# Amateur Radio Communication to and from the Moon with Lunar Mission One

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# Contents

**Abstract**

The Lunar Mission One craft will be placed on the moon, which is a significant distance from the Earth, and orbits it constantly. Because of this, the radio relay that is placed on the moon will be travelling towards and away from the Earth at different times, causing either a redshift or blueshift depending on the direction it is travelling. In order to ensure the relay works as it should, the range of frequencies these shifts cause LM1 to receive must be found. Distance must also be considered since it causes a delay in the time taken for signals to be received and transmitted.

We have used data from the Jet Propulsion Laboratory Horizons system [1] to compute the time delay and Doppler frequency shifts for both one and two-way communication with Lunar Mission One over a year. The range in these parameters for observers anywhere on Earth will be computed and the impact of the variation in frequency on the communication channel will be investigated. The parameters found will then be used to determine the specifications of the transmitter and receiver installed on LM1. This will allow those with transmitters on the Earth to communicate both with LM1 and with people on other ends of the planet using the receiver and transmitter on the surface of the moon.

The data collected shows that the motion of the moon relative to Earth has little effect on the received frequencies, and should not cause any issues with the relay that is placed on the moon. It was found that the greatest impact was created by the rotation of the Earth, but this effect was lessened as the station on the Earth was moved further from the equator.

# 1 Introduction

The Lunar Mission One craft could help amateur radio enthusiasts by featuring a radio receiver and transmitter to be used as a relay on the moon. This will allow voice communication from one point on the earth to another via the moon. There are currently over 80,000 amateur radio licences issued in the United Kingdom alone, all owners of which would have access to the relay on the LM1 craft. [2] Some of the details of communicating with a low-power radio beacon on the surface of the moon, operating in the amateur radio bands 144–146 MHz and 430–440 MHz will be investigated.

## 2 Lunar radar experiment and laser ranging

One way to measure the distance between the Earth and the moon with high accuracy is by using laser ranging. The first tests which produced results successfully were carried out by the Massachusetts Institute of Technology in 1962 by reflecting laser beams off of the moon's surface and recording the time it took for them to reach the Earth again. [3] This technique was improved upon when NASA's Apollo 11 mission left a retroreflector array on the moon in 1969, allowing space agencies across the world to reflect laser beams off of these arrays much like they did with the moons surface, but with minimal power loss. This is the method used by JPL Horizons to collect data on the position of the moon and its distance from Earth. This data is then used to predict the future position and range of the moon with great accuracy. [4]
Similarly to this, amateur radio enthusiasts have reflected radio waves off of the surface of the moon for communication across the world, but there was a great loss in power with this method due to the moon's surface not being a perfect reflector, causing the minimum transmission power to be rather high. The idea of Earth-to-moon, moon-to-Earth as opposed to Earth-moon-Earth communication was investigated before by Professor Graham Woan, and this report will expand on the research he has done. [5]

## 3 The effect of distance and radial velocity

The issues at hand are the distance between the Earth and the moon, and the velocity of the moon relative to Earth. The distance is important since it causes a delay in the reception of the radio signals. The velocity of the moon relative to the Earth is also important since the receiver's motion through the wave-crests causes the received signal to be of a higher or lower frequency than that transmitted. This causes the receiver to receive a range of frequencies of signals rather than a constant frequency, this means the receiver must be able to receive this range of frequencies in order to communicate with the transmitter on Earth. The radial velocity of the Earth refers to the effect of the Earth's spin on the overall velocity of the signal transmitted. As the Earth rotates one side of it is travelling towards the moon and the other is travelling away. This will have a greater effect on the frequency compared to the orbit of the moon, but there is still a slight difference in the frequency received by the receiver on LM1 caused by the orbit. This can be seen in Figure 3.

# 4 Data collected from JPL Horizons

In order to determine the range in redshift or blueshift due to the rotation of the earth and moon, data was collected every hour for 30 days using JPL Horizons and plotted on graphs programmatically using Python and the matplotlib library. Figure 1 shows the distance between Glasgow and the centre of the moon as a function of time. This data shows that there are two main factors affecting the distance between Glasgow and the Centre of the moon, the Earth's spin, and the orbit of the moon, the latter having the greatest impact. Figure 2 shows the shift in velocity of the moon towards or away from the Earth using the same data as in Figure 1.

