DC to Daylight—*Part 1*

You may have heard the term “DC to Daylight” used to describe wideband operating, or to emphasize microwave operation. Of course, we are not meant to take idioms literally, but what about those frequencies in the upper regions? We call all frequencies from 30 GHz to 300 GHz the *EHF band*, for Extremely High Frequency. These are also called millimeter waves because their wavelength is between 1 cm and 1 mm. Successful operation on these frequencies represents one of the exciting frontiers in ham radio. Only a handful of hams have completed contacts in the most difficult bands, but many more are building equipment and making contacts at 47 GHz and 80 GHz each year.

Atmosphere

The atmosphere consists of various gases, two of which are significant absorbers of EHF signals—water vapor and oxygen. Figure 1 is a graph of the absorption curves over the microwave spectrum up to 260 GHz. The vertical axis shows a scale in decibels per kilometer. You must add this figure to the normal R^2 (distance) losses that occur because signals spread out as they travel. These absorption losses can become a very dominant part of the system losses when you are trying to establish a communication link.

For example, consider a situation where your communication link has 50 dB of signal-to-noise ratio (S/N) at a distance of 1 km. In our example, we are operating at 145 GHz where there is a 1 dB/km atmospheric attenuation. Doubling the distance to 2 km adds 6 dB in R^2 losses and 1 dB in atmospheric loss, yielding 7 more decibels of system loss, or dropping to 43 dB of S/N. But, increasing from 1 km to 100 km there are an additional 40 dB of R^2 loss and 99 dB of atmospheric loss, yielding a link S/N of –89 dB (no chance of signal reception). Without the atmospheric losses—for instance, if we were operating at 10 GHz where the total atmospheric loss might be 2 dB—the link would be a strong 8 dB of S/N at 100 km, which is enough for easy CW or even an SSB conversation.

Note that the right hand side of this chart represents frequencies that are less than 1/1000 the frequency of light! The “sub-millimeter wave” region between 300 GHz and infrared is largely unexplored—so there is a huge gap between the highest frequencies that hams (or anyone) use in the normal RF sense and infrared laser communications at about 450 THz (one terahertz is 1000 GHz).

Water Vapor

The electrically polarized nature of the H_2O molecule in its gaseous form causes an overall trend of increasing absorption with frequency. For all practical purposes, the atmosphere becomes opaque in the sub-millimeter wavelengths, and becomes very transparent again in the infrared and visible wavelengths. Figure 1 shows the major absorbers in the EHF area. The absorption peaks at 22.2 and 183.31 GHz correspond to specific mechanical resonances of the H_2O molecule as its electric field interacts with RF energy. Between the peaks, a low-loss, or transmission, “window” appears.

In practical terms, water vapor is the only major contribution to absorption on the 245 GHz band, and significant DX could be achieved when the air is extremely dry. During normal summer conditions, however, attenuation exceeding 10 dB per km could be a difficult obstacle for even a “minimum” contact over a few kilometers.

Figure 1 shows the Amateur Radio bands overlaid upon the atmospheric absorption chart. In this chart we see the effect of lowering the amount of atmospheric water to extremely low levels. The solid curve would be typical for a cool, dry spring or autumn day in New England (40% relative humidity, 65ºF). Clearly, the best DX is possible only during very dry weather—the drier the better. In temperate climates, the very lowest atmospheric water content is achieved in the winter. The dashed line represents *extremely* dry winter conditions—such as might occur at 15% relative humidity around 10ºF. Typical dry days in the winter will fall about halfway between the two lines. This chart is drawn from standard literature [Crane 1981, ARRL 1990, Ulaby 1981], and it is quite adequate for determining attenuation on the EHF bands—except for the 120 GHz band.

Oxygen

The oxygen molecule O_2 has no electrical dipole moment of consequence, but does have a magnetic moment. As the molecule changes between various quantum states, these magnetic moments change, giving rise to specific energy absorption. There are many such “hyperfine” moments that result in a family of over 30 absorption frequencies around 60 GHz (53 to 65 GHz) and a single absorption line at 118.750343 GHz. At high altitudes (low pressure and temperature) the molecular interactions are minimal, and the individual hyperfine frequencies can be resolved, but at altitudes where amateurs operate, normal atmospheric pressure induces smearing of these frequencies, resulting in a very broad peak centered at 60 GHz. The 118 GHz line, however, is a single, distinct line.

