4 are used to increase the input dynamic range. They are controlled by one chip with electronic switches. ES4 has a different gain compared to the ES1, ES2 and ES3 because of its shaded.

The accuracy and repeatability of the measurements is referenced by a precision reference voltage source of 2.5 V. Temperature measurement of the board are used for self-analyze the work of the board and eventually make adjustments to the data outputs.

To counteract the polarization of sensors, is used a DAC-voltage to symmetry them to the area around zero. That way is avoided the out of range output of the ES-signal. In this case is used one chip, 8 bit DAC. It is managed by the CPU through the SPI interface. The value is set according to the constant component of the measured inputs. Voltage correction for ES4 is operated differently from the ES1, ES2, and ES3 due to its shadowed position to the Sun.

2.2. Digital part

The digital part is galvanically isolated from the analogue part, to reduce harmful interference by integrated circuits. The allowed data transfer is up to 10 Mb/s [7].

A processor with own flash memory is used for the programs and is programmed on the board (Fig. 5). This CPU supports SPI interface for ADC and DAC. It has a built-in 2 serial communication interfaces. It uses a flash memory to save the settings. The CPU uses an random access memory (RAM) to collect the measured data in the sending blocks.

Duplicated RS485 serial interface is used for data exchange with control scientific equipment (CSE). It has a place for a high capacity 4÷8 MB (or 32÷64 Mb) serial flash memory to keep collected blocks for 4.5÷9 h in the event of an interrupted connection.

3. Results

The memory blocks consist of: an identifying header, next number, status and error codes, information section with data from the measurement of the input quantities, and slow voltage and temperature control measurements. The total block size is 224 Bytes per 1 second measurement. For each block, in order to recover properly the input values the amplifier gains and the input range of the ADC are recorded. The communication block can have up to 3 changes per second. Similarly, polarizing voltage corrections are recorded. The Bulgarian side provided in 2013 in the city of Moscow, a complete set of the technological copy: device AMEF-WB, sensors for electric field and control measuring equipment (CME). A full device test was performed for more than 2 years in *Lavochkin* Research and Production Association (or shortly *Lavochkin* Association, LA) a Russian aerospace company and Space Research Institute of the Russian Academy of Sciences (SRI-RAS).

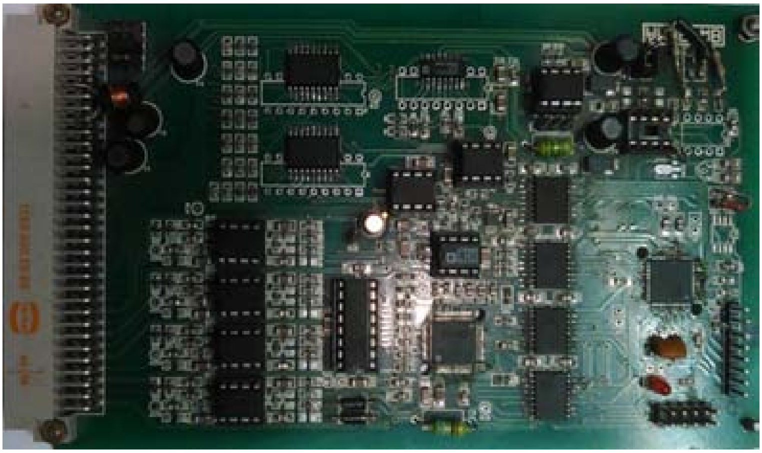

Fig. 6. Digital block for space electric field measurements

The device can be improved by using new electronic parts and by alteration of functional scheme. This is a preliminary study for next developments.

4. Discussions and Conclusions

The AMEF-WB is a 3-components (X, Y, Z) receiver of extremely low frequencies (ELF) space electric field. For high frequency electronic capacity suppression is applied in electric fields sensors. That and CPU control allows to use instruments in the entire frequency range from DC to 1 MHz electric fields.

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БОРДЕН ЦИФРОВ БЛОК ЗА ИЗМЕРВАНЕ НА КОСМИЧЕСКО ЕЛЕКТРИЧЕСКО ПОЛЕ

Б. Хотинов, П. Граматиков

Резюме

В статията е представен българският цифров блок от българския прибор Анализатор на многокомпонентно електрическо поле – широколентов (AMEF-WB).

Цифровият блок е разработен за измерване на космически електрически полета в широк честотен диапазон с помощта на 4 сензора. Измерването на електромагнитните полета и параметрите на плазмата е съобразено с научните цели и техническите задачи на космическите експерименти по проект РЕЗОНАНС. Цифровият блок е част от инструментите на научен спътник за измервания на амплитуди и честоти на електрически полета от квази постоянно напрежение до 1 MHz. Приборът AMEF-WB предава сигнали в 3 различни честотни ленти за обработка от външните приемници ELMAWAN (Чешка Република) и HFA (Полша) от състава на вълновия комплекс.