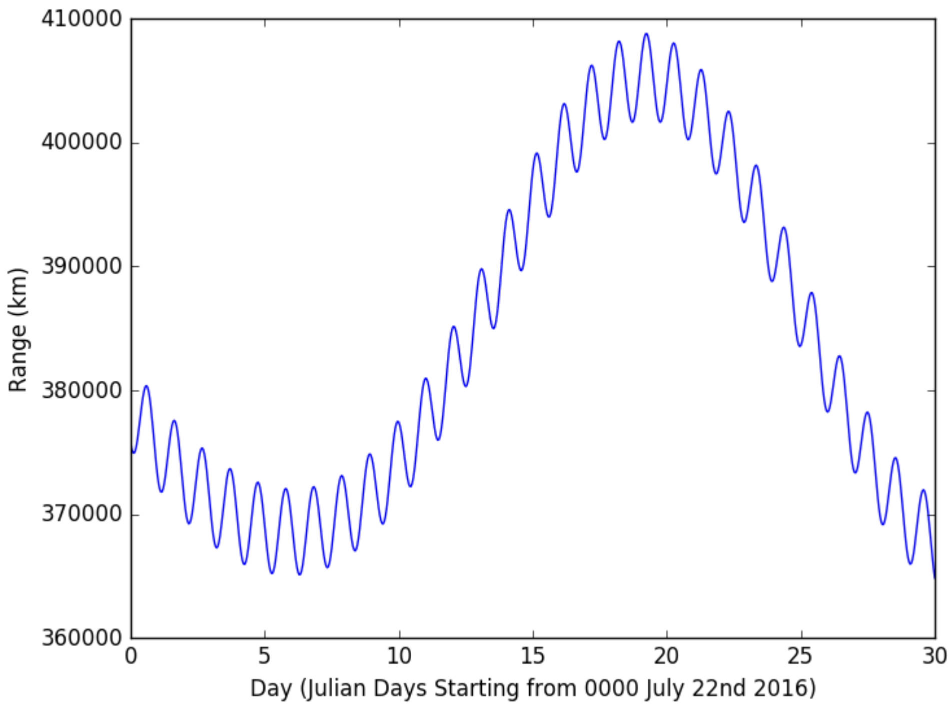


Figure 1: The radial distance between Glasgow and the centre of the moon as a function of time, as computed by the JPL Horizons system. The low-frequency component is due to the Moon's orbit and the high-frequency component is due to the Earth's spin.

