What Mode of Propagation Enables JT65/JT9/FT8?

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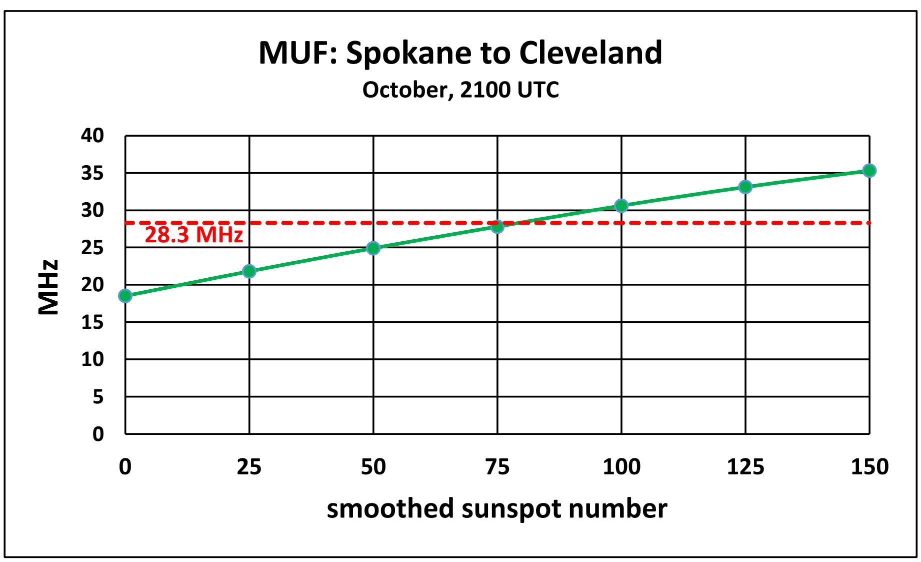
The purpose of this article is <u>not</u> to rigorously analyze how much improvement each JT mode offers – the purpose is to introduce the concept of a well-documented but less well-known mode of HF propagation and how it ties into the success of the JT modes.

It should be obvious that K1JT's JT65/JT9/FT8 digital modes are making big changes in band usage, especially on the higher bands as we approach solar minimum between Cycle 24 and Cycle 25. Is there a new propagation mode lurking here? Or is it just a less-known propagation mode that hasn't received much attention? Let's analyze a 10-Meter path between Spokane, WA and Cleveland, OH (approximately 3000 km – one-hop via the F2 region) to understand what's going on.

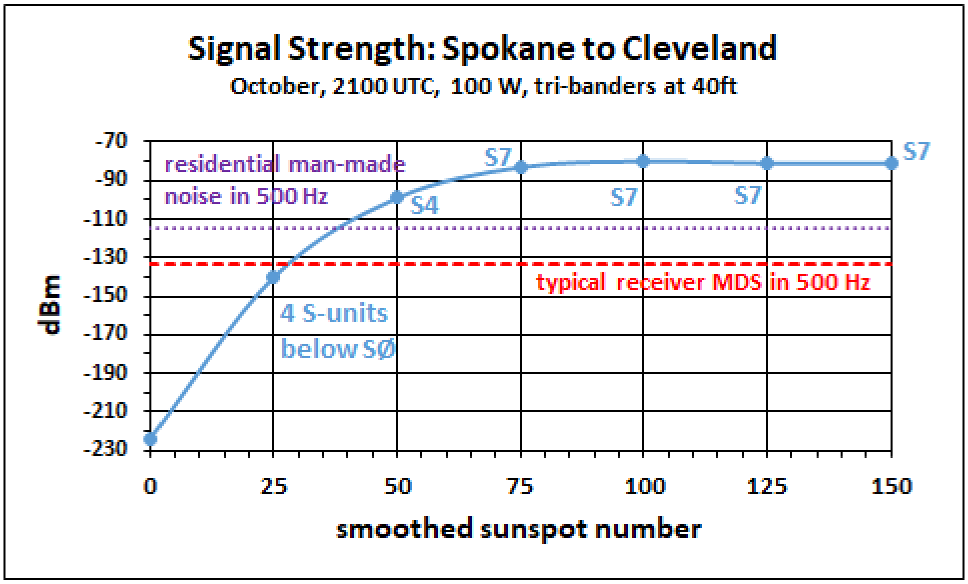
We'll use VOACAP to do this at a frequency of 28.3 MHz, with the transmitter in Spokane at 47.66° North latitude / 117.43° West longitude and the receiver in Cleveland at 41.50° North latitude / 81.70° West longitude. The month is October (a very good month for ionospheric propagation via the F2 region in the northern hemisphere) and the time is 2100 UTC (the best time for F2 region propagation between Spokane and Cleveland).

