Unscrambling the Mysteries of HF State-wide Communications
Part One: Critical Frequency

by Gordon Gibby KX4Z

Amateur radio operators, particularly those in "net" or emergency communications, are often familiar with "Maximum Usable Frequency" but not with an even more important and more-easily measured datapoint, **Critical Frequency**. *Critical Frequency is the key to choosing bands that will most likely allow both nearby and farther cities within one state to communicate.* The D-Layer of the Ionosphere is the other key(covered in Part Two).

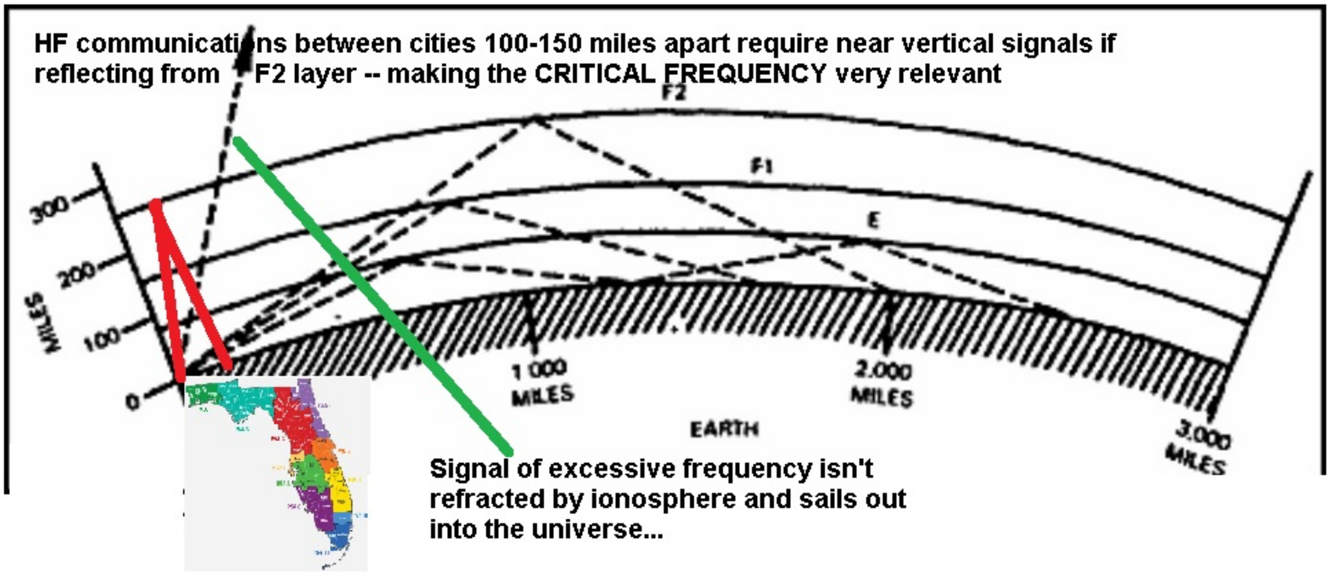
While measuring the maximum usable frequency that works between say, Miami and Pensacola can be difficult, it gives no information whether Gainesville can hear Jacksonville, or Panama City can hear Tallahassee. *But Critical Frequency is routinely measured every 15 minutes by multiple federal stations, including one at Eglin Air Force Base, and gives huge information useful to statewide or section-wide nets.*

Critical Frequency is measured by sending a continuous "chirp" moving from the bottom of the HF range (typically < 2 MHz) through 10-20 MHz, vertically up into the sky, and recording the straight-down return signal. This technology is >50 years old. The return signal is only detected when the ionosphere is able to refract the frequency by a full 180 degrees (reflect). The reflection/refraction is accomplished by **sufficient electron density to create an apparent conductive layer** (caused by UV / Xray ionization of oxygen molecules/atoms – hence the name "ionosphere"). Above a certain frequency, dependent on time of day/solar irradiation, the space between ions is too great to reflect the smaller size of the higher frequency radio wave....and no return signal is heard. That frequency is known as the Critical Frequency. Above that frequency, you are basically NOT going to be able to hold a skywave contact with a (nearby) ham on the other side of your city. And with Florida's poorly-conducting sandy soil, *ground waves just don't go very far…*

What's even better, knowing the critical frequency and the general physics of radio wave refraction, the ionosonde web page will also give you <u>good estimates of the MUF (maximum usable frequency) for various distances</u>! (Allowing your net to plan for an auxiliary frequency for relays if required due to D-layer issues.)

