Meteor and aircraft detection

The use of electromagnetic waves for space observation

Cédric Willemin
Schweizer Jugend Forscht, Switzerland

Abstract: The French military radar GRAVES emits electromagnetic waves consistently at a frequency of 143.05MHz. These waves propagate in the air and are reflected by electrically conductive objects. If the object is moving, the reflected frequency will change. This effect is known as the Doppler shift.

The aim of this project was to extend the technique often used in military operations to a civil application, focused on astronomy. In the study, reflected waves were received by an antenna positioned on the roof at the Gymnase de la rue des Alpes, in Biel, Switzerland. The reflected signal was thereafter transmitted to a computer which displayed the Doppler shift graphically.

Results proved that the detection technique is very versatile as it can identify signals reflected by aircrafts, satellites like the International Space Station, and meteors. Since these objects are moving with very different speeds, the induced Doppler shifts are highly contrasted, which makes them easy to distinguish. Numerous concrete objects were identified in the study, from the meteorite swarm of the Perseids to the International Space Station (ISS).

1 Introduction

The French military radar GRAVES (**G**rand **R**éseau **A**dapté à la **VE**ille **S**patiale, which means Large Network Adapted to Space observation) emits electromagnetic waves consistently at a frequency of 143.05MHz. The transmitting antennas of the GRAVES network are located in the French department Haute-Saône, between Dijon and Vesoul, and consists of four panels emitting electromagnetic waves in a southerly direction (see Figure 1) [1]. Electrically conductive objects, such as satellites, aircrafts or ionized trails of meteors when they pass through the atmosphere at high speed, reflect the waves generated by the radar [2]. The signal retransmitted by the object is thereafter detected by a network of about a hundred antennas located at the Albion plateau in France.

Figure 1. Transmitters of the GRAVES radar, located between Dijon and Vesoul (France). [1]

The purpose of this project was to extend this technique to a civil application, focused on astronomy. The detection of meteors was carried out according to the same principle, using the GRAVES radar as transmitting antenna and a Ground-Plan ¾-λ antenna as receiver, placed on the roof of the *Gymnase Français* in Biel. Such system is commonly called a bistatic radar due to the transmitter being at a significant geographical distance from the receiver [4]. The signal received by the antenna was thereafter sent to a PC where it was processed with appropriate filtering and displayed on a frequency spectrum using the software Spectrum Lab V2.

If the object is moving, the reflected wave increases or decreases in frequency depending on its radial speed relative to the radar, and the movement of the observer. This phenomenon of frequency shift is known as Doppler effect and can also be observed acoustically; if a sound source moves towards an observer, like a fire truck with the siren on, the sound change in frequency. This shift makes it possible to identify the actual speed of the object, its trajectory and other information about the nature of the object.

A similar experiment was carried out in the 1940s. However, the technology at that time was insufficient for detecting meteor showers easily, automatically and efficiently. The aim of the study was to listen to the echo of the meteors in a radio. Audio files were recorded on magnetic tapes, which, today, clearly is an obsolete technology.

2 Method

Antennas are characterised by their specific radiation patterns, determining the direction of receiving (or emitting) a signal efficiently. An antenna with a uniform radiation pattern in all directions is called isotropic antenna and is physically unfeasible. In some cases, it is more beneficial to use directional antennas, these antennas have a radiation pattern focused in one direction. A common type of directional antenna is the Yagi antenna [3].

For this project an antenna capable of receiving signals from a maximum of directions had to be used. A Yagi type antenna was not suitable, as the opening angle for such an antenna is approximately only 46°. Therefore, the antenna in this project, a Ground-Plan antenna ¾-λ, was designed, simulated, and realized specifically for this application (see Figure 2). The antenna was tested in the Electromagnetic Compatibility (EMC) laboratory of METAS, Swiss Federal Institute of Metrology, to precisely measure its characteristics and compare them with theoretical data.

Figure 2. Reception system positioned on the roof of the high school of Biel (Switzerland).

The signal collected by the antenna ¾-λ was transmitted to the receiver via a coaxial transmission line, commonly used by radio amateurs. However, the length of the line proved to be too long, approximately 30 meters, which caused a lot of interferences and losses. The impedance of this cable was 50Ω [3].

Figure 3. Receiver Funcube Dongle Pro+

The receiver was positioned on a computer equipped with a SDR (software-defined radio), model Dongle Funcube Pro+ (see Figure 3). This Dongle was calibrated to the chosen frequency. It digitalized the signal from the antenna and transmitted it via USB to a port on the PC. A free software, Spectrum Lab V2, was used to visualize the signals. The graphical interface displayed the Doppler Shift in the form of a waterfall. The Y-axis represented the time, and the Doppler shift, i.e. the offset from the frequency of 143.05MHz, is given by the X value. Positive X values corresponds to an increase in frequency from the nominal, while negative values indicate a received frequency lower than that emitted by the radar.

