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LOW-TECH HIGHLY EFFICIENT RADIOTECHNICAL SOLUTIONS FOR METEOR AND SATELLITE OBSERVATIONS

Single-station technique of meteor observation using inexpensive receivers has been developed. The receivers are also suitable for observing the active artificial Earth satellites on solar-synchronous orbits when measuring the Doppler shift frequency at which they emit.

Keywords: artificial satellites, meteors, Doppler shift, and radio-engineering solutions.

In the Solar system, there are many celestial bodies that can be divided into the following groups: *the planets, the comets, the asteroids*, and *the meteoroids* (*meteors*). Today, the planets have been studied better than the other groups; the asteroids and the comets are enquired actively and effectively, but the situation with the meteoroids is much more complicated. The reasons for this state of research is an extremely wide range of meteor size (from 100 microns to few tens of meters [1]), the complexity of their observations because of the small size, a low interest of astronomical community and a relative complexity of the techniques for observation and data processing. However, due to an intensive use of the near-the-earth space for engineering purposes, interest for studying the meteoric activity and its impact on the artificial Earth satellites (AES) has arose recently.

The rapid development of digital telecommunications and computer hardware and software has led to the simplification of production, cheapening, and wide application of radio equipment by everyone (for example, *Realtek* RTL2832U that is a very convenient tool for observing the meteoric activity and AES radiation). Similar observations can be done using an inexpensive and simple equipment.

OBSERVATIONS OF METEORS

The main point of the study of meteoric activity in the radio frequency band is the fact that instead of a part of energy emitted during the burning of meteors in the atmosphere, a portion of energy reemitted by terrestrial broadcasters is recorded [2, 3]. This method is called the forward scattering (FS) and has a number of advantages over the backward scattering in terms of energy efficiency, unlike the radars consuming tens of kilowatts for illumination of meteor train, but requiring sophisticated mathematical calculations [4].

The RI «MAO» has implemented computerized observations of meteors using a hardware & software complex (HSC) consisting of:

1) PC with the following parameters: 500 GB hard drive, 2.5GHz processor, 4GB RAM, and 64-bit operating system (OS);

2) *Realtek* RTL2832U;

3) a Yagi-type directional antenna for required frequency band (88–108 MHz);

4) installed HDSDR application to control receiver and to store information obtained by it in the computer;

5) installed Python 3.4 language interpreter with the following libraries: numpy, matplotlib, and wave;

6) applications for processing the air data sets, in Python.

The stored data have a length of 65.536 million samples with a sampling frequency of 250 kHz for each file. The next step is to focus on data processing algorithm. The algorithm in Python-3 language developed at the RI «MAO» enables effortless use of libraries rich with algorithms and data processing on any 64-bit operating system compatible with given interpreter. In practice, the processing has been implemented on Linux and Windows 7 operating systems using their standard tools. The processing algorithm is carried out in several stages:

1) sampling rate is reduced to the real one by introducing adjustment coefficient for removing the receiver's clock run errors from observations;

2) calculation of amplitude-frequency-time sweep with normalization of selected range using the algorithms described in [2];

3) required range of ±5 kHz where the main spectra of phonemes are located is selected from the amplitude-frequency-time sweep since the range of ultrashort-wave station is only ±20 kHz from carrier frequency (88.2 MHz);

4) the averaged spectra are defined for point in time (sum as analog of signal energy in the observed spectrum);

5) the values exceeding 5 σ that corresponds to meteor lifetime (5 s) are selected from the average values of all samples;

6) initial time of meteor echo and all values of output signal where the echo is found are saved;

7) finally, the meteor time parameters are computed and sent out to check the operation of entire system.

AES OBSERVATIONS AND RESULTS

The same composition of hardware & software system is used to record signals from AES actively emitting in radio frequency band such as CUTE-1. However, the operating frequency (436.808 – 436.815 MHz) and the processing data algorithm are different. The algorithm steps are as follows:

1) sampling rate is reduced to the real one by introducing adjustment coefficient for removing the receiver's clock run errors from observations;

2) calculation of amplitude-frequency-time sweep with normalization of selected range using the algorithms described in [2];

3) the noises are removed from the amplitude-time-frequency sweep with its further binarization where «one» is assigned to a part of the sweep satisfying the conditions for signal detection;

