REPORT ITU-R P.2011

PROPAGATION AT FREQUENCIES ABOVE THE BASIC MUF

(1997)

1 Introduction

Recommendation ITU-R P.373 defines the basic MUF as "the highest frequency by which a radio wave can propagate between given terminals, on a specified occasion, by ionospheric refraction alone". The Recommendation also recognizes that this does not necessarily define the maximum transmission frequency for those circumstances, since a definition is also given for the operational MUF.

The various mechanisms which may contribute to propagation above the basic MUF are described in § 2. However the situation is complicated for two main reasons:

– the definition implies that the basic MUF is determined by extraordinary mode propagation, taking no account of any differences in signal amplitude from that of the ordinary mode;

– for ITU purposes it is necessary to predict signal intensities; such predictions have their basis in monthly median maps of ionospheric characteristics and the instantaneous values of basic MUF will not be known. Moreover the day-to-day variability in ionospheric characteristics may result in the frequency being used for communication being above the basic MUF on some days and below on others.

It may be noted that instantaneous basic MUFs may only be determined from the examination of oblique incidence ionograms measured over the propagation path. An approximation to this may be obtained by using well placed vertical incidence soundings and assuming ionospheric homogeneity along the path. It may be noted that real-time channel evaluation systems will not generally give a clear indication of the basic MUF.

2 Propagation mechanisms responsible for propagation at frequencies above the basic MUF

Propagation mechanisms and ionospheric characteristics which may give rise to propagation at frequencies above the basic MUF are as follows:

2.1 Ionospheric roughness

Ionospheric roughness or irregularities, as may be indicated on vertical incidence ionograms as spread-F, with spreading in either range or frequency, may permit propagation by refraction or scatter at frequencies above the basic MUF for the bulk of that region of the ionosphere. This mechanism may be seen on some oblique incidence ionograms where the maximum observed frequency is determined by a "nose extension" beyond the junction frequency. Ionospheric irregularities may be expected to have electron densities as a proportion of the bulk ionosphere, thus this effect is expected to be multiply-related to the basic MUF.

2.2 Ground back- and side-scatter

Off great circle, two-hop paths, out to a scattering region on the Earth's surface and returning to the receiving location, may permit propagation at frequencies up to the 4 000 km basic MUF. The ground scatter coefficient depends upon azimuth, the presence of land or sea, the ground roughness, and also upon focusing due to ionospheric curvature for grazing radiation angles. The back scatter intensity at frequencies above the basic MUF for the wanted path will depend on the ratio of the path length to 4 000 km, and will vary as a multiple of the basic MUF.

2.3 Higher order mode back-scatter

As an extension of the two hop ground back-scatter case, there may be back-scatter from longer ranges, involving multiple hop propagation, in cases where there are significant ionospheric horizontal gradients in electron density.

2.4 Ducted modes

In some instances low angle radiation may be able to enter into ducts formed by particular electron density height profiles. In such cases propagation may be possible to long ranges and at higher frequencies than the basic MUF. This mechanism, combined for instance with off great circle ground backscatter, may contribute to above the basic MUF propagation.

2.5 Chordal hop propagation

Tilts in the ionosphere, most notably on either side of the magnetic equator, but also in the sub auroral troughs, may permit ray paths which proceed from refraction in one location to another without an intermediate ground reflection. Trans-equatorial propagation of this kind has been observed to extend to frequencies well into the VHF range, perhaps when associated with ionospheric irregularities. This mode, when combined with ground back-scatter may give significant propagation above the basic MUF.

2.6 Direct ionospheric scatter

Signal energy may be scattered from any of the ionospheric regions, both along the great circle path and at other orientations. In high, auroral and equatorial latitudes strong ionisation density gradients may permit significant F-region scatter, but where there are no strong gradients scatter from the E-region is likely to be more important, and in this case would be limited to ranges of about 2 000 km. The ionospheric scatter mode is discussed in detail in ex-CCIR Report 260-2 (1974) (now formally deleted). This Report indicates that, at least for frequencies above 30 MHz, the signal intensity varies as the inverse 7.5 power of the frequency.

