DETERMINATION OF FREQUENCY DEVIATION CAUSED BY DOPPLER EFFECT ON EARTH-MOON-EARTH COMMUNICATION

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Abstract: *Making an Earth-Moon-Earth communication (EME), at the RX frequency occurs the change of frequency compared to the transmission one. This change is due to the appearance of the Doppler effect caused by motion of the transmitter and the receiver. Because the change of the frequency it is variable in time domain, in this paper it is presented the lawfulness of varying the Doppler effect.*

The changing of the frequency in the time domain is represented in a graph obtained through the algorithm implemented in C++ language . Doppler deviation calculation can be performed using input data (UTC, communication frequency and geographical coordinates of the reception/transmission station. Doppler deviation algorithm was designed in a C++ library and can be implemented in other PC applications or microcontrollers.

Keywords: *Earth-Moon-Earth, Doppler, Azimuth, Elevation, communication, earth station, moon.*

1. Preface

Earth-Moon-Earth communication (EME), known also as moonbounce, became a popular form of amateur radio communication through space. The concept is simple: The moon is used as a passive reflector of communication between two locations on Earth (Figure 1). This communication can be performed over long distances but with a low rate of speed communication. Since the distance to the reflector (Moon) is high (~ 385000 km), at the EME communication occurs big losses. It requires the use of large, high power antennas. And receivers must reduce the noise to the minimum. However, the use of modern coding and modulation techniques can significantly reduce these requirements. Thus, a communication via EME presents unusual issues at the design of ground stations.

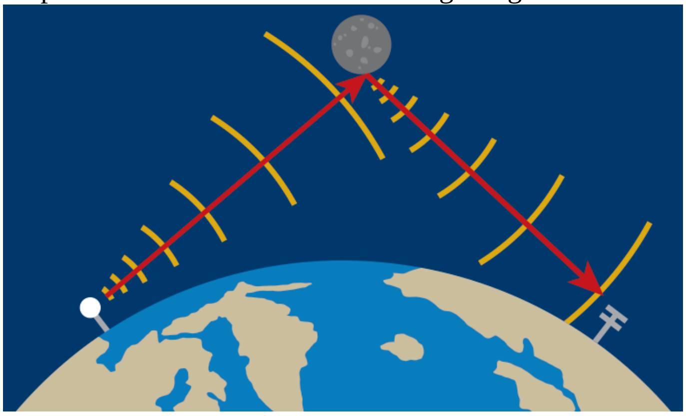

Fig. 1 The method of communication Earth-Moon-Earth

EME signals are also affected by the Doppler shift caused by the relative movements of the Earth and Moon. The received frequencies may be higher or lower than those submitted. The main factor it is Earth rotation. For echo signals, the frequency change will be positive and maximum at the rising moon, and the maximum negative at moonset. Doppler shift for receiving stations consists of the sum of the transmitting and receiving stations frequency deviations. For echo signals, Doppler shift is multiplied by two, because we have two periods of time: for transmission, and for receiving. The maximum values of the deviations are approximately 440 Hz at 144 MHz, 4 kHz at 1,296 MHz and 30 kHz at 10 GHz.

2. Algorithm for Doppler deviation calculation

The required data to calculate the frequency deviation are: date, current time, the frequency of communication and geographical coordinates of the station. In the next picture, you can view the algorithm for deviation calculation. After we calculate Coordinated Universal Time (first formula) occurs the call of functions that supposed to calculate the vectors from the center of Earth to the Moon.

$$UT = hour + min/60 + sec/3600 \quad (1)$$

The basic formula for Doppler shift it is:

$$f_r = f_t * C / (C+V) \quad (2)$$

Where: f_r – reception frequency (RX); f_t – transmission frequency (TX); C – light speed $3*10^8$; V – velocity between transmitter and receiver.

If the distance between the receiver and the transmitter becomes bigger, the sign is positive as in previous formula. But if they becomes closer to each other - the sign becomes negative. EME communication consists of two paths: one for transmission to the moon and another for signal reception. The total shift is calculated by multiplying of these 2 deviations:

$$f_r = f_t * [\, C / (C + V_t)] * [\, C / (C + V_r)] = f_t * C^2 / [\, C / (C + V_t)] * [\, C / (C + V_r)] \quad (3)$$

Where: V_t – radial velocity during transmission, and V_r – radial velocity during reception. V – It depends on the relative velocity of the Earth, the Moon and the current time.

