The Mysteries of HF Radio & Statewide Nets, Part II:
The D-Layer & Workable Solutions

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In Part I of this discussion, the extreme importance of the Critical Frequency to state-wide communications was explained. The Critical Frequency can be thought of as the "Maximum Usable Frequency" to reach anyone in a nearby city. It tells you the maximum frequency that can be fully refracted 180 degrees by the ionosphere, satisfying the simple up/down geometry required to reach other stations that are only a few scores of miles from your station. Furthermore, it is the main HF parameter that is *measured* continually throughout day and night, every day of the year, by governmental monitoring stations all over the world, and *readily available to all* During the winter of low-sunspot years, at night the critical frequency can drop below 3 MHz (making 75-meter voice nets unable to hear many intra-state stations) and during the daytime it may not even make it to 7 MHz, making 40-meter nets difficult for those fleeing 75 meters.

If you know the current critical frequency, because the geometry of the globe and the ionospheres are well described, simple math can predict the maximum usable frequency for any desired distance. (The MUF is critical frequency divided by the secant of the incidence angle required by the geometry.[1])

"MUF Boost Factor"[2]									
Take-off angle	90	80	70	60	50	40	30	20	10
Multiplier of critical frequency	1.0	1.02	1.06	1.15	1.31	1.56	2.0	2.9	5.8

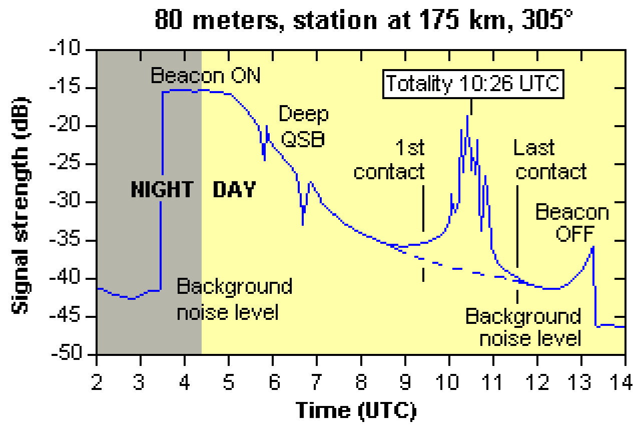
Moving To The D-Layer

In this paper, the second most important ionospheric effect, absorption of signal energy by the D-layer, will be explained.[3] The D-layer is a lower layer in the ionosphere. Ionization is created by incident solar radiation (that made it past the higher ionospheric reaches), principally **visible and UV light.** Thus the ionization starts up at daybreak, reaches a peak around local solar noontime, and then wanes into the late afternoon, and usually disappears shortly after sundown. The rapid disappearance is because the density of air molecules is still significant at the 50-80 km height of the D-layer, so recombination of ions and electrons occurs at a good pace, requiring continuous incident sunlight to maintain ionization.[4]

The D-layer is crucial because the fields of a radio wave traversing this layer cause energy-robbing movement of those ions. The effect is much, much worse with lower frequencies. Some say that the absorption is inversely proportion to the square of the frequency – a very strong frequency impact, badly damaging lower frequency signals.

Exactly how great is this absorption? Because the D-layer is so dependent on continuous sunlight, eclipses have provided valuable chances for measurement of D-layer absorption. Data show that the impact of the D-layer on 80 meter radio waves is in the range of **25 dB loss for a round trip of a nearby station's signal**. Anecdotal data on 160 meters suggests 35 dB. Loss at 40 meters is still significant but much less, and by 20 meters, there is insignificant effect. You can easily make simple measurements to confirm these figures by observing the signal of a ham friend 20 or so miles away, on 80 meters, at local solar noontime, as compared to an hour after sunset. The difference will be significant.

Real-time measurement of D-layer absorption changes during an eclipse have been measured as shown in the following figure:[5]



Explanation: The beacon in darkness was received with a signal strength of approx -15 dB. As the sun rises higher, the signal strength declines markedly. But as the moon begins to obscure the solar irradiation at about 0930 UTC, the beacon signal level begins to increase due to a decrease in D-layer absorption. At totality of eclipse, the signal has become roughly 25 dB stronger; then as the eclipse begins to wane, D-layer absorption begins to return and the signal again fades. ["Contact" in the graph refers to moon in front of sun.] Beginning at about 1230 UTC the beacon begins to become stronger likely due to the passage of local solar noontime. The beacon turned off at about 1330 UTC.