2.7 Sporadic E propagation

The occurrence of sporadic E may permit propagation, either by partial reflection or scatter, to significantly high frequencies. This mode may not be recognized and is in any case not included in most prediction procedures. Thus it may be considered as a further contributor to propagation above the expected basic MUF, on path lengths up to 2 000 km.

2.8 Auroral scatter

Field aligned irregularities in the auroral region, associated with geomagnetic disturbances, are a special case of sporadic E. Reflections from such irregularities have to obey particular conditions of specularity, but in these conditions propagation is possible well into the VHF range. Although multihop propagation has been observed, the effect will generally be limited to path lengths less than 2 000 km.

2.9 Meteor scatter

Propagation utilizing reflection or scatter from transient meteor ionization is dealt with in Recommendation ITU-R P.843. With the appropriate geometrical circumstances, short duration propagation events may occur well into the VHF range for path lengths less than 2 000 km.

3 Measurement data already collected

Much of the limited measurement data which exist comprise examples of variations of signal intensity with frequency, or with time as the basic MUF changes, over specific paths. These measurements are described by Hagn *et al*. [1993]. The data are insufficient for the establishment of comprehensive models which would include the dependence on path length, location, time, etc.

4 Statistical models of signal intensity at frequencies above the basic MUF

The ITU-R data banks include observations of signal intensity at frequencies above the basic MUF, although the values for the basic MUF corresponding to each measurement are unknown and could not have been determined without special additional measurements. The results are dealt with on a statistical basis.

It may be noted that the day to day variation within a month of the basic MUF will have an interdecile range of 30 to 40% of the median basic MUF. Frequencies used for communication within this range will on some days be below the basic MUF and on other days above. Thus the modelling of these circumstances will seek to combine the signal intensity for a refracted path at a frequency just below the basic MUF with the contributions to above the basic MUF propagation described above, and then to include the statistics of day to day variability.

This approach will give a probability estimate that signal intensity will occur, and this may be appropriate for the assessment of compatibility. However the approach may be inadequate for the prediction of circuit performance where the channel transfer function in terms of fading rate, the time delay spread, and the frequency spread and shift may be different for frequencies below and above the basic MUF.

5 The definition of ABM loss

The reduction in signal intensity at frequencies above the monthly median path basic MUF, as compared with the intensity for a refracted path at a frequency just below the basic MUF, is referred to as the ABM loss.

6 Existing loss formulae

The various formulae which have been proposed for ABM loss are described by Hagn *et al.* [1993].

6.1 The Phillips-Abel model

This model, based on measurements made in the United States of America, is the only model which is intended to relate to instantaneous values of the basic MUF. The model assumes that the ionosphere comprises a number of patches which would each yield a different basic MUF for the path. These MUFs are assumed to be normally distributed and the standard deviation of the spatial MUF variation, σ, is the parameter used in the model.

Phillips indicated that σ , ranged between 1 and 4 MHz dependent on ionospheric disturbance, for a path length of about 3 000 km. Subsequent measurements by Wheeler and Hagn indicated values for σ of between 0.9 and 3 MHz.

In this model above the MUF loss L_m (dB) is given as:

$$L_m = 10 \log p$$

where:

$$p = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x/a} \exp(-x/2\sigma) \, d(x/a) \qquad \text{and } x = f - f_b$$

Note that this model uses the difference between the working frequency, f, and the basic MUF, f_b.

6.2 The Recommendation ITU-R P.533 model

For ranges up to 7 000 km, Recommendation ITU-R P.533 predicts the value of L_m for each of the propagation modes considered, prior to performing a power summation to obtain the overall field strength.

The criteria for the consideration of each potential mode are indicated in the aforesaid Recommendation, and for these modes L_m is given by:

$$L_m = 0 \text{ dB}$$

when $f \leq f_b$ for the mode being considered.