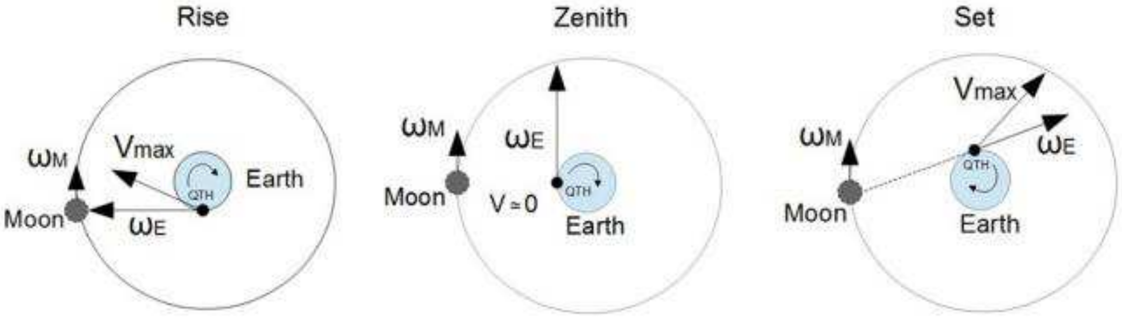

Fig. 2 Rotation vectors of the Earth and Moon

Moon rotates around the Earth in the same direction as Earth, but at a much higher rate. Immediately after moonrise, the frequency increases slightly and then gradually decreases to almost zero at zenith. Zenith is where the Moon is at the highest level and always occurs south (local midnight, when the moon is full). The rate of frequency change is minimal for the given period. The frequency then becomes negative because the Moon moves away from the location on Earth, and tends to decrease until moonset.

Figure 3 algorithm calculates both: Doppler deviation and the positioning angles of the moon relative to the ground station. Azimuth angle provides additional information about the position of the moon and the angle of elevation can be useful for stopping the Doppler calculation. To calculate the angles it is necessary to perform the same calculations.

To make positioning antenna to the moon automatically is necessary to control the action elements (motors). But to achieve an intelligent motor control, the device must know the position of the Moon. Thus, the given algorithm can be used not only to achieve a communications but can be useful for making a good mechanisms designed to position antennas in the direction of the moon.