- If the frequency offset is large and its duration is short, this is typically the signature of an object with a very high speed, such as a meteor.
- If the offset is large and its duration is long, the object moves at a relatively high speed, probably signature of a satellite.
- If the offset is small and the duration is long, then the object is moving at a low speed, an aircraft would be responsible for such a signal.

The software recorded the measurements automatically and saved them as a graphic JPG files and audio WAV files.

In order to get more selectivity and sensitivity, a preamplifier and filter was added to the receiving system. A preamplifier enabled amplification of the signal and was inserted just after the antenna to prevent amplification of the noise induced by the long coaxial line. In addition, a band-pass filter was inserted after the transmission line in order to reduce the background noise on the specific frequency band.

The whole installation was grounded to avoid accidents in case of lightnings shocks.

3 Results

Aircraft: Aircrafts can be identified due to their cruising speed, the generated Doppler effect is therefore relatively low. Moreover, they are very numerous.

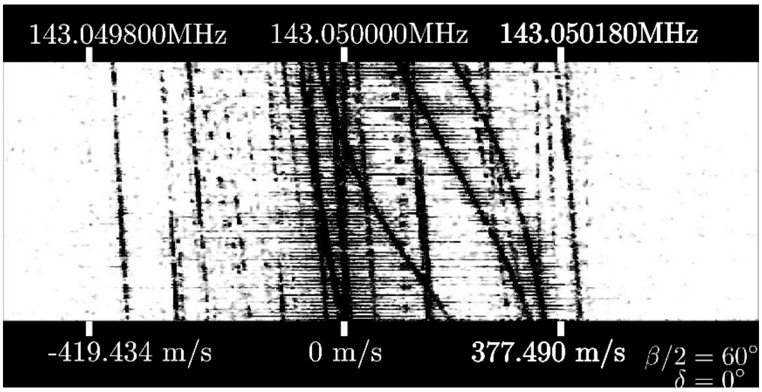

Figure 4. Aircraft signature, their offsets in frequency is relatively low.

Meteors: Many meteors penetrate the atmosphere of the earth daily and the majority of them burn up almost instantaneously. In contrast to an aircraft, a meteor generates a very strong Doppler shift over a short period of time. A significant increase of meteor detections was observed during a period of meteor shower, like the Aquariids or the famous Perseids in August 2019. A signature of a meteor is displayed in Figure 5.

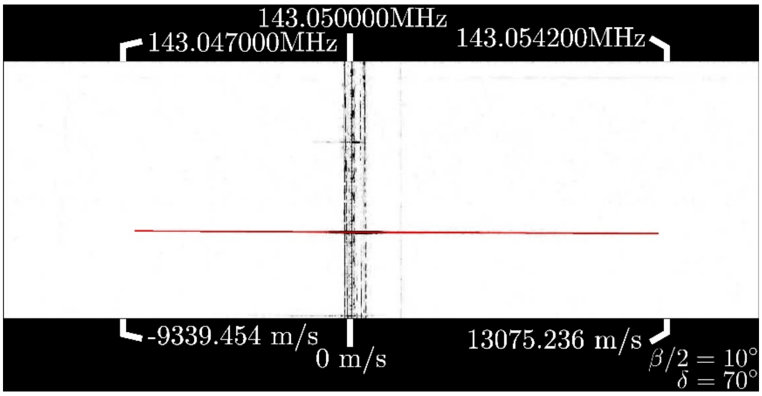

Figure 5. Signature of a meteor, the Doppler shift is very big during a very short duration.

Satellites: The trajectory of satellites, such as the ISS (International Space Station), are available on the web [6]. However, this is not the case for all satellites. The set up used in this project enables detection of all satellites independently of whether their respective data is public.

A satellite moves with significantly higher speed that an aircraft, typically 24'000km/h. This speed is lower than the speed of meteors but relatively high in relation to aircraft, which generate smaller shifts (see Figure 6). earth [5].