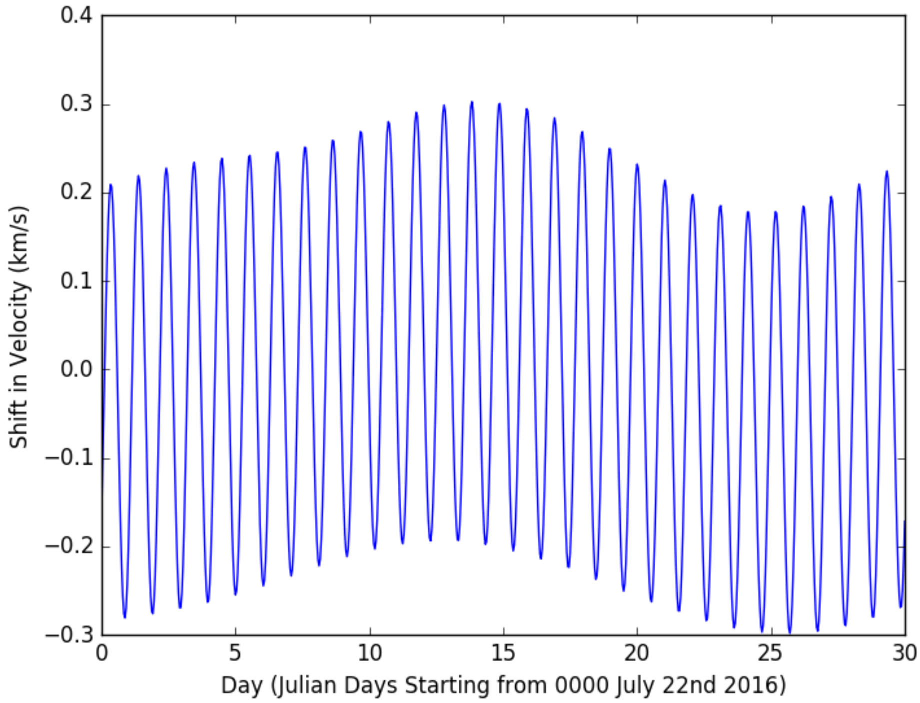


Figure 2: Shift in Velocity of moon compared to Earth Against Time

The relative separation of an Earth-bound observer and the LM1 spacecraft will vary, due to both the nature of the moon's orbit and the spin of the Earth itself. This varying separation imparts a Doppler shift to any communication channel which changes the apparent frequency of a received signal. A signal transmitted from Earth at a frequency $f_0$ will be received on the moon with a frequency

$$f = f_0 \left(1 - \frac{v}{c}\right) \tag{1}$$

where $v$ is the radial velocity of the receiver with respect to the transmitter and $c$ is the speed of light. A narrow-band communication-link would therefore have to be re-tuned over time to compensate for the shift. The formula $f = f_0(1 - \frac{v}{c})$ is used to find the frequency that LM1 would receive if a frequency of 145 MHz was transmitted from Earth. This is shown in Figure 3. Data was also collected for different latitudes on the Earth, to examine the effect this has on the range. This data was collected over 60 days instead of 30 in order to further examine the effect the orbit of the moon has on the range. This data is shown as a graph against time in Figure 4.

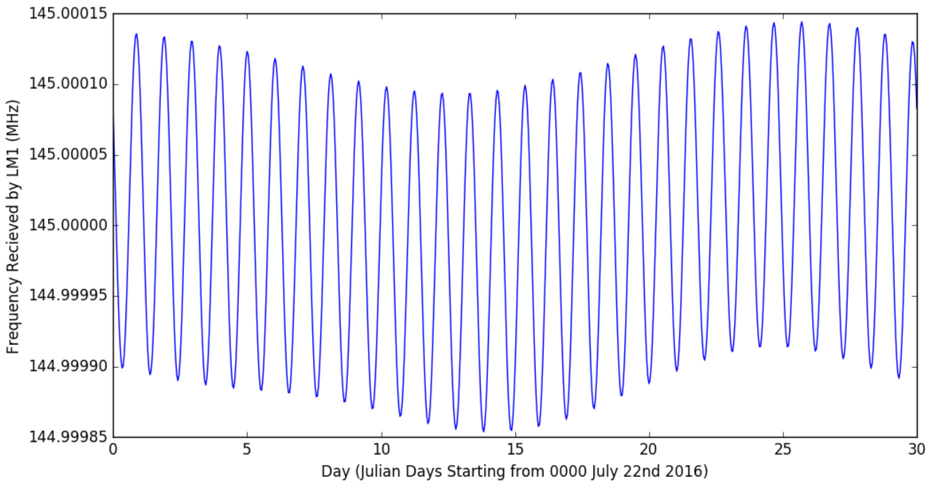


Figure 3: Frequency received by LM1 against time (initial frequency = 145 MHz)

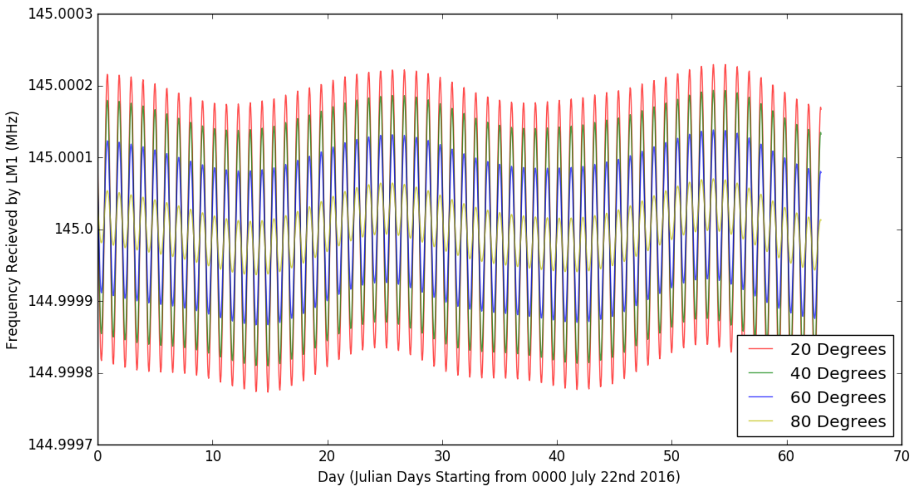


Figure 4: Frequency received by LM1 against time from different latitudes on earth

