Elevation Angles Required for 6m Sporadic E

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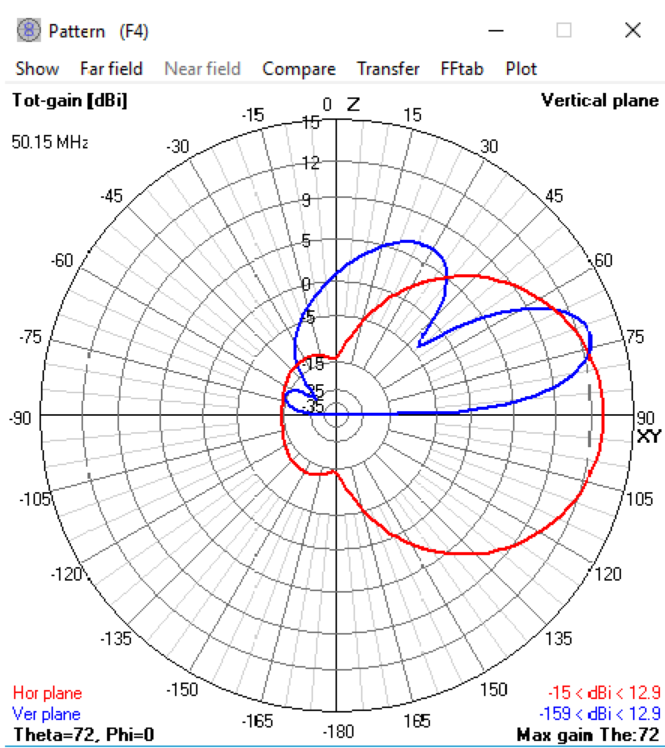
Introduction

As the ARRL June VHF contest approached last month, traffic on the SMC (Society of Midwest Contesters) reflector increased significantly as this contest was one of the big ones for club participation.

Although I'm just out of the SMC circle and thus my score wouldn't count towards the SMC effort, I still got all fired up to do a single-band 6m effort as that's all I have on VHF/UHF at the moment. I do have an old Kenwood 2m multi-mode transceiver, but it needs some repair work.

Another reason to do the contest was to finally assemble the MFJ 3-element 6m Yagi that was still in its box in my garage. It went together quickly, and was very easy to mount fixed to the southeast at 15 feet on two sections of existing Rohn 25 tower. The model of it at 15 feet over average ground using 4nec2 (available free at http://www.qsl.net/4nec2/) shows the following:



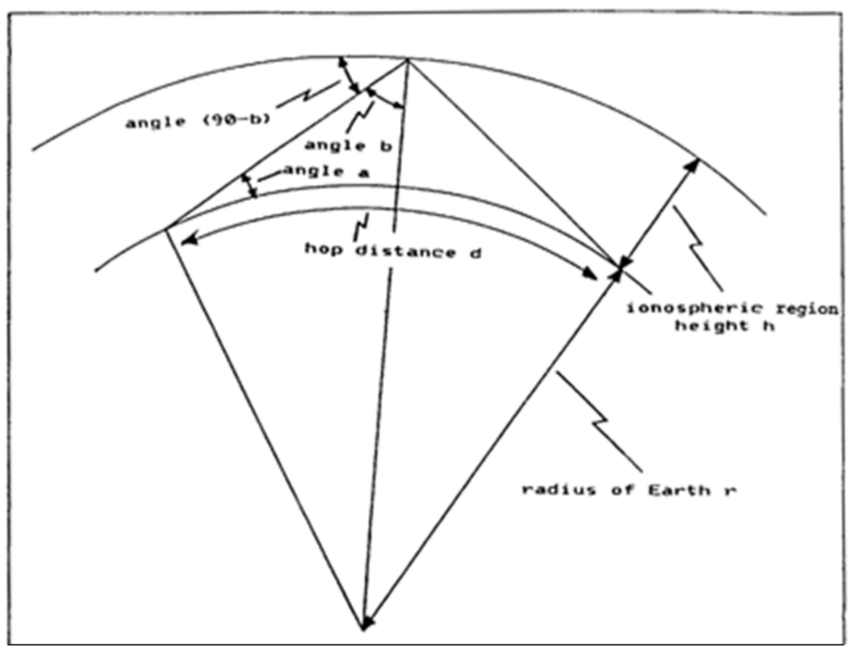
The azimuth pattern (Hor plane) is the red curve and the elevation pattern (Ver plane) is the blue curve. Note that the 4nec2 elevation plot is in terms of the zenith angle (overhead is 0^{o} and 90^{o} is on the horizon), not elevation angle. The peak of the lowest lobe in the elevation pattern is around 18 degrees elevation, which makes sense as the antenna is slightly lower than one wavelength high (an antenna at one wavelength has its main lobe at about 15 degrees).

