VHF and UHF PATHLOSS CALCULATIONS for AMATEURS.

by:

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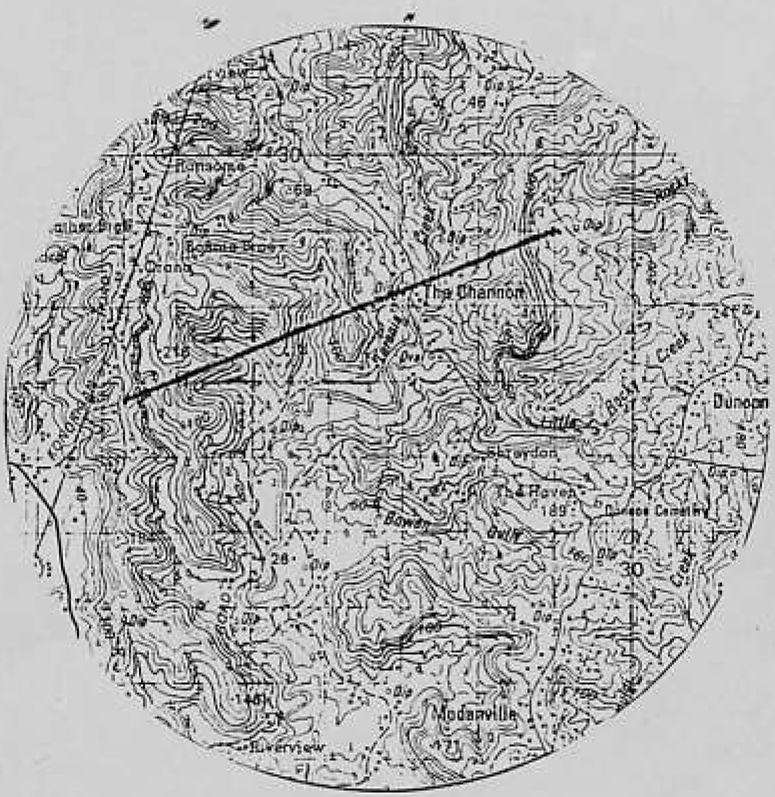

VHF and UHF PATHLOSS CALCULATIONS for AMATEURS.

Ever wonder why you can talk on 2M (145 Mhz) to the chap over the horizon but can barely hear the station on the other side of the first hill?

The following tries to explain why and show you how to assess the likely performance of VHF and UHF paths under "average conditions", using only a contoured map and a pocket calculator.

If you are into computers you should be able to translate it into simple programs and save the "brain strain".

This article has been published in a much abbreviated "serial" form in the Summerland Amateur Radio Club Newsletter over the last year and it is requested that normal credit be given if reproduced.

All the material has been extracted from numerous published works who's authors are unknown to me but to whom I give full credit. I only claim credit for assembling and simplifying it.

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VHF & UHF PROFILES AND LOSSES

Reflection, Refraction and Diffraction.

It is assumed that the reader has an understanding of the Reflection, Refraction and Diffraction of light and radio waves; and also the attenuation of radio waves close to the earth's surface. Losses as a consequence of these effects are significant when an obstacle interferes with the direct path of a radio wave.

Put simply, when a radio wave encounters a conducting object in it's path, the object will absorb and then re-radiate energy in all directions from the point. In the case of an object adjacent to the line of sight path, the re-radiated wave will recombine with the direct wave at the receiving antenna, either enhancing or cancelling the direct wave depending on phase.

When the obstacle (such as a mountain ridge) is above the line of sight, the only signal to reach the receiving antenna is that part re-radiated forward and down from the top of the obstacle.

If the top of the obstacle is a sharp "Knife Edge", forward diffraction will be at a maximum, but "broad topped" obstacles , (especially ones with rough surfaces) are less efficient. The worst cases are signal attenuation over the earth's surface (at the horizon), especially if it is rough rather than smooth. Therefore a high, sharp -topped mountain range appearing above the horizon will propagate a stronger signal to a station beyond the horizon than one that has "scraped around" the earth's surface at the horizon.

The following work deals with paths having ONE obstacle only. If there are two or more obstructions, the path can be divided into several sections treated separately and the resultant losses added together.