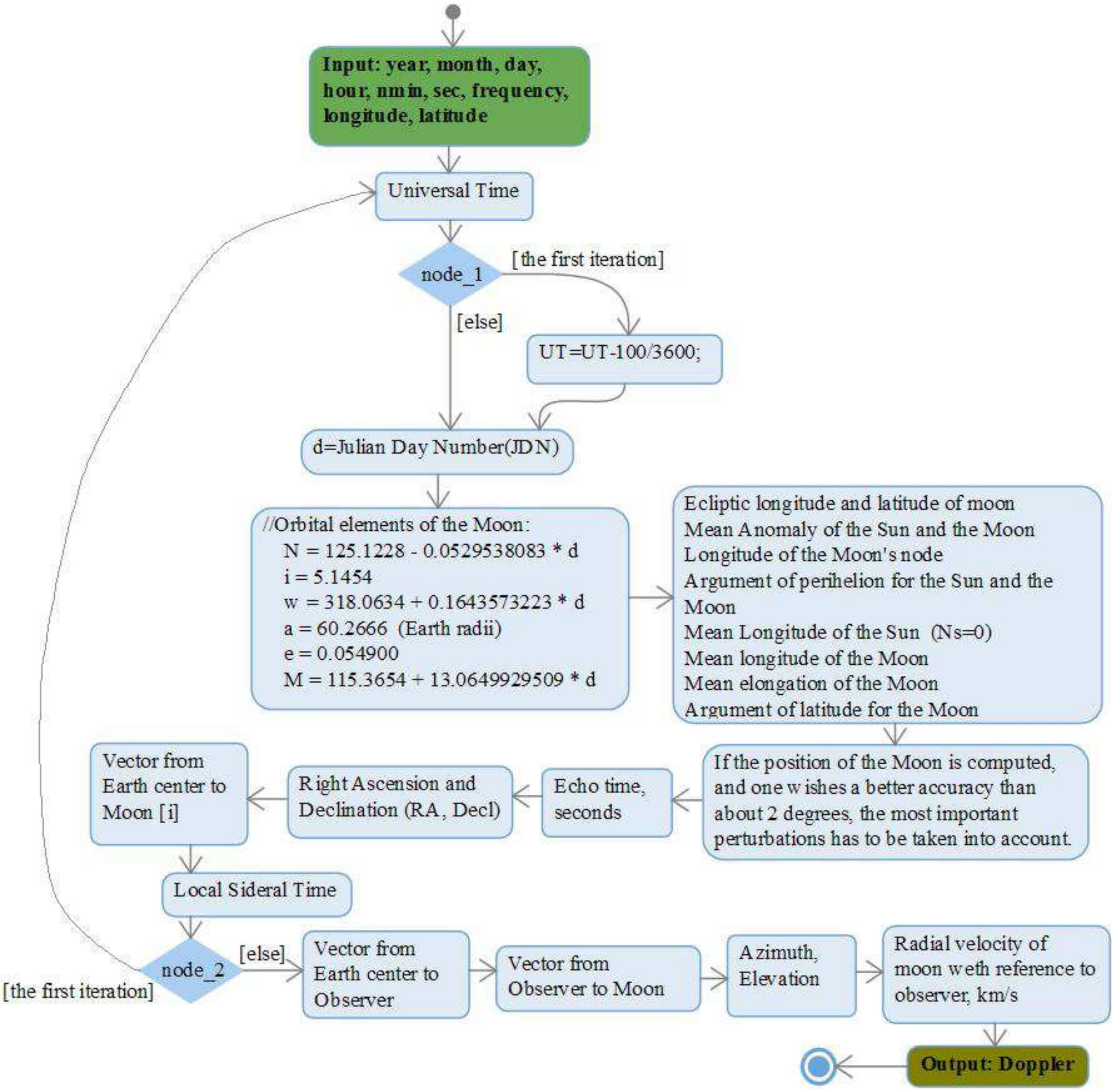

Fig. 3 The algorithm for calculation of frequency deviation caused by the Doppler effect

3. The test of the program

Based on developed the algorithm was designed Doppler deviation calculation library in C ++. Before it call the function for calculating Doppler deviation input variables were declared.

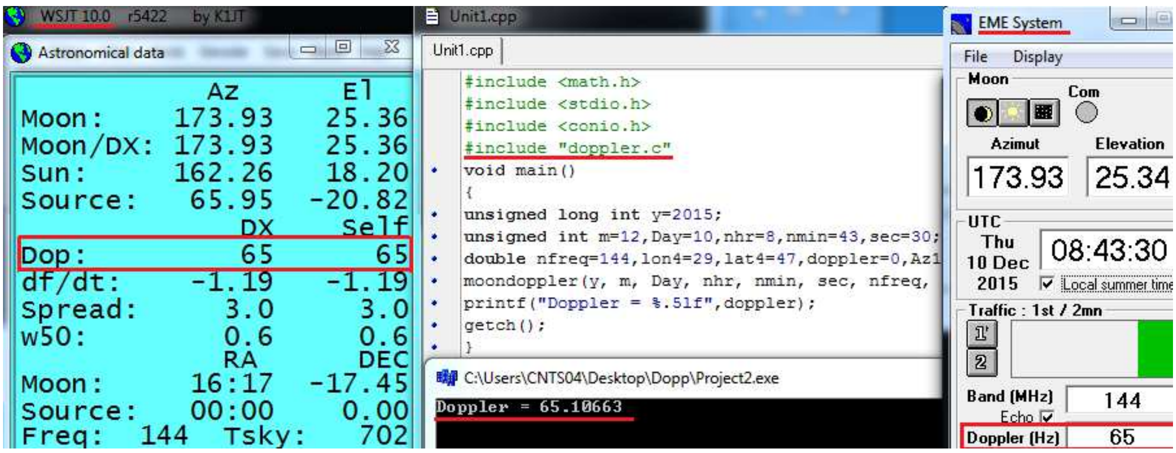

Fig. 4 Running the algorithm for frequency deviation calculation

The calculation result is returned in the "moondoppler" function and it is displayed in the console. It is necessary to verify the calculation, that's why, the displayed result was compared with the results of other programs. As it is shoe, the numbers coincide, so we can say that the library was developed properly. But to be sure is needed to perform an EME communication using given algorithm.

4. Results

Using the developed library was generated a database that contains calculations of the frequency deviation caused by the Doppler effect for a period of three months with a discredited calculation 10 minutes. The chart below shows the change of the frequency deviation that occurs due to the Doppler effect.