Attempting to conduct a section-wide or state-wide communications on a band that is ABOVE the critical frequency will result in considerable frustration as stations within a modest number of miles from each other just can't hear each other – and you'll end up having to continuously use farther stations as relays.

It becomes a simple geometry problem. Lets look at some of vast amount of research that has gone into solving this in the past decades:



The Figure, drawn from older ionospheric training materials, shows a scale drawing of the curvature of the Earth and the relative heights of E, F1 and F2 layers – and some geometries of dashed-black-line signals that were able to be refracted to reach stations at more than 1000 miles distance. However, Florida is less than 400 miles wide; I have added an image of the approximate size of Florida. In order to go from Pensacola to Panama City, or even Tallahassee, given the hundreds of miles upward to the F1 or F2 primary HF refracting layers, **the only workable geometry involves a signal going almost straight up.**

Such a vertical signal must then be refracted almost 180 degrees in order to make it to the desire station 100-200 miles away. Thus, if the chosen frequency is much above the Critical Frequency, this just isn't going to work. The signal will sail out into the universe (e.g.: the green line points to a signal that coudn't be refracted sufficiently). Some smaller fraction may be refracted enough to be heard in Texas or Maryland – but that won't do much good for the two stations in Florida trying to reach each other. We say, "the band has 'gone long'". *We simply need to move to a band that is at or below the Critical Frequency.* Traffic nets in upper midwest states have sometimes switched to 160 meters.

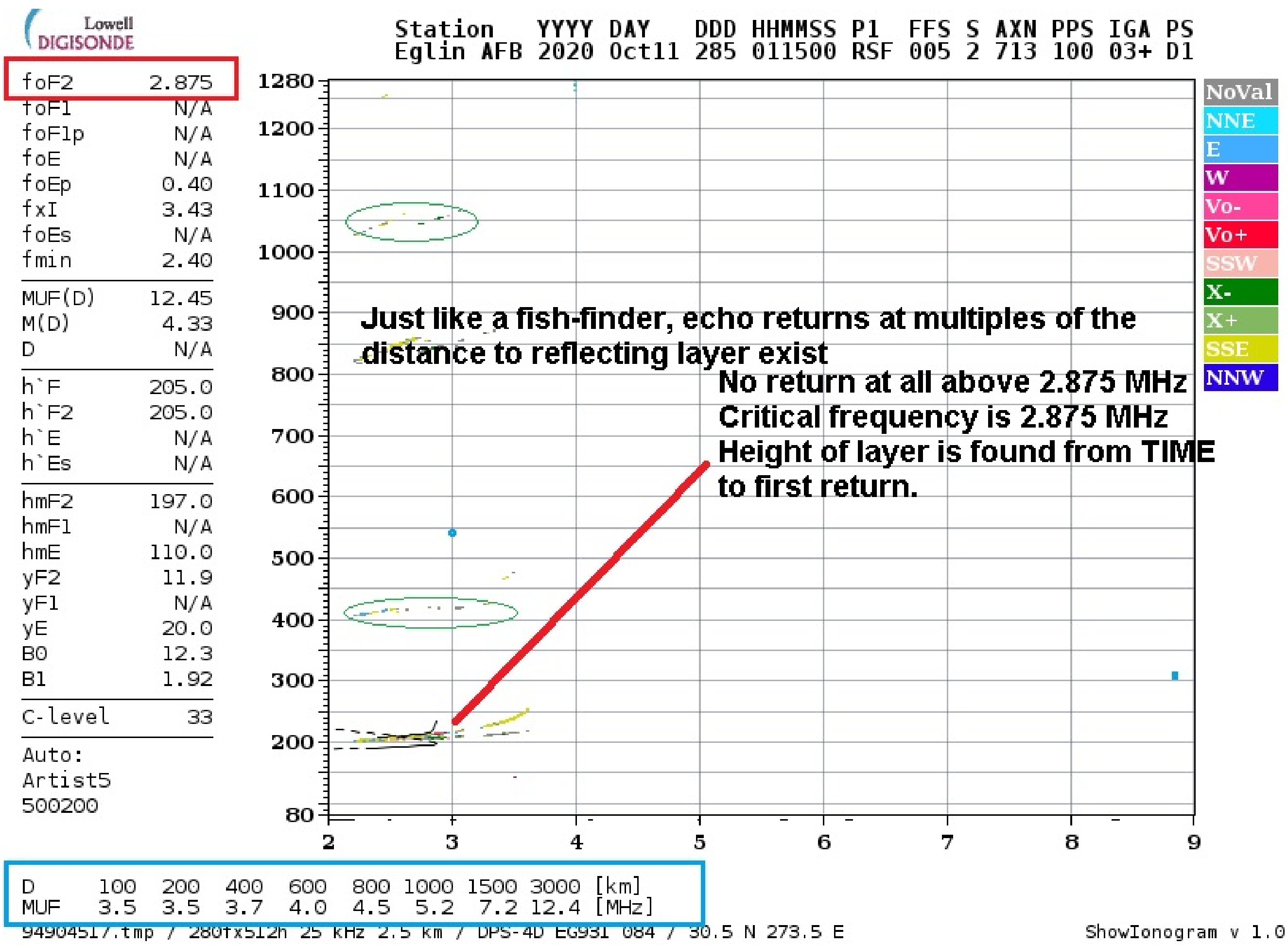
> Brief Interlude on NVIS Antennas[1]
> The geometry shown in the Figure above demonstrates that if you wish to make radio connections within your own state by high frequency sky-waves, you need near-vertical radio waves. That is NOT the forte of most Vertical antennas (which optimize low-angle radiation, much more useful for DX contacts). The traditional antenna whose interaction with the ground-reflection results in a stronger signal heading UP than horizontally, is some sort of HORIZONTAL antenna (center, off-center, or end-fed) that is a modest fraction a wavelength above "ground." In Florida's low-conductivity soil, it's not clear to me what is the optimal height, but I seem to do OK with antennas from 15-40 feet off the ground on 80/40 meters.

