UNDERSTANDING DOPPLER SHIFT: CRITICAL KNOWLEDGE FOR SUCCESSFUL EME ON THE HIGHER BANDS

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Abstract: This paper discusses the shift in signal frequency caused by the Doppler Effect during moonbounce communications. It explains the importance of understand this effect and gives strategies to improve your success when operating both CW and JT EME modes by using knowledge of the Doppler Effect.

Introduction:
Understanding the Doppler Effect is critical to successful EME on the higher EME bands for both CW and JT operation. On 144 MHz the maximum change in frequency during EME due to the Doppler Effect is not much more than 350 Hz and of little concern. On 1296, however, it is greater than 3 kHz, and on 10 GHz more than 30 kHz! With these large frequency changes, even with the help of a Software Radio's waterfall display, you need to known a signal's Doppler shift to find a weak station. Even on 432, where the maximum difference is only near 1 kHz, I have seen QSOs missed because the Doppler Effect was not well understood.

Doppler Basics:
The basic Doppler equation is

$$fr = ft\ C / (C + V) \quad (1)$$

where fr is the received (RX) frequency and ft is the transmit (TX) frequency; C is $3x10^8$ m/s (the speed of light and of radio waves); V is the relative velocity between the receiver and transmitter. If the receiver and transmitter are moving apart, the sign is plus as shown in (1). If they are approaching each other, the sign changes to negative. In the case of moonbounce, the situation is a little more complicated since there are two paths; one path from the transmitter to the Moon, and a second path from the Moon to the receiver. The total frequency shift is the product of the two paths

$$fr = ft\ [C / (C + Vt)]\ [C / (C + Vr)] = ft\ C^2 / [(C + Vt)(C + Vr)] \quad (2)$$

where Vt is the relative velocity between the transmitter and the Moon, and Vr is the relative velocity between the Moon and the receiver. When listening to your own echoes, Vr and Vt are the same and

$$fr = ft\ C^2 / (C + V)^2 \quad (3)$$

V depends on the relative velocity of the Earth and the Moon at your QTH. At moonrise, the rotation of the Earth is causing your location to catch up with the Moon. (The Moon is rotating around the Earth in the same direction as the Earth at a much higher rate is revolving about its axis – see Figure 1). The resulting relative velocity (V) is near its greatest and the frequency shift near its positive maximum. Right after moonrise, the frequency shift slightly increases and then gradually decreases to zero near zenith.

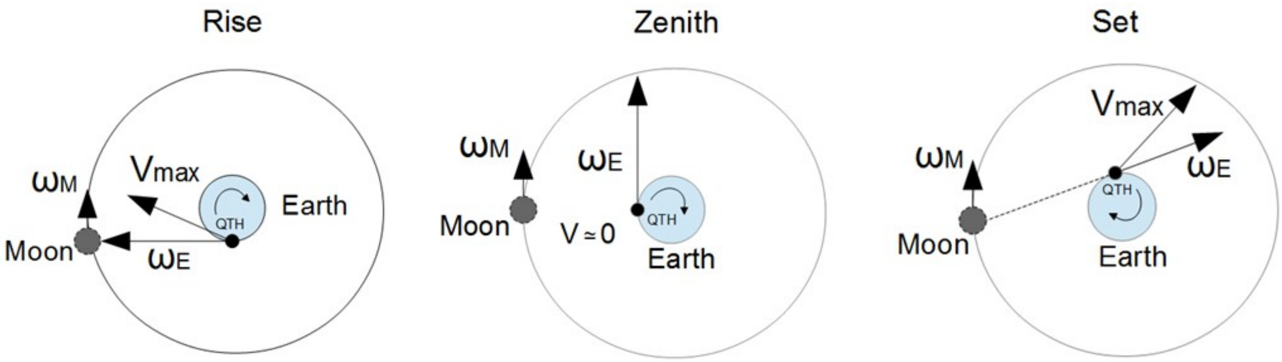

Fig. 1: Relative velocity of the Earth and Moon

Zenith is the point where the Moon is at its highest and always occurs due south, (and at local midnight when the Moon is full). The rate of frequency change is also at its smallest near zenith. The frequency shift then turns negative as the Moon moves away from your location on the Earth. The negative frequency shift then gradually increases and reaches minimum (maximum negative shift) near moonset. (The maximum, zero change and minimum frequency points do not occur exactly at moonrise, zenith and moonset, respectively because of the different contributions to the total relative velocity of the Earth's rotation about its axis and the Moon's rotation about the Earth). This frequency shift is referred to as your Self Doppler Shift (SDS) – see Astronomical Data Box in JT65 and Figure 2.