The antenna model shows decent gain (the 12.9 dBi at 15 feet translates to about 6 dB gain over a dipole – which is reasonable for a 3-element Yagi) and good F/B (front-to-back) in the high twenties.

A good question to ask is "*is my 6m Yagi too low for sporadic E propagation on 6m?*" We can reasonably answer this question by doing some simple calculations of the Earth-ionosphere system using spherical geometry.

<u>Model of Earth-Ionosphere System</u>

The model of the spherical Earth-ionosphere system is shown below.



From spherical geometry, three equations are used to determine the hop distance d, the angle b (needed to calculate the angle of incidence of the ray on the ionosphere, which is the angle 90-b), and the M-factor (which is multiplied by the critical frequency to determine the MUF – the maximum useable frequency – alternatively, knowing the M-factor allows one to determine the critical frequency needed for a desired MUF).

$$\textit{hop distance d in km} = 2\, r\, \{90 - a - \sin^{-1}[r \sin(a + 90) / (r + h)]\} / 57.3$$

$$\textit{angle b in degrees} = \sin^{-1}[(r / r + h) \sin (a + 90)]$$

$$\textit{M-factor} = 1 / [\sin(90-b)]$$

The radius of the Earth ‘r’ is assumed to be 6371 km. The elevation angle ‘a’ is the launch angle of the RF referenced to the horizon. The sporadic E layer height ‘h’ is assumed to be 105 km. Also see Note 1.

Required foEs

Using the three equations in the previous section, the hop distance and required sporadic E critical frequency foEs for an MUF of 50.1 MHz for various elevation angles (the angle ‘a’ in the Earth-ionosphere system sketch) can be calculated. This data is shown in the following table.

angle ‘a’	hop distance ‘d’	angle ‘b’	M-factor	required foEs
0^o	2297 km	79.67^o	5.58	8.98 MHz
5^o	1438 km	78.53^o	5.03	9.96 MHz
10^o	965 km	75.96^o	4.04	12.40 MHz
15^o	700 km	71.85^o	3.21	15.61 MHz
20^o	537 km	67.59^o	2.62	19.12 MHz
25^o	428 km	63.08^o	2.21	22.67 MHz
30^o	350 km	58.43^o	1.91	26.23 MHz