4) the received sweep is wiped by binary masks that leave properly inclined groups of pixels corresponding to the actual Doppler shift;

5) third-order polynomial is superposed on the data received in the previous stages, which helps remove the points that do not meet the trend of the received signal Doppler shift;

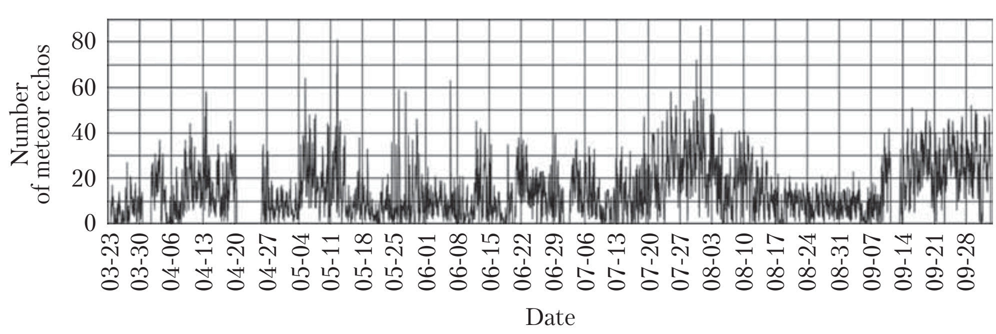

Fig. 1. Hourly meteor activity

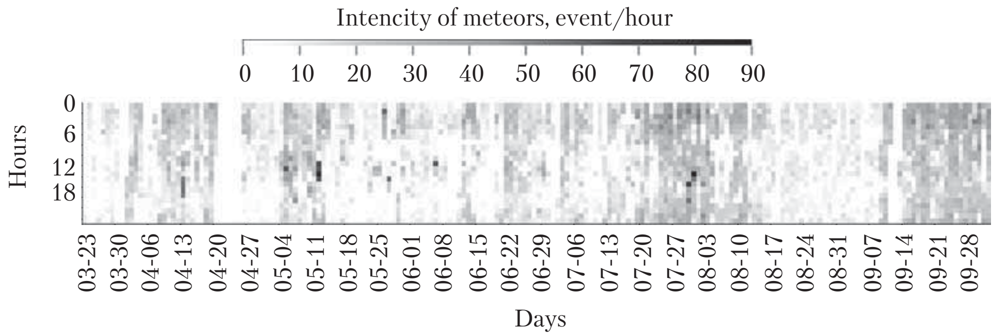

Fig. 2. Daily and hourly intensities of meteor showers

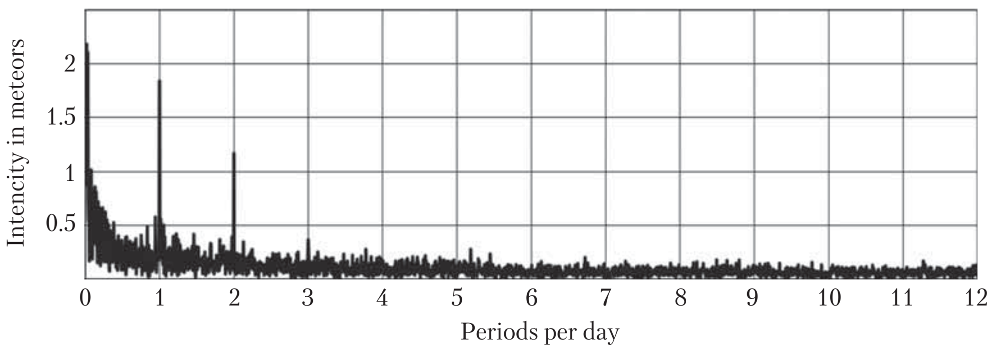

Fig. 3. Periodicity of meteor showers

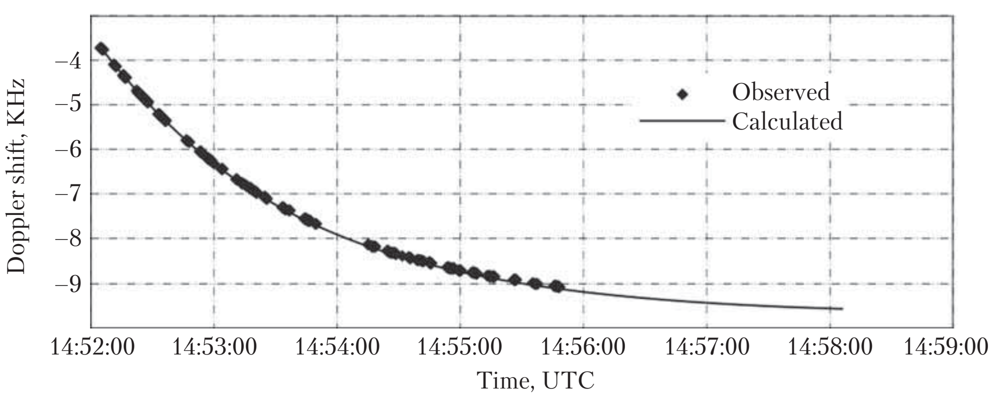

Fig. 4. Measured Doppler frequency shift (*observed*) as compared with the theoretical one (*calculated*)

6) the Doppler frequency shifts derived from the selected signal are compared with the calculated values for the initial conditions taken from NORAD [5] and the satellites are identified;

7) the initial conditions taken from NORAD in TLE format for the satellite identification are adjusted based on the measured Doppler frequency shift.

On March 23, 2016, the RI «MAO» started observations using the above mentioned H&S complex. As of early October 63 892 meteor echoes were recorded (Fig. 1). The hourly average amounts to

13.74 with a standard deviation of 3.26 meteors. It should be noted that within the observation period two highly intensive meteor showers were recorded: η-Aquariids with duration from April 19 till May 28, and a maximum on May 5 and Perseids, from July 17 till August 24, with a maximum on August 12 [6]. The intensities of these streams are given in Fig. 2.

One more important factor having an impact on data processing is the existence of daily (1.84) and half-day (1.17) meteor shower intensity harmonics (Fig. 3).