PATH PROFILE

Before the losses along any path can be calculated, it is necessary to draw a "Path Profile" or section showing the line of sight between the antennas at each end and the position of any obstacles which will cause losses. This is done from a contoured topographical map of convenient scale. If the map scale is large or the path length small, both stations may be located on the same sheet. More likely the stations will be on different map sheets, with perhaps two more sheets in between! How then do you draw an accurate bearing line across several sheets?

BEARING AND DISTANCE FROM GRIDDED MAPS.

Great Circle bearings and distances are best calculated by spherical trigonometry using Lats. and Longs. However for distances of a hundred Km. or so, it is accurate enough and much simpler to use grid references on standard Topographical maps and plane trigonometry,

All Australian metric series maps have a Grid Origin to the SW of the Continent, (and a number of False Origins to keep the projection straight and the numbers small!) and the numerical value of the Grid numbers increases to the North and East of this point. These values are denoted on the edges of the sheet by Bold grid numbers and occasional small subscript numbers. This allows calculations across several map sheets. WARNING: Familiarize yourself with your maps—they may be different to mine!

Each Grid Square (GS) has sides 1 Km long and the vertical and horizontal grid lines are related to Grid North (GN). These Grid Squares are further subdivided (mentally) by 10, so that a Grid Reference can be given to within 100 metres, which is the accuracy of the map.

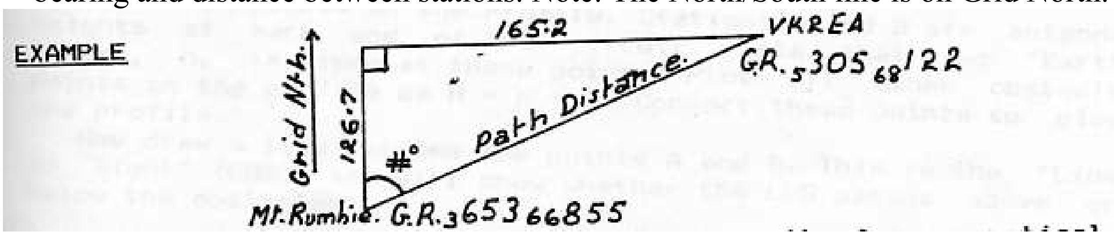
<u>EXAMPLE:</u> Find the bearing and distance from the Glen Innes repeater, VK2RNE on Mount Rumbie and the QTH of VK2EA in Goonellabah.

Mt. Rumbie (Glen Innes 1:100,000 sheet) GR = 3^653 66^855
Goonellabah (Lismore 1:100,000 ") GR = 5^305 68^122

Subtract the lesser from the greater Grid ref. (in terms of Kilometres) remember that the last figure is one tenth of a Km.

=	530.5	6812.2
	- 365.3	- 6685.5
	165.2 Km. East	126.7 Km. North

Now construct a "Right Triangle" with the North/South side 126.7 units long and the East/West side 165.2 units long . The Hypotenuse then represents the the bearing and distance between stations. Note: The North/South line is on Grid North.



Grid North can be considered True north for practical purposes, but the actual difference is shown in the map margin.

Therefore, Angle # = $\tan^{-1}$ 165.2 / 126.7 = 52.5 degrees Grid. This is the bearing from VK2RNE to VK2EA. The reciprocal is 52.5 + 180 = 232.5 degrees.

Length of Path = $\sqrt{126.7^2 + 165.2^2} = 208.2$ Km.

If the triangle is drawn to scale on graph paper, bearing and distance can be measured without the mathematics!

Be sure to make sense out of the direction of the bearing!

Take care drawing the section line across more than one map - Grid North gradually varies.

CONSTRUCTION OF PATH PROFILE:

Having determined the Bearing and Distance between two points and drawn this line on a map, a Path Profile can be drawn on graph paper.
Select a suitable scale, say 10 Km. to 1 Cm. horizontal and 500 metres to 1 Cm. vertical. For paths of more than a few Km. long it is necessary to include the "Bulge of the Earth's Curvature" on the section.
The atmosphere refracts both light and radio waves beyond the horizon. This bending varies with temperature, humidity, density and lapse rate, etc.
The Refractive Index "K" averages about 4/3, or 1.33. The higher the 'K' index, the flatter the earth's curvature looks to radio waves. (As 'K' is varying all the time it is sometimes necessary to adopt "K" as low as 0.8 for very reliable circuits).
The height of the Earth Bulge at any point along the Profile is calculated as:

$$h = \frac{d1 \times d2}{17}$$

where h = Earth Bulge in metres;
d1 and d2 = the distance from each end in Km.
The 17 is derived from K = 1.33.