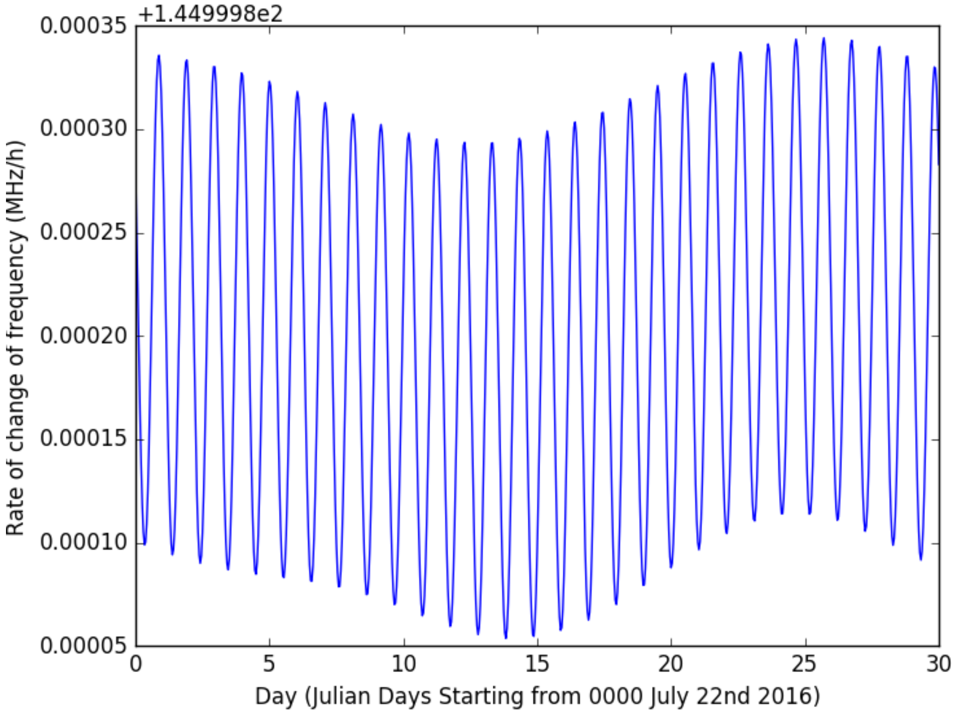


Figure 5: Rate of change of frequency received against time

# 5 Conclusions drawn from the data taken from JPL Horizons

Observing the final graph drawn, which shows the frequency received by LM1 on the moon from different latitudes on the Earth, it is confirmed that the receiver on the moon must be able to receive frequencies of 144.99985 –145.00015 MHz in order for it to be fully functional in receiving signals transmitted from various points on the Earth at 145 MHz.

# 6 Effect of lunar libration on the operation of the relay

One thing to take into consideration is which part of the moon is directly above the transmitter on Earth at each time of day or month, since the visible section of the moon varies very slightly depending on the time of day and more so depending on the time of month. This apparent change in the orientation of the moon relative to Earth, known as Lunar Libration, causes the point on the moon directly above the transmitter to move at a small speed. This speed is the value that may have a slight effect on the received frequency of the signals since the point may be moving away or towards the Earth if the receiving point happens to be on a limb of the Moon. The word "limb", in the context of the moon, refers to either of the apparent "edges" of the moon, where some parts may only be visible at certain points in time from Earth. This is illustrated in Figure 6. [6] The apparent speed of a point on the moon can be seen in Figure 7. This graph shows that libration has little effect on the apparent velocity of the receiver towards or away from the Earth.