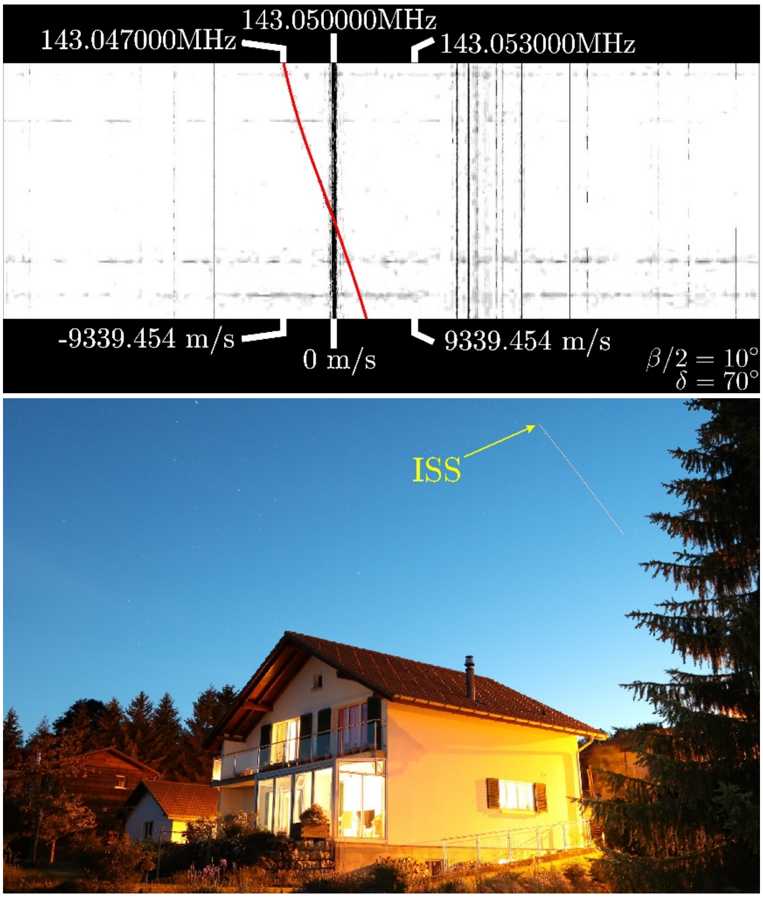

Figure 6. Two illustrations of the ISS captured simultaneously: optically (photography) and by bistatic radar detection.

4 Discussion

The setup developed within the frame of this project proved to be applicable for civilian purposes, more specifically in observation of astronomical phenomena, and can be used for monitoring, for instance, a meteor shower remotely. To extend the data analysis, a digital processing of the signal received by the antenna, preamplifier and filter could be added i.e. improving the signal with a computer for better quality results. In the case of a study with focus only on meteor signatures, all other signatures could be rejected, which would make a counting system more relevant.

A detection system based on this configuration is operational day and night. The number of meteor detections was approximately 10 per hour. The plausibility of the results has been verified in several ways, for example during the Perseids in August 2019 in which the frequency of meteor detection was about 30 per hour (see Figure 7). As the measurements are automatically stored in a log [2][7].

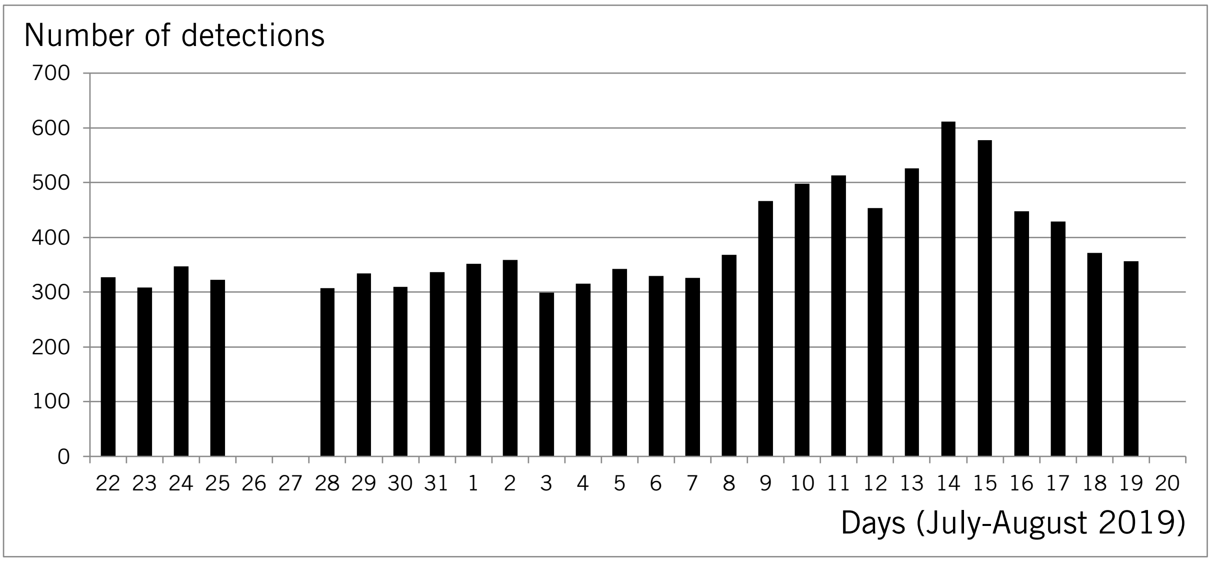

Figure 7. Number of meteors detected during the Perseids with this instrumentation. The number of meteors increases at the peak of activity (11-15 August). On 26 and 27 July as well as on 20 August, the measurements were not carried out due to a technical problem.

Another important improvement of the system could be to position several receivers on different sites, based on the method of triangulation. Using this method, the path of the observed objects could be precisely reconstructed. For instance, predicting the impact of a meteor on the surface of earth [5].

References

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