Maximum Mid-Latitude foEs Values

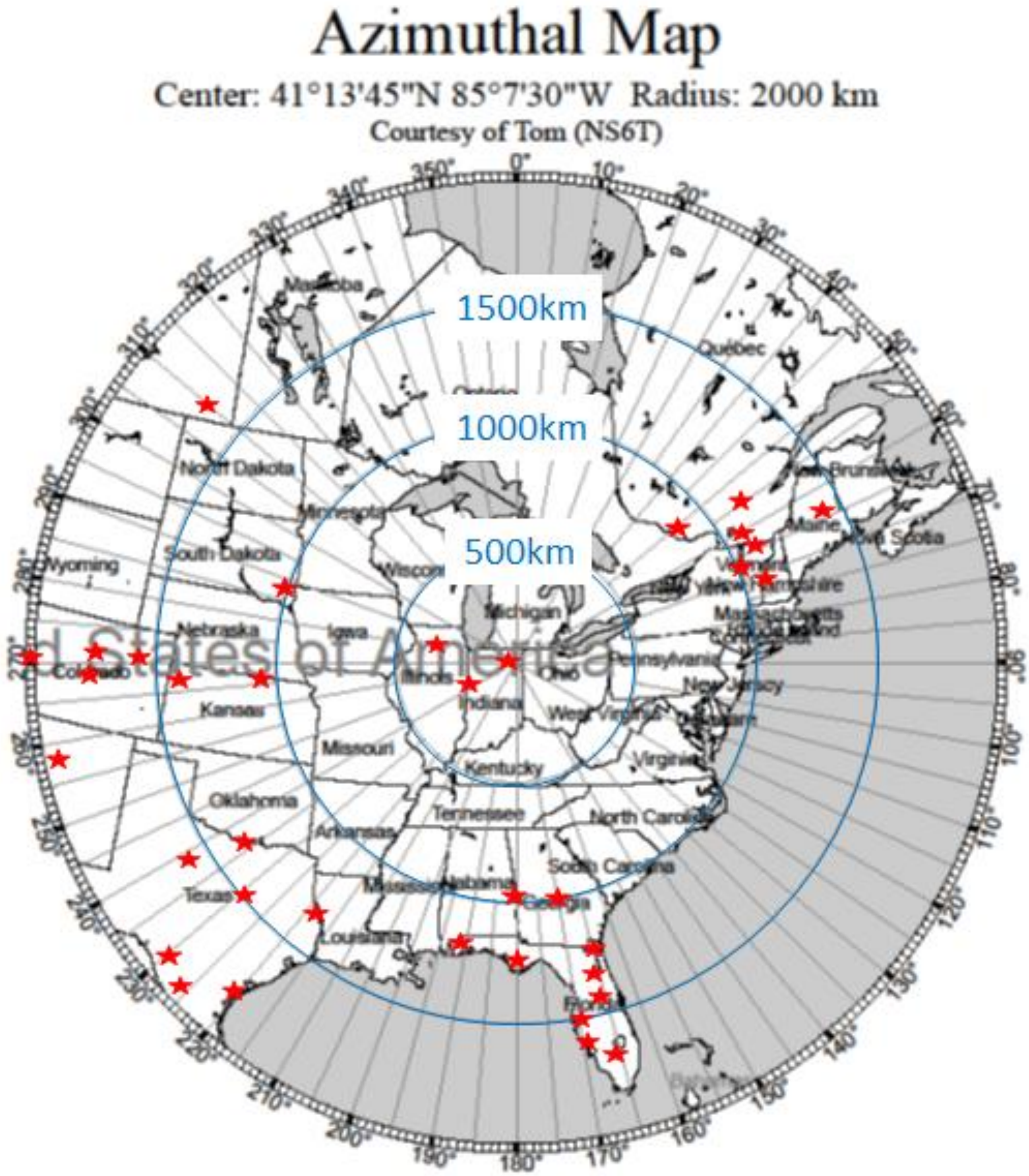
Knowing the required foEs now begs the question “*what is a maximum value of foEs?*” We can answer that question by reviewing data from several mid latitude ionosondes in the North American sector. These ionosondes are Dyess AFB (TX), Wallops Island (VA), Millstone Hill (MA), and Boulder (CO). They were reviewed for maximum foEs values during the summer of 2006 (June 1 through August 31).

The highest foEs value observed was 11.9 MHz. To allow for higher foEs values that would occur at a low probability and to allow for a ‘better’ Es season than 2006, let’s increase the 11.9 MHz value by 25% to 15 MHz. Note that a 15 MHz foEs would translate to an MUF of around 75 MHz for low elevation angles (M-factor about 5).

From Table 1, this 15 MHz value says 6m sporadic E propagation is limited to a minimum distance of around 700 km, which requires an elevation angle of about 15^o.