Dropping in frequency from the 200 GHz window, the next available window is between the 118 GHz oxygen line and the 183 GHz water vapor line (see Figure 1). The 145 GHz amateur band is situated in this window. We should con-

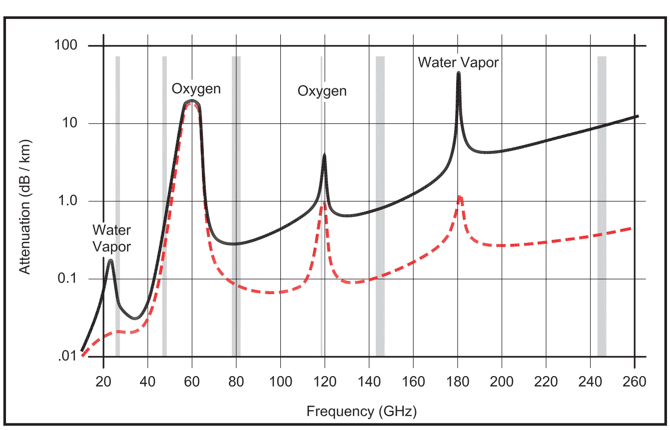

Figure 1—Atmospheric absorption at EHF. The solid line assumes water vapor of 7.5 grams per cubic meter, while the dashed line presents 0.25 grams. The EHF radio amateur bands (and 24 GHz) are shown in gray.

Tom Williams, WA1MBA ◆ wa1mba@arrl.org

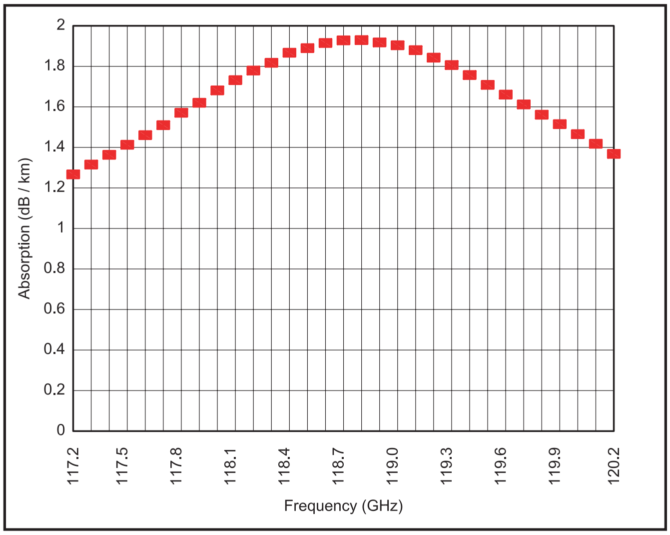

Figure 2—This figure details the 118 GHz oxygen line for reasonably dry conditions of 7.5 grams per cubic meter of water vapor. The 120 GHz band is at the far right part of this chart (119.980 to 120.020 GHz).

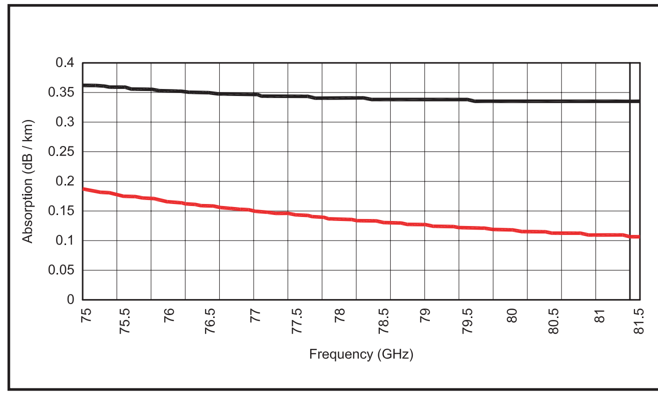

Figure 3—The absorption chart for the 80 GHz amateur band region of the EHF spectrum. The top line represents dry conditions (7.5 g/m^3), while the bottom represents extremely dry (0.25 g/m^3) conditions.

sider ourselves lucky to have a wide amateur band in this region. Attenuation is still dominated by water vapor, so that in extremely dry conditions this band is only slightly better for propagation than 245 GHz, but in more typical conditions it can be significantly better than 245.