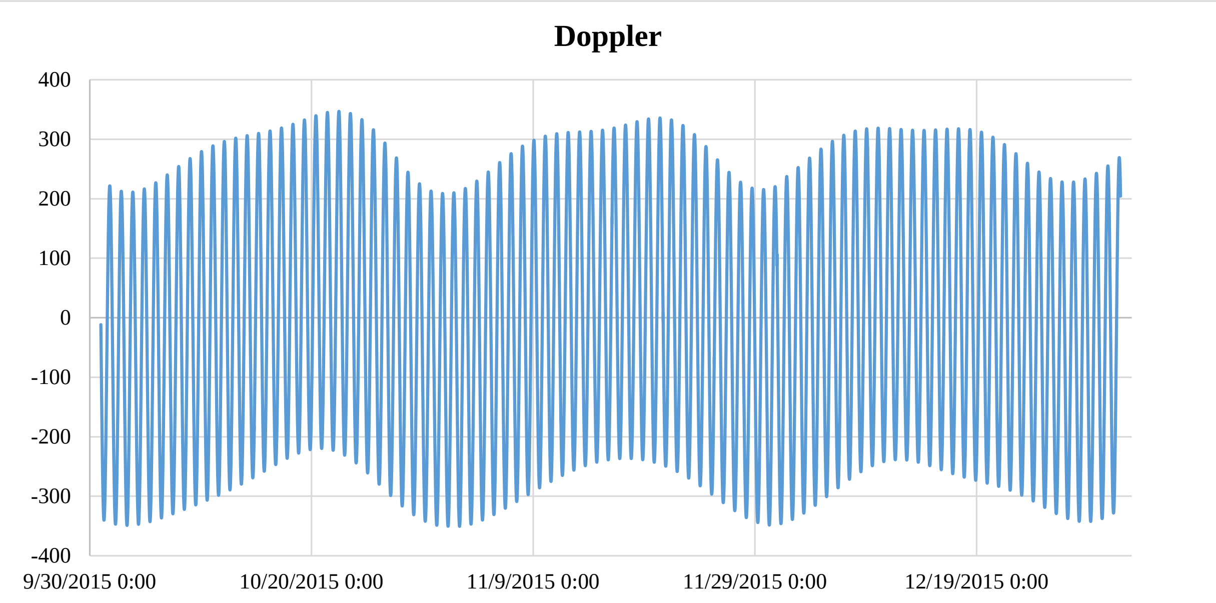

Fig. 5 The results of calculations for frequency deviation during 3 months

Whenever the moon appears, frequency deviation is different but it repeats the lawfulness of frequency deviation. The magnitude of change depends on positioning coordinates of the station, the declination of the Moon and other geometrical factors.

As different points of reflection on the lunar surface produce different time delays, they also produce different changes in the frequency and reception. Moon's rotation and orbital motion are synchronized, the face of the moon always faces toward Earth, but the Moon's orbit is eccentric, so that orbital velocity varies, leading directly to change the frequency of communication. Other changes are caused by ± 5.1° inclination between the orbital planes of Earth and the Moon.