Typical Critical Frequencies
In the winter months near the bottom of the sunspot cycle, the critical frequency isn't very high At night it can easily drop below the 80 meter band! And even during the daytime, it may NEVER reach

1 My reviewers asked that I add in this section.

the 7 MHz 40 meter band. [For October, 2020, the Austin, Texas ionosonde demonstrated daytime critical frequencies generally 5-6 MHz and only rarely reaching 7 MHz.] That makes 80 and 60 meters very important (or access to the plentiful frequencies of the SHARES system). (But there is a fly in the ointment: D-layer absorption, which will be discussed in Part II).

You can easily examine the measurement of the critical frequency by referring to Eglin AFB measurements down the page at: https://region6armymars.org/resources/solarweather.php
Here is their measurement made at 10 PM EDT on Saturday, October 10, 2020:



Red Box: foF2 = critical frequency for the F2 ionospheric layer

Red line: The only returns were below 3 MHz. There were NO returns above about 3 MHz. The measured critical frequency for the F2 layer (determined height based of time of flight to hear the return) is 2.875 MHz (red box). That means that *Ocala is simply not going to hear the Villages* on 75 meter phone!

Blue Ellipses: Echoes from multiple reflections can occur. The signal can bounce back off the earth, into the sky and back down – there are multiple "echo" returns visible (ellipses). (Same thing fishermen see if they set the gain of their fish finder too high and see multiple echoes of the "bottom".)

Blue Box: The small table in the blue box shows the calculated (not measured) maximum usable frequencies for various distances. Note that the 40 meter band only works if your intended target at this dark hour is more than 1000 km away! Not very useful for a state-wide net! The MUF for 4.0 MHz is estimated at 600 kilometers: even holding a statewide net on 75 meters with relays is going to be DIFFICULT. One might turn to 160 meters or SHARES frequencies below 80 meters in such a situation. And even in the sunny afternoon, in the bottom of the solar cycle, the critical frequency may not make it to the 40 meter band.

CONCLUSION

The Critical Frequency is an easily measured parameter, widely available, and can help planners and net managers and net control stations much more effectively choose their techniques. Every 15 minutes on the bands, you may indeed hear that fast moving "chirp" as the Eglin ionosonde does its job!

REF:
http://solar-center.stanford.edu/SID/StudentWork/SophieMurray.pdf Incredibly educational paper from Stanford.

http://solar-center.stanford.edu/SID/StudentWork/SophieMurray.pdf
https://www.ukssdc.ac.uk/ionosondes/ionogram_interpretation.html Very simple explanation of reading an ionogram

https://www.ngdc.noaa.gov/stp/space-weather/online-publications/miscellaneous/afrl_publications/handbook_1985/Chptr10.pdf Very in-depth discussion of ionosonde development and ionospheric measurements.