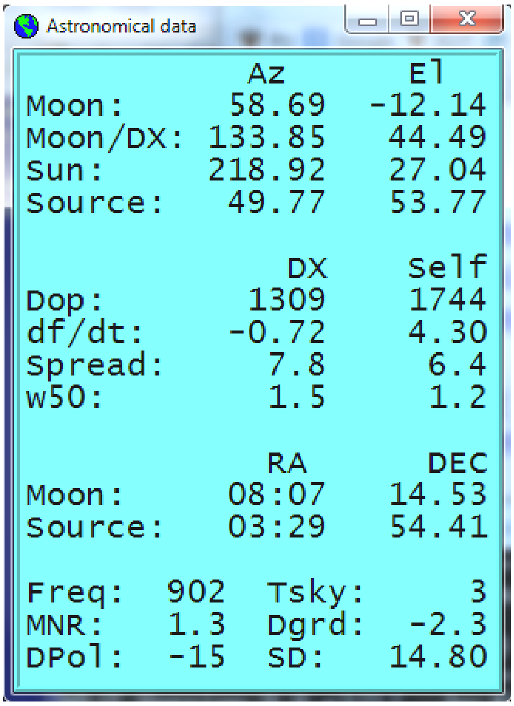

Fig. 2: Self is SDS and DX is MDS

Where to listen and call:
Things get more complicated when you are listening to a station that is located at a different location on Earth. Vt and Vr are not the same. For two stations at different locations, the Moon may be moving away from one location, while approaching the other station as shown in Figure 3. The difference in frequency between the TX frequency (ft) and the received (RX) frequency (fr) at the second location can be significantly different

than the SDS. This shift is referred to as the Mutual Doppler Shift (MDS). If you accurately know a TX station's frequency, it tells you where to listen for this station's echoes. MDS is also shown in the Astro

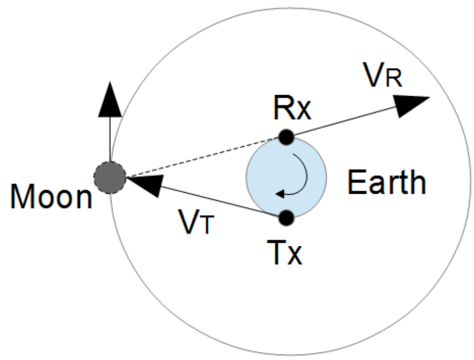

Fig. 3: The Moon may move away from the TX location, while approaching the RX site

Listening on your echo:
A key insight from equations (2) and (3) is that if you set your TX frequency (ft) so that your (self) echoes fall on the same frequency as you hear a station (fr), that station will hear you on the same frequency as he hears his own (self) echoes. This occurs because the Doppler shift is independent of direction. For CW random operation, stations normally listen on the same frequency as they hear their (self) echoes. Even if you can't copy your own echoes, you still should listen where your echoes should be, on your SDS. This can be easily accomplished with a transverter with an accurate RIT, by setting it to the SDS. (I find it convenient to use the Astronomical Data box in WSJT for Doppler information. I use the WSJT screens when I operate both CW and JT EME modes). If you operate the higher microwave bands, you need an RIT with a wide range of adjustment. I use a TS2000X, which can be adjusted +/- 20 kHz. (This seemed more than satisfactory until I started seriously operating on 3 cm where the SDS is greater than 30 kHz at Moon rise and set.) Another solution is to use a transceiver with split operation, where the TX and RX frequencies can be set separately. Listening on your echo is also becoming the preferred procedure for random JT operation, although not yet universally followed by all JT operators.

Listening on your TX frequency:
The alternative is to listen on your actual TX frequency. (You cannot offset your RX frequency with an MDS, since you do not know where a random calling station will be located). This requires that a station replying to your CQ: 1) Determine your actual TX frequency from the MDS. This information can be obtaining from WSJT by entering your call and viewing the Astronomical Data box. 2) Subtracting the MDS from the frequency you are received on (fr) to get your actual TX frequency. 3) Then subtracting the MDS again to obtain the TX frequency (ft) to reply on to you. Steps 2) and 3) can be combined by subtracting the MDS twice.