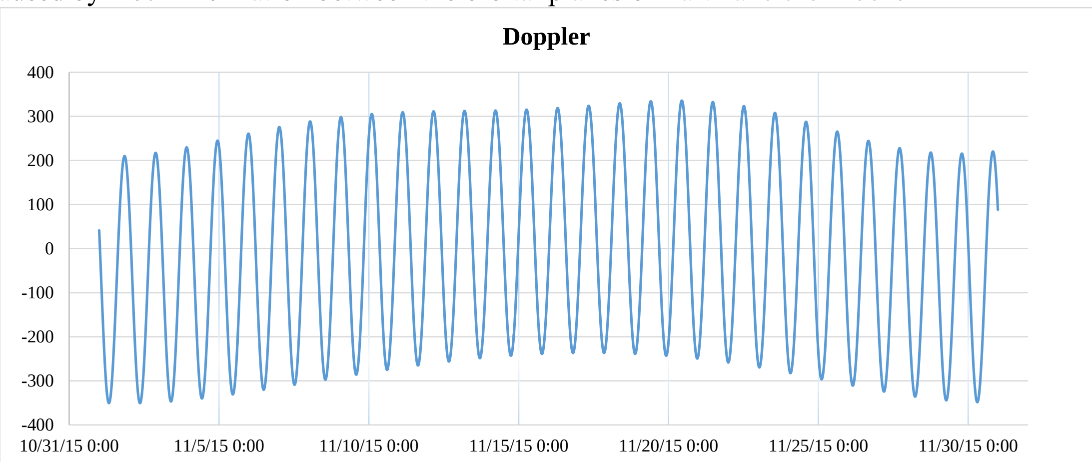

Fig. 6 Frequency displacement calculation results for November

At an EME communication with 144 MHz frequency, the value of RX frequency is changed by ± 400 Hz. Value change of frequency varies from day to day with a few tens of Hz (Figure 6). To decrease the frequency deviation is required to perform calculations for all time periods using the input parameters current time and date.

Figure 6 shows the results of calculations for a month, but moon is not permanent visibility in the communication stations. Thus, it makes no sense to perform calculations for the frequency deviation when it is not possible to make an EME communication due to lack of Moon visibility. In this case there is need for calculating the angle of elevation (or altitude) for the Moon relative to the observer plane (Figure 7).

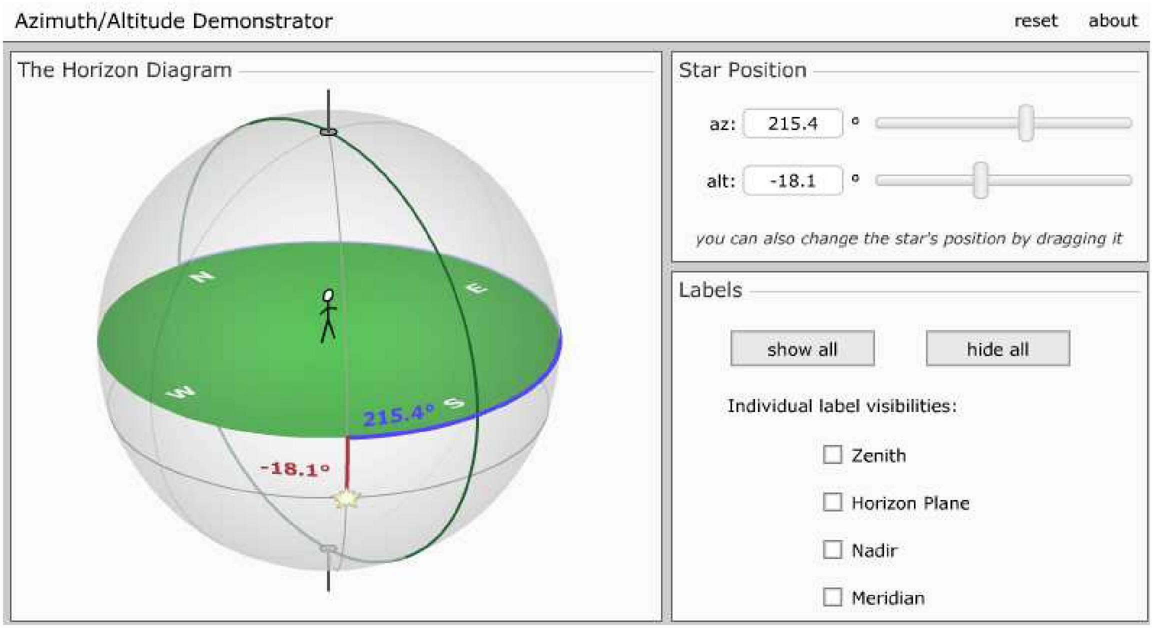

Fig. 7 Representing azimuth / altitude angles for a celestial body

If the altitude of the Moon is negative then it is not visible for the observer plane. If Moon is not observed there is no need for calculating the Doppler deviation. An EME communications can be made only during hours when the elevation angle is positive.

At the algorithm has been added a new condition, if elevation angle is not negative, then it is calculated frequency deviation. The chart below shows the periods of time when the moon can be used as a reflector.