<u>Quantified D-Layer Absorption Points to State Net Solutions</u>

Let's consider how this very practically affects state-wide HF nets. If the twilight signal from a net participant was only 10 dB above the background noise (sufficient for voice communications), adding 25 dB of additional loss at local solar noon will move that station's signal now 15dB BELOW the noise level making noon-time voice communications completely impossible. Moving to higher frequencies reduces the D-layer absorption – but again there is a hard limit! Going higher than the **critical frequency** ends up with zero signal. Thus during the daytime, a statewide net is caught between D-layer absorption on lower frequencies and critical frequency limits on the higher frequencies. This can be a very tight trap to amateur radio stations with limited bands from which to choose, and helps explains the development of the Amateur Radio RELAY League.

However, the D-layer is a quantifiable ***non-total*** obstruction (different from critical frequency effects). The 80 meter loss is on the order of 25 dB. Adding more transmitter power will make the signal stronger. Amateur radio operators can often increase their transmitted signal strength on the order of 10 dB by simply adding an amplifier. **However the greatest asset is probably improved modulation and detection techniques.** *Low-signal techniques, modulations that have a lower signal level threshold for success, provide a significant tool to conquer D-layer absorption*.

Pieter-Tjerk de Boer, PA3FWM and other researchers and developers have provided valuable work in quantifying the signal-to-noise threshold of multiple types of signal modulations. [6]

Approximate SNR required for message passing by various modulation modes	
Mode	Typical Necessary SNR @ 2500 Hz receiver bandwidth **NOTE: These are not exact numbers.**
SSB voice	+10 dB
CW	-12 to -26 dB, various measurements
RTTY	- 5 dB
PSK31	-10 dB
Pactor 3	At least as good as -10 dB based on published Figure 9.[7]
Pactor 4	-18 dB @ 2400Hz[8] -20 dB (@ 4kHz)[9]
JS8 (using FT8 original modulation)	In the range of -18 to -20 dB (@2500Hz)[10]
JT65	-24 dB
Theoretical Limit	Somewhere around -57 dB

SSB Voice requires a signal that is significantly stronger than the background noise. By contrast there are now an abundance of digital modulations that would **allow successful net traffic transfer more than 25 dB (typical D-layer peak absorption) less signal than SSB voic**e.

The primary reason that so many advanced digital modulations can move traffic at fantastically lower signal-to-noise ratios (that is, when referenced to the voice 2500 Hz bandwidth) is because they simply don't need to deal with all that noise in the 2500 Hz bandwidth! They digitally filter out most of that bandwidth of noise, and filter down to just the narrow signal they are working to demodulate. (see https://tapr.org/pdf/DCC2018-KC5RUO-TheReal-FT8-JT65-JT9=SNR.pdf for further explanation) Thus, volunteer communicators who are determined to succeed at any time in the day or night moving traffic need to be facile at multiple techniques in order to accomplish their mission. and some of these advanced techniques offer far more advantage over SSB voice, than the 25 dB typical penalty of high-noon D-layer absorption. In other words: they are far more likely to succeed any time, day or night.

Thus, if you can hear a SSB signal from a crucial station during optimal times, and are willing to move to different techniques when their signal is degraded by as much as 25 dB due to D-layer absorption, you can easily continue to move traffic even at worst-case high noon D-layer absorption. Matthew Curtin, KD8TTE, reports that some Ohio Section HF traffic nets are now taking some advantage of these advanced techniques, QSY'ing to side frequencies within the CW/digital portion of the band to move traffic. These techniques may be the solution for conquering difficulties hindering 24-hour continuous HF traffic movement.

1 https://www.electronics-notes.com/articles/antennas-propagation/ionospheric/maximum-lowest-critical-optimum-usable-working-frequency.php
2 Redrawn from Table “MUF Boost factor” in http://www.astrosurf.com/luxorion/qsl-eclipse-d-layer.htm
3 D-layer absorption has been recognized and studied since at least 1957: https://www.sciencedirect.com/science/article/abs/pii/002191695790154X
4 https://www.arrl.org/files/file/Technology/pdf/119962.pdf
5 http://www.astrosurf.com/luxorion/qsl-eclipse-d-layer.htm
6 http://www.pa3fwm.nl/technotes/tn09b.html
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