To be heard on a station's TX frequency, you must TX so your ft = fr – 2 MDS (4)

As you can see it gets complicated. This is why for random operation, most stations TX so that their echoes fall on the frequency they hear a station that they want to QSO.

Calling on a specified frequency (example):
If it is agreed that everyone will call on a specific frequency, say 070, then for example on 23 cm, when you are calling CQ from Europe (EU) with the Moon near zenith, other EU

stations will be heard very close to your TX and echo frequency as both the SDS and MDS will be small. However, North American (NA) stations will be heard more than a 1 kHz higher in frequency than the EUs (assuming they are transmitting on 070); and Asian stations would be more than a 1 kHz lower. Of course knowing about Doppler, you will tune to the MDS of the stations in these other areas of the world. But if you are working other EU stations, to be heard, a NA would need to TX on 070 minus MDS; not on 070. If the Moon was near set, other EUs (and your own echoes) would be close to -3 kHz below your TX frequency, while NA stations would be heard about 1.5 kHz low. The NA stations can again put themselves near the same frequency as other EU stations by subtracting the MDS and adding your SDS. (The SDS did not need to be added in the zenith case because it was near zero). Unfortunately, this is your SDS, not the SDS shown in the NA's station's WSJT Astronomical Data box. The NA can get this value by estimating it based on his SDS for a similar Moon position at his QTH. I know of no software that will easily supply this data. (The NA station can obtain your SDS by changing his grid locator in WSJT [in Options] to your grid).

How to be heard:
The general rule for putting your signal where it will be heard by a desired station (a dxpedition or contest station, etc.) communicating with another station (or group of stations) in a given part of the world involves the following: 1) You need to know the desired station's TX frequency (fdx) and location. 2) You need to know the communicating station's frequency (fc) and location. 3) You then need to TX at

$$ft = fdx - MDSt\text{-}dx + MDSdx\text{-}c \qquad (5)$$

where ft is your TX frequency, fdx is the TX frequency of the desired station, MDSt-dx is the MDS between you and the desired station (can be obtained from the WSJT Astronomical Data box), and MDSdx-c is the MDS between the desired station and the station he is communicating with - (can be estimated/determined as already discussed).

Finding a DX (desired) station:
Equation (5) assumes that all stations are TXing on the same frequency. If you are not sure of a desired station's frequency and hear a station communicating with him, you can calculate where to listen for the desired station from heard station's frequency (frc). If the station heard is set to the same frequency as the desired station (the procedure we are assuming), then the desired station will be received on:

$$frdx = frc - MDSt\text{-}c + MDSt\text{-}dx \qquad (6)$$

where MDSt-c is the MDS between you and the copied station.

If the desired station is listening on his (self) echoes as earlier recommended, then all you need to do is look for him on his announced frequency, fdx, plus the MDSt-dx, and reply so your echoes fall on this frequency. Although he should hear all calling stations on this frequency no matter what their location, you will not hear all calling stations on this frequency. If you are not sure of the desired station's frequency and hear a station calling him, you can calculate where to listen from this station's received frequency (frc), but this calculation is more complicated than when everyone is on the same TX frequency. Assuming the communicating station has set his frequency correctly, the desired station's TX frequency should be:

fdx = frc - MDSt-c - MDSdx-c + SDSc (7)

where MDSdx-c is MDS between the desired station and the station you are copying, MDSt-c is the MDS between you and the copied station, and SDSc is the copied stations self echo Doppler.

You would then listen for the desired station at fdx + MDSt-dx. (8)

Conclusions:
The rules and equations presented in this paper should help you make more EME QSOs.

Generally the preferred method for random EME operation is to call CQ on a given frequency and listen for replies on the same frequency as your echoes, which is given by your SDS, (ft + SDS). Stations replying to your CQ, should reply so that their echoes fall on the frequency they receive you on. If you copy a station replying to an unheard station, you can estimate where to listen using equations (7) and (8).

If a station is listening on his TX frequency as is done by some stations that operate JT, you should hear him on his TX frequency + MDS, but you should reply on the frequency you hear him on – 2 x MDS.

If you sked a station, where you are both to TX on the same frequency, you both should listen on the sked frequency + MDS.