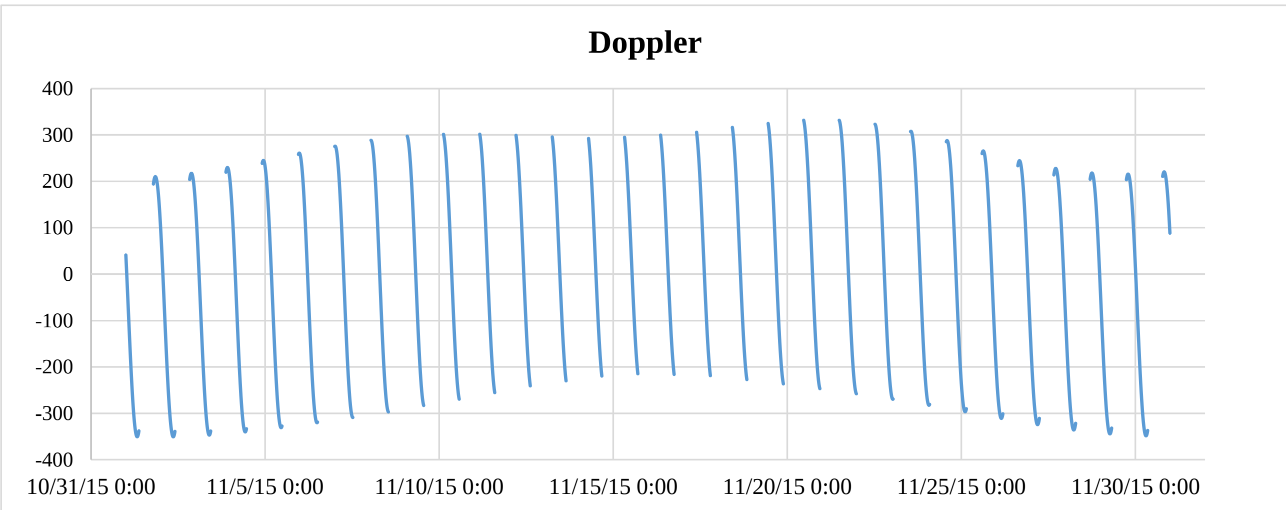

Fig. 8 Frequency shift calculation results for November

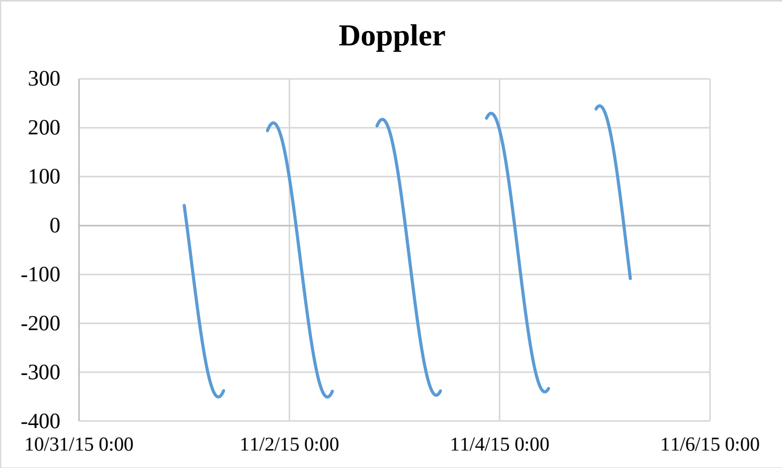

Fig. 9 The calculation results for frequency deviation for three days

There are instances when the moon begins to depart at sunrise and to approach at sunset from Earth and the Doppler deviation is different because of this effect. (Figure 9).

Conclusions

To ensure a better quality in the EME communication process was developed an algorithm to calculate the numerical value of the frequency deviation caused by the Doppler effect. In this algorithm the necessary data entry is: UTC, geographic location and frequency communication station. Frequency deviation veracity was confirmed by a comparative analysis with other software currently available: WSJTX, EME SYSTEM. After applying of this algorithm and analysis of data obtained can mention the following:

• The offense value is a high accuracy, and its weight is directly proportional to EME communication frequency.

• This algorithm can be used not only to achieve a communications but can be useful for making a leadership mechanisms designed to position antennas in the direction of the moon.

• As long as the elevation angle is less than zero, it does not require calculation of frequency deviation based to the impossibility of establishing an EME communications.

• The algorithm can be used for both communication - echo (reception by own station) and communicating with other stations.

• When communicating with a frequency of 144 MHz, frequency deviation shall not exceed ± 400 Hz.

• Doppler effect is minimal when the moon is in the zenith.

Finally it can be mentioned that although EME is a communication used mainly for radio amateurs, it could be used as a means of communication during natural disasters, and ensuring a better quality including using the mentioned algorithm for correction Doppler becomes a necessity in this case.

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