The antennas at both ends are assumed to be small Yagis at 40 feet over flat ground. The ground parameters used are for average ground – a conductivity of .005 Siemens per meter and a relative permittivity of 13. The resulting antenna gain is about 12 dBi at a peak elevation angle of 13 degrees. The transmit power is 100 Watts. The following are the predicted MUFs (maximum useable frequencies) from VOACAP at various smoothed sunspot numbers. The MUF is the first parameter needed for a QSO to be made – it must be high enough to assure that the signal gets from Spokane to Cleveland.



The important observation from the above plotted data is that F2 region propagation at 28.3 MHz should only be supported on this path when the smoothed sunspot number is greater than 75 because the MUF is greater than the operating frequency. The usual assumption here is that refraction occurs when the MUF is greater than the operating frequency. In other words, the ionization is sufficient to refract (bend) signals back to Earth. When the MUF is less than the operating frequency, the signal is not refracted enough and goes off into space, with no signal reaching the target.

Now let's look at the predicted signal strength from VOACAP. Signal strength is the second parameter needed for a QSO to be made – the losses must be low enough so you can hear the other station's signal. Here's what VOACAP says for signal strength versus smoothed sunspot number for the selected path.



There are two important observations to be made from this data. The <u>first observation</u> is that when the smoothed sunspot number is high enough so that the MUF is above the operating frequency (greater than 75 in this example), the signal strength is pretty much constant. This signal strength (actually signal power) is around -83 dBm, which translates to around S7 (as annotated on the plot) assuming S9 = -73 dBm and an S-unit is 5 dB (which is what I've measured on my receivers).

What's happening when the smoothed sunspot number is greater than 75 is refraction coupled with minimal ionospheric absorption (absorption is inversely proportional to the square of the frequency – it is less than a dB per hop on 10-Meters – this is one of the reasons why 10-Meter signals can be so strong). As a side note, all the signal strength values include the antenna elevation pattern of both Yagis at 40 feet.

Note that when the smoothed sunspot number is greater than 75, there is a huge amount of dB difference between S7 and the typical MDS (minimum discernible signal – a.k.a. sensitivity) of our receivers at around -133 dBm (the dashed red line) in a bandwidth of 500 Hz (a typical CW bandwidth). The difference is around 50 dB! This means the Spokane station could reduce his/her transmit power by 50 dB (to 1 milliWatt – now that's QRP!) and still be heard in Cleveland.

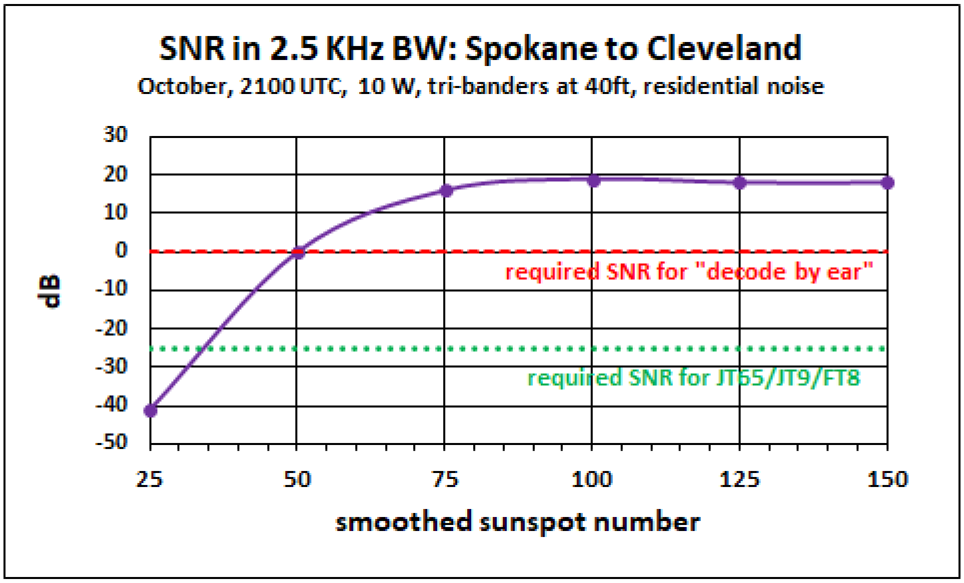
But we need to watch it here – usually man-made noise, even on 10-Meters, limits the sensitivity of our receiving system. Using the data in the ITU (International Telecommunications Union) document ITU-R P.372-13 for a residential noise environment indicates the true sensitivity of the Cleveland station is limited to around -115 dBm in a 500 Hz bandwidth (the dotted purple line). Realistically the Spokane station could now only reduce his/her power to 100 milliWatts when the smoothed sunspot number is greater than 75. Still not bad, though!

