MUF, LUF, and FOT - The Basics of the Maximum Usable Frequency

There are two definitions for the abbreviation, "MUF." The International Telecommunications Union ITU-R (Recommendation P.373-7 10/1995, in force) recommends two definitions for MUF:

1. Operational MUF (or just MUF) is the highest frequency that would permit acceptable operation of a radio service between given terminals at a given time under specific working conditions (antennas, power, emission type, required S/N ratio, and so forth), and,

2. Basic MUF, being the highest frequency by which a radio wave can propagate between given terminals by ionospheric propagation alone, independent of power.

The difference in frequency between operational MUF and basic MUF is in practice from ten to thirty-five percent. In most prediction software and in amateur radio and shortwave listening references the MUF refers to the first definition. On each day of the month at a given hour, there is a maximum observed frequency (MOF) for a mode. The median of this distribution is called the MUF. In other words, the MUF is the frequency for which ionospheric support is predicted on 50% of the days of the month, i.e. 15 days out of 30 days. So on a given day communications may or may not succeed on the frequency marked as the MUF.

To ensure a good communication link between two locations, the operating frequency is typically chosen below the predicted MUF. A commonly used formula for finding the optimal operating frequency for a given path is to calculate between 80 to 90% of the MUF. Depending on what model you use for determining MUF and OWF, this percentage of usable days may be 50% or 90%. VOACAP uses 50%, for example. Synonyms for the optimal operating frequency are FOT (frequency of optimum traffic), OTF (optimum traffic frequency or optimum transmission frequency), and OWF (optimum working frequency).

So, as an example, if you find that the MUF is 23 MHz on a day with a Smoothed Sunspot Number of 130, over a path between you and some far off point, you would find the OWF as between 18.4 MHz and 20.7 MHz. You might be able to work 15 meters to that distant point. Most likely, you would find better conditions on 17 meters.

There are more factors involved in finding the "right" frequency to use between two points. These include absorption by lower regions (like the D layer), the "take off angle" of the radio signal from the originating antenna, and so forth.

The ionosphere is made up of several regions. The ionosphere is that part of the atmosphere, extending from about 70 to 500 kilometers, in which ions and free electrons exist in sufficient quantities to reflect and/or refract electromagnetic waves. These regions are the F2 region (250 to 400 km above the Earth), the F1 region (160 to 250 km), the E region (95 to 130 km), and the D region (50 to 95 km), under which is the Troposphere and so forth.

When a radio signal (an electromagnetic wave) propagates into the ionosphere, it might be absorbed, attenuated, refracted, or it might shoot right through and out into space. If a signal makes it through the lower regions, a redirection will occur for those signals whose frequencies are at or below a "critical" frequency (that being the frequency just below those that punch through the F regions and out into space). The redirection is a bending by a complex processing involving reflection and refraction. Depending on the angle of the radio wave (or, "angle of incidence") as it enters the region where it is redirected, the signal will be "reflected" back to the Earth at some variably distant point. Think of a flashlight beam that you shine at a mirror. When you shine on the mirror straight on, you have the beam of light coming almost straight back at you, but if you angle the light beam, the reflected light will move further away from you. The amount of radio wave bending depends on the extent of penetration (which is a function of frequency), the angle of incidence, polarization of the wave, and ionospheric conditions, such as the ionization density.

The Lowest Usable Frequency (LUF) is that frequency in the HF band at which the received field intensity is sufficient to provide the required signal-to-noise ratio for a specified time period, e.g., 0100 to 0200 UTC, on 90% of the undisturbed days of the month. The amount of energy absorbed by the lower regions (D region, primarily) directly impacts the LUF. If a signal at 5 MHz is totally absorbed by the D region, but a signal at 6 MHz makes it through without a lot of loss, and the E or F layer refracts the 6 MHz signal, the LUF will be near that 6 MHz part of the spectrum. The MUF might be 12 MHz. The OWF (optimum working frequency) will be somewhere between 6 and 12 MHz, probably around 10 MHz.

Frequency of Optimum Transmission (FOT): In the transmission of radio waves via ionospheric reflection, the FOT is the highest effective frequency (or best working frequency) for a given path that is predicted to be usable for a specified time for a percentage of the days of the month.

(for more information, here are a few references to check out:

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Critical Frequency, LUF, and MUF

When looking at ionospheric propagation, there are several frequencies that are important, and are often mentioned. These include the Critical Frequency, the Lowest Useable Frequency (LUF), and the Maximum Usable Frequency (MUF). Their definitions are at the centre of determining which frequencies will provide the optimum performance.

Critical Frequency
This is an important figure that gives an indication of the state of the ionosphere. It is obtained by sending a signal pulse directly upwards. This is reflected back and can be received by a receiver on the same site as the transmitter. The pulse may be reflected back to earth, and the time measured to give an indication of the height of the layer. As the frequency is increased a point is reached where the signal will pass right through the layer, and on to the next one, or into outer space. The frequency at which this occurs is called the critical frequency.

The equipment used to measure the critical frequency is called an ionosonde. In many respects it resembles a small radar set, but for the HF bands. Using these sets a plot of the reflections against frequency can be generated. This will give an indication of the state of the ionosphere for that area of the world

LUF
As the frequency of a transmission is reduced further reflections from the ionosphere may be needed, and the losses from the D layer increase. These two effects mean that there is a frequency below which communication between two stations will be lost. In fact the Lowest Usable Frequency (LUF) is defined as the frequency at below which the signal falls below the minimum strength required for satisfactory reception.

From this it can be seen that the LUF is dependent upon the stations at either end of the path.

Their antennas, receivers, transmitter powers, the level of noise in the vicinity, and so forth all affect the LUF. The type of modulation used also has an affect, because some types of modulation can be copied at lower strengths than others. In other words the LUF is the practical limit below which communication cannot be maintained between two particular stations.

If it is necessary to use a frequency below the LUF then as a rough guide a gain of 10dB must be made to decrease the LUF by 2 MHz. This can be achieved by methods including increasing the transmitter powers, improving the antennas, etc..

MUF

When a signal is transmitted over a given path there is a maximum frequency that can be used. This results from the fact that as the signal frequency increases it will pass through more layers and eventually travelling into outer space. As it passes through one layer it may be that communication is lost because the signal then propagates over a greater distance than is required. Also when the signal passes through all the layers communication will be lost.

The frequency at which communication just starts to fail is known as the Maximum Usable Frequency (MUF). It is generally three to five times the critical frequency, dependent upon the layer being used and the angle of incidence.

Optimum frequencies

To be able to send signals to a given location there are likely to be several different paths that can be used. Sometimes it may be possible to use the either the E or the F layers, and sometimes a signal may be reflected first off one and then the other. In fact the picture is rarely as well defined as it may appear from the textbooks. However it is still possible to choose a frequency from a variety of options to help making contact with a given area.

In general the higher the frequency, the better. This is because the attenuation caused by the D layer is less. Although signals may be able to travel through the D layer they may still suffer significant levels of attenuation. As the attenuation reduces by a facto of four for doubling the frequency in use this shows how significant this can be.

Also by increasing the frequency it is likely that a higher layer in the ionosphere will be used. This may result in fewer reflections being required. As losses are incurred at each reflection and each time the signal passes through the D layer, using a higher frequency obviously helps.

When using the higher frequencies it is necessary to ensure that communications are still reliable. In view of the ever-changing state of the ionosphere a general rule of thumb is to use a frequency that is about 20% below the MUF. This should ensure that the signal remains below the MUF despite the short-term changes. However it should be remembered that the MUF will change significantly according to the time of day, and there fore it will be necessary alter the frequency periodically to take account of this.


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