In April 2016, an experimental observation of CUTE-1 (NORAD ID 27844), operating frequency 436 837.5 kHz was carried out. Twenty satellite passes were recorded within the period from 05.04.2016 till 13.04.2016. The average intrinsic error of radial velocity measurement is 2 m/s. The synchronization accuracy is 1 s. Maximum deviation from the theoretical curve obtained for the NORAD initial conditions (satellite orbit elements in TLE format) is 50 m/s, that after the adjustment of initial conditions is 16 m/s. The example is showed in Fig. 4.

CONCLUSIONS

Proceeding from the above said the following can be concluded:

1. The use of affordable computerized radio equipment is reasonable for observing the meteor activity and AES.

2. Within the period from March 23 till October 3, 2016, 63 892 meteor echoes were recorded with an hourly average of 13.74 and a standard deviation of 3.26 meteors.

3. Twenty passes of CUTE-1 were recorded within the period from 05.04.2016 till 13.04.2016. The average intrinsic error of radial velocity measurement is 2 m/s. Maximum deviation after the adjustment of initial conditions is 16 m/s.

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НИЗЬКОТЕХНОЛОГІЧНІ ВИСОКОЕФЕКТИВНІ РАДІОТЕХНІЧНІ РІШЕННЯ ДЛЯ СПОСТЕРЕЖЕНЬ МЕТЕОРІВ ТА СУПУТНИКІВ

Розроблено методику однопозиційного спостереження метеороїдів за допомогою недорогих приймачів. Ці приймачі зручні також для спостережень активних штучних супутників Землі на сонячно-синхронній орбіті при вимірюванні допплерівського зміщення частоти, на котрій вони випромінюють.

Ключові слова: штучні супутники, метеори, допплерівське зміщення, радіотехнічні приймачі випромінювання.

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НИЗКОТЕХНОЛОГИЧЕСКИЕ ВЫСОКОЭФФЕКТИВНЫЕ РАДИОТЕХНИЧЕСКИЕ СРЕДСТВА ДЛЯ НАБЛЮДЕНИЙ МЕТЕОРОВ И СПУТНИКОВ

Разработана методика однопозиционных наблюдений с использованием недорогих приемников. Эти приемники удобны также для наблюдений активных искусственных спутников Земли на солнечно-синхронной орбите при измерении допплеровского смещения частоты, на которой они излучают.

Ключевые слова: искусственные спутники, метеоры, допплеровское смещение, радиотехнические приемники излучения.