For E-modes (up to a maximum range of 4 000 km), when $f > f_b$

$$L_m = 130 \left[\frac{f}{f_b} - 1 \right]^2 \quad \text{dB, or 81 dB whichever is the smaller.}$$

For F2-modes (up to a range of 7 000 km), when $f > f_b$

$$L_m = 36 \left[\frac{f}{f_b} - 1 \right]^{1/2} \quad \text{dB, or 62 dB whichever is the smaller.}$$

The model does not specifically include ABM loss for ranges greater than 9 000 km.

Note that this model uses the ratio of the working frequency, f, to the basic MUF, f_b.

7 Factors to be considered in further development of ABM loss formulations

7.1 The magneto-ionic mode to be assumed for the determination of the basic MUF

Recommendation ITU-R P.533 utilizes the predicted monthly median o-wave mode for E region basic MUF and the monthly median x-wave mode for the F2 region. This may represent the best frequency reference for ABM loss formulations, but this conclusion should be confirmed.

7.2 Amplitude reference

ABM loss is assumed to be 0 dB at frequencies below the monthly median basic MUF for the mode. Thus, following Recommendation ITU-R P.533, it seems appropriate to predict ABM loss with respect to the field strength or signal intensity predicted for the monthly median basic MUF, ignoring deviative absorption. This reference seems appropriate for formulations based on the presently used concepts, but other references may be appropriate if models are formulated in different ways.

7.3 Frequency scaling factor

As noted above, the Recommended procedure uses the ratio of the basic MUF to the working frequency, whereas the Phillips-Abel method uses the frequency difference. The various mechanisms described in § 2, are likely to depend on the ratio of the frequencies, or to vary with absolute frequency, regardless of the basic MUF for the path. Thus at HF it seems appropriate to base a formulation on the ratio of frequencies. If methods are prepared for compatibility assessments at VHF, then it may be more appropriate to use a formulation which does not include the basic MUF for the path.

7.4 Path length dependence

Present methods do not include a dependence upon path length. However it seems likely that different mechanisms will predominate for path lengths less than 2 000 km, where E region modes are important, as compared with those for longer path lengths, where the ratio of path MUF to 4 000 km MUF may be important.

7.5 Allowance for transmitting and receiving antenna gain

Many of the mechanisms described in § 2 become more important for low elevation angles. Thus propagation above the basic MUF may be less important when high elevation angle antennas are employed. This effect could be included in a general way by modifying the distance dependence for ABM loss for short path lengths, with the assumption that appropriate antennas will be employed for the wanted path.

Apart from the mechanism due to ionospheric roughness, for which the frequency ratio may be rather limited, and the mechanism due to direct ionospheric scatter, most of the mechanisms are likely to involve off great circle propagation. Further studies are needed to determine whether the antenna gain along the great circle, the maximum antenna gain, or some function of the antenna gain, should be used.

8 Quality of ABM signals for reliability and compatibility considerations

Some of the mechanisms described in § 2 do not require significant ionospheric roughness or irregularities, but depend upon normal propagation in some direction in conjunction with ground back scatter. In these cases it is likely that the channel transfer function will be rather similar to that for propagation at frequencies below the basic MUF.

On the other hand some mechanisms may be very significant in some cases, for example at equatorial and high latitudes, and in magnetically disturbed conditions. In these cases the transfer function may contain rapidly varying and large time and frequency spreads. In these cases it may be expected that the quality of speech and particularly of music would suffer, particularly for double side-band modulation with envelope detection. The performance of digital modulation systems will depend upon the modulation design and the signalling rate.

Thus, dependent on the sensitivity of the modulation method to these effects, it may be appropriate to base the determination of the maximum frequency for planning a wanted service upon the basic MUF, while interference assessment for compatibility purposes may be based upon a higher frequency which will include ABM propagation.

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