$$v_L^2 = \left(\frac{dl}{dt}\right)^2 = r^2 \cos^2\phi \left(\frac{d\lambda}{dt}\right)^2 + r^2 \left(\frac{d\phi}{dt}\right)^2 \tag{2}$$

This equation is used to find the speed of the position as it changes on the surface of the moon, this can then be used to find the change in frequency:

$$\Delta f_L = f_0 . \frac{v_L}{c} \tag{3}$$

Figure 6: An illustration of lunar libration showing the “limbs” of the moon

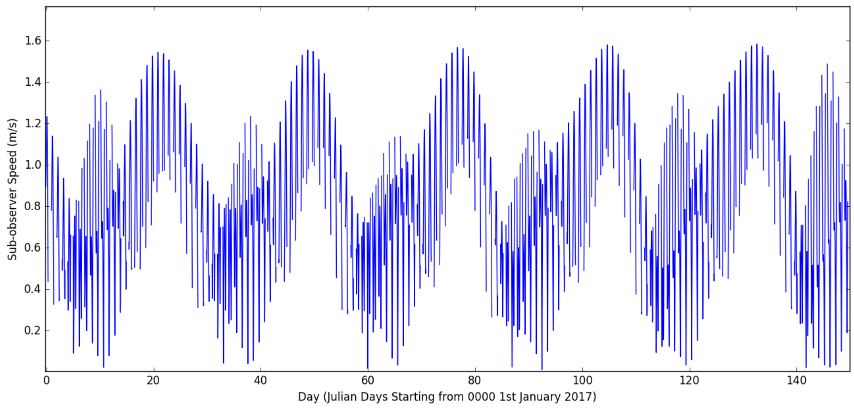


Figure 7: The apparent velocity of a point on the moon as seen by an observer on Earth (adapted from Woan (2016)) [7]

# 7 The significance of geo-spacial effects in radio communication in space

Looking at the data collected in the research above, it can be seen that the geo-spacial effects are insignificant in this case, and are not something to be worried about, however on a larger scale this may create more of an issue, for example, communication with a relay on another planet such as Mars. This information could be useful in the future if there are ever plans on landing a similar craft on a body further away from the Earth than our moon.

# 8 Power requirements and signal to noise ratio

One of the issues that must be addressed is that on the moon, LM1 will not have access to a great amount of power, 10 W is the estimated maximum without the drill running. This means both the receiver and transmitter on LM1 must be very low-power while still being able to operate correctly, and hopefully be able to relay audio from one side of the moon to the other. To work out the power received by the receiver on the moon, the fraction of the area covered by the transmitter on the Earth must be worked out. Once this fraction is worked out, it can be used to find the fraction of the power that is detected by the receiver. In one dimension, the effective opening angle of a transmitter beam can be found using the equation:

$$\theta = \frac{\lambda}{D} \tag{4}$$

But in this situation one dimension is not enough, the effective angle must be found in two dimensions, in this case,

$$\Omega = \frac{\lambda^2}{A_e}, \tag{5}$$

Here Omega is the solid angle, and $A_e$ is the effective area of the dish. The detected power can be expressed as $\frac{A_e}{A}$ where $A$ is the overall area that the power is transmitted to. Using this fraction we can find the power received using the equation:

$$P_{rec} = P.\frac{A_e}{A} = \frac{PA_{eR}}{\Omega t_x r^2} = \frac{PA_{eR}A_{eT}}{\Lambda^2 r^2} \tag{6}$$

Where $P_{rec}$ is the power received, $A_{eR}$ is the effective area of the receiving dish, $A_{eT}$ is the effective area of the transmitting dish, and $P$ is the transmitted power.

# 9 Bibliography

## References


[1] NASA. JPL Horizons.

[2] Neil Meads. The very particular world of amateur radio. 2013.

[3] Louis D. Smullin and Giorgio Fiocco. Optical Echoes from the Moon. *letters to nature*, 194:1267, 1962.

[4] Charli Schuler. Apollo 11 Experiment Still Going Strong after 35 Years. 2004.

[5] Professor Graham Woan. A lunar repeater/transponder for amateur radio, 2016.

[6] Astronomy from South Florida. Lunar Libration.

[7] Professor Graham Woan. Unpublished libration code, 2016.