The second observation is that VOACAP still predicts signal strengths when the smoothed sunspot number is less than 75 – in other words, it predicts that propagation is still possible although full refraction cannot happen. At a smoothed sunspot number of 50, the predicted signal level is -99 dBm, which translates to around S4 and it is still above the man-made noise level. Is this an error on VOACAP's part? No, it isn't. VOACAP is simply trying to reflect (no pun intended) the real world.

In the real world, measurements over many paths have shown that a readable signal is still present even when the MUF is below the operating frequency. This called an above-the-MUF mode of propagation, and VOACAP includes the Phillips-Abel theory (**note 1**) to do the necessary math to predict propagation under this condition (**note 2**).

The mechanism for an above-the-MUF mode is believed to involve random patches of ionization that have a higher electron density than the background plasma and/or scatter – it could be ionospheric scatter, ground scatter or even sea scatter (**note 3**). Regardless of the specific mechanism, the one thing in common is additional loss. Thus the difference between the MUF and operating frequency is critically important – the more the difference, the more the loss. In summary, the above-the-MUF mode is why VOACAP still predicts signal strength (instead of abruptly cutting off the prediction) when the MUF is below the operating frequency.

Now that we've looked at the normal "decode with ear" scenario, let's move on to the JT65/JT9/FT8 scenario. Our analysis will make three major changes – we'll switch from signal strength to SNR (signal-to-noise ratio), we'll switch from 100 Watts to 10 Watts and we'll use a 2.5 KHz bandwidth. These changes put the analysis in line with current JT65/JT9/FT8 practices (**note 4**). The SNR versus smoothed sunspot number follows (**note 5**). The data point at a smoothed sunspot number of 0 is not plotted to give better resolution to the other data.



If Spokane is operating on CW at 10 Watts, Cleveland should be able to decode by ear the Spokane station's 10-Meter signal in the 2.5 KHz bandwidth when the smoothed sunspot number is above 50. This assumes humans can copy CW at an SNR of 0 dB, which is a realistic assumption.

But by using JT65/JT9/FT8, we should be able to make the QSO all the way down to a smoothed sunspot number of around 35. This assumes JT65/JT9/FT8 can decode down to an SNR of around -25 dB (a ballpark value for all three modes in the 2.5 KHz bandwidth – remember the purpose of this article is not to rigorously analyze the improvement with each JT mode). The 10-Meter band may be "dead" assuming the normal definition, but JT65/JT9/FT8 gives us the possibility of still making QSOs via the above-the-MUF mode.

An interesting corollary here is that VOACAP should be able to be used to predict JT65/JT9/FT8 openings on our higher bands (15-Meters, 12-Meters and 10-Meters) as Cycle 24 declines and we go through solar minimum. How accurate would it be? Recording observed openings and comparing to SNR data from VOACAP (using appropriate power levels, noise environments, bandwidth and antennas) would shed light on that question.

As far as I'm aware, the Phillips-Abel theory should also apply to 6-Meters. Unfortunately VOACAP does NOT include 6-Meters, so you can't use VOACAP for any above-the-MUF predictions on 6-Meters. However, one might be able to extract the Phillips-Abel losses for the above-the-MUF mode from VOACAP, and then apply these losses to real-time MUF data (for example, at http://af7ti.com/).

In summary, there appears to be a lot of RF flying around up above us that is below our normal noise level thanks to what we can generally call "scatter". Using JT65/JT9/FT8 allows us to "hear" some of that. Finally, to reiterate, there doesn't appear to be a new propagation mode for JT65/JT9/FT8. It's just a less-known propagation mode that hasn't received much attention.

Notes

1) J. L. Wheeler, *Transmission Loss of Ionospheric Propagation Above the Standard MUF*, **Radio Science**, Vol. 1, No. 11, November 1966

2) For analysis of above-the-MUF modes, see L. F. McNamara, T. W. Bullett, E. Mishin and Y. M. Yampolski, *Nighttime above-the MUF HF propagation on a midlatitude circuit*, **Radio Science**, Vol. 43, RS2004, doi:10.1029/2007RS003742, 2008

3) R. Silberstein, *Great-Circle and Deviated-Path Observations on CW Signals Using a Simple Technique*, **IEEE Transactions on Antennas and Propagation**, January 1965

4) Steve Ford, *Work the World with JT65 and JT9*, **ARRL**, First Edition Second Printing, 2015-2017

5) Although a 2.5 KHz bandwidth is used in the plot for an apples-to-apples comparison, most CW operators use a narrower bandwidth (around 500 Hz) – which would offer CW a 7 dB performance improvement over that in the plot