Conclusion – Elevation Angles Required for 6m Sporadic E

The conclusion of this analysis is that elevation angles from 0^o to 15^o are most important for 6m sporadic E propagation. These angles cover 700 km to 2300 km. Here are my ARRL June 2018 VHF Contest 6m QSOs on an azimuth equidistant map centered on my QTH (thanks NS6T). The red stars can indicate multiple QSOs in the same grid. The outer ring is 2000 km, with 500 km, 1000 km and 1500 km distances indicated in blue.

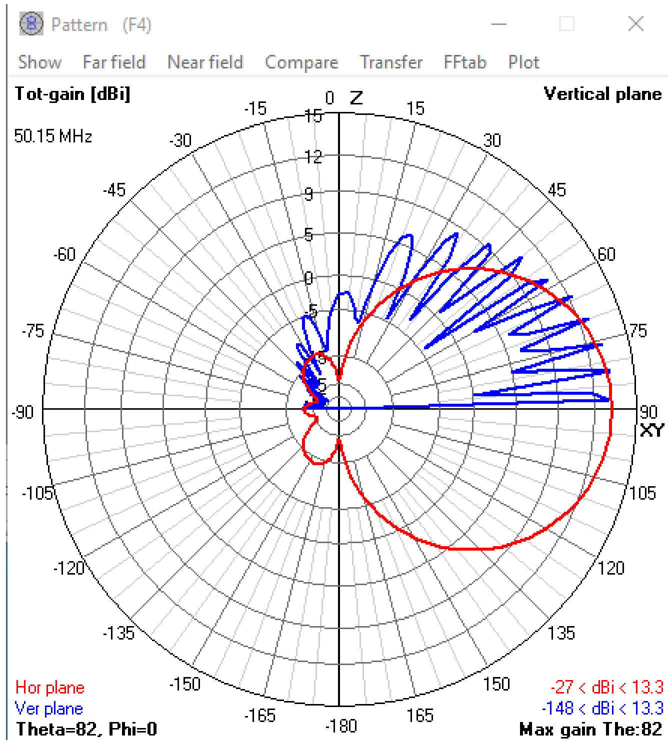


As can be seen, all but three of the stars fell within the 700-2300 km range. Several QSOs were with locals here in Ft Wayne (northeast IN), and were essentially line-of-sight. The two shortest QSOs at under 500 km (in northern IL and on the central IL/IN border) had very weak signals.

Thus based on actual QSO results, higher angles can be supported at times. There are short-term enhancements in the ionosphere that simply aren't caught in our model of the ionosphere – or even in the ionosonde measurements. There's always scatter, too (which likely accounts for the QSOs in northern IL and on the central IL/IN border).The bottom line is don't be surprised if you occasionally make QSOs shorter than 700 km.

Can A 6m Antenna Be Too High?

Yes. As we put the antenna up higher and higher in terms of electrical wavelengths, nulls develop – even at very low elevation angles in the 0-15^{o} range. For example, here's my 3-element 6m Yagi at 100 feet.



The gain has gone up a bit (0.4 db, in fact), the F/B is still very good, but the elevation pattern now is broken up into many lobes. There are nulls at about 7^{o} and 13^{o} – not good based on our conclusion. Of course this should be tempered with the fact that in the real-world the nulls likely won't be as deep as predicted by the 'perfect' model. Regardless, if I was to move my little 6m Yagi up higher, I'd put it between 30 and 40 feet.

Note 1

The sporadic E layer is always cited to be very thin – only several km in vertical extent. This suggests *pure refraction* isn't the mechanism for sporadic E as there isn't enough vertical extent to turn a 50 MHz electromagnetic wave back to Earth. It very well could be that *partial reflection* is what's mostly happening with sporadic E. This appears to be confirmed by a 1970 Master of Science thesis by Ruey-Yuan Han at Utah State University titled "A Study of The Secant Law for Sporadic E". This thesis is available at https://digitalcommons.usu.edu/etd/3322/.