Looking at Figure 1, it is easy to believe that 120 GHz would be the most difficult upper EHF amateur band. While the upper two bands are relatively free of absorption from oxygen, in order to achieve DX on the 120 GHz band, one has to contend with the 118 GHz oxygen line nearby as well as water vapor absorption. Not much is published about this oxygen line, primarily because the 60 GHz lines are so interesting, and also because much of the original work on oxygen absorption was performed when it was difficult to measure frequencies this high [Van Vleck 1947]. Figure 2 is a plot of the shape of this line at standard pressure and temperature as derived from equations in a computer program [Liebe 86]. Note that in the band of interest, the total path loss is only 1.5 dB per km for average conditions and falls to under 1.2 dB in dry conditions—only slightly worse than 145 GHz.

Because of recent interest in the 80 GHz band, we should take a closer look at attenuation there. As can be seen in Figure 3, the difference between dry and extremely dry conditions can, at say 100 km (the range of the world record), make a difference of over 20 dB (35 dB for dry and 15 dB for extremely dry). Twenty decibels is a huge difference in signal levels.

Propagation

Situations where microwave DX is generally enhanced may also be useful to EHF. Extending line-of-sight by increasing altitude is common enough. Remember that the two enemies are water vapor and oxygen. Because great DX will always be hampered by water vapor, some European amateurs have taken advantage of the drier air when working from high mountains. Also, at higher altitudes, the atmosphere is less dense, and so there is less oxygen, too, enough to make a difference.

Rain scatter is a distinct possibility at EHF, where there is a significant forward scattering component. So far, I have not heard of any successful experiments with rain scatter in these bands.

Tropospheric inversions offer an interesting set of advantages to EHF propagation, in that they not only significantly improve DX by offering ducting, but usually also have extremely low dew points—lower than the 2.5 g/m^3 lines on these charts. In an inversion, a drier and less dense air mass becomes trapped in heavier air, forming a long fold. This presents a sharp difference in refractive index and, much like a dielectric waveguide, can become a transmission medium for microwaves. Such inversions may be hundreds of miles long. So far, there have not been enough EHF contacts to explore the types of propagation that might be available.

In Part 2 of DC to Daylight, Microwavelengths will describe devices and circuits for these frequencies and give some examples of successful ham radio communications in the rarified portions of our hobby.

The EHF Amateur Bands

The EHF Amateur Radio bands are 47.0 to 47.2, 75.5 to 81.0,* 119.98 to 120.02, 142 to 149 GHz, and 241 to 250 GHz. All frequencies above 300 GHz constitute another single amateur band that includes laser communications.

*The US allocation for the 80 GHz band was changed in 1998 to allow for automotive collision avoidance radar in the 76 to 77 GHz region. Amateurs now have primary status at 75.5 to 76 GHz, but 76 to 77 GHz is suspended; therefore there is no amateur operation 76 to 77 GHz. 77 to 77.5 GHz is secondary, 77.5 to 78 GHz primary for amateur (this represents an upgrade), and 78 to 81 GHz secondary. See FCC report FCC98150 (**www.fcc.gov/Bureaus/Engineering_Technology/Orders/1998/fcc98150.txt**).

References

The ARRL UHF/Microwave Experimenter's Manual, "Antennas, Components and Design" (Newington: ARRL, 1990). Available from your local dealer or the ARRL Bookstore, tel (toll-free in the US) 888-277-5289 or elsewhere 860-594-0355, or **www.arrl.org/shop/**. ARRL order no. 3126, $20 plus shipping.

Crane, R. J. (1981), "Fundamental Limitations caused by RF Propagation," *Proceedings of the IEEE*, 59, pp 196-209.

Liebe, H. J., (1983) "Atmospheric EHF Window Transparencies near 35, 90, 140, and 220 GHz," *IEEE Transactions on Antennas and Propagation*, AP-31, pp 127-135.

Liebe, H. J., (1986) "TBLNGEN" (A Fortran Program), Institute for Telecommunication Sciences, NTIA/ITS.S3, Boulder, Colorado, Jun 1986.

Ulaby, Fawwaz T., Richard K. Moore, and Adrian K. Fung, Microwave Remote Sensing Active and Passive, Volume 1, chapters 4, 5 and 6. (Norwood, MA: Artech House, 1981).

Van Vleck, J. H. (1947), "The Absorption of Microwaves by Oxygen," *Physical Review*, 71, pp 413-424.