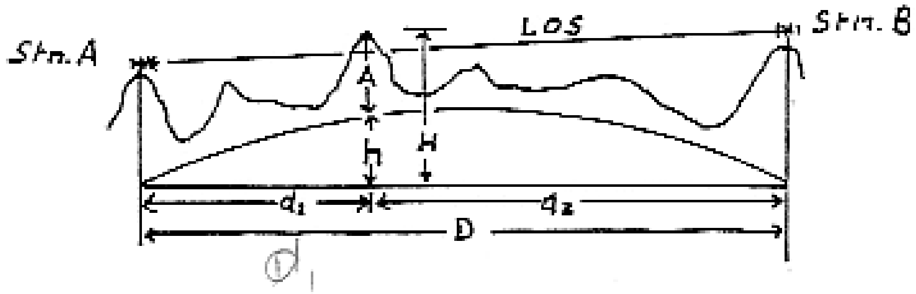
It is only necessary to calculate "h" at possible obstruction points. A convenient method is as follows:

$$H = \frac{(D - d1) \times d1}{17} + A$$

where H = plotted height of the obstacle above the plotted base;
D = length of path in Km.
A = altitude of the obstacle in metres above sea level.
D1 = distance to obsticle.

Plot all points on the Profile. Stations A and B are antenna heights at each end of the circuit. Note that the "Earth Bulge", h, is zero at these points. Plot all other obstacle points on the profile as h + A. Connect these points to give the profile.
Now draw a line between the points A and B. This is the "Line of Sight" (LOS), and will show whether the LOS passes above or below the obstacles.

EXAMPLE:



Now having drawn a path profile and determined whether the Line of Site path is above or below the obstacles, the magnitude of signal losses can be calculated.

FREE SPACE LOSS:
A signal in free space is attenuated at the following rate:

$$FSL = 32.4 + 20 \text{ Log } d(\text{Km.}) + 20 \text{ Log } f(\text{Mhz.})$$

This loss is expressed in dBm. Even if the radio path clears the obstruction, (horizontally as well as vertically), losses can occur due to a reflected signal arriving at the receiver antenna and cancelling the direct signal if it is out of phase.

If the direct radio path is masked by an obstacle, some of the signal will be diffracted over (or around) the obstacle   The resulting loss is determined by the nature of the obstacle, it's position along the path and the angle of diffraction.

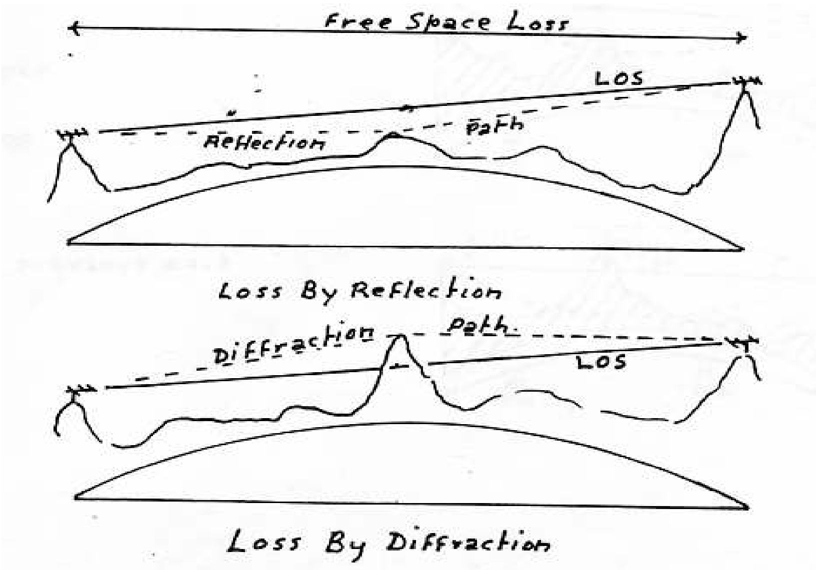
Losses due to reflection and diffraction must be added to the "Free Space Loss". Sometimes all three occur on one path.

Mathematical solutions have been devised to calculate losses over true "Knife Edge" obstructions. There are also a number of empirical solutions for specific conditions and localities, some of them graphical.

A lot of Judgement is required in classifying the nature of obstructions:-

Knife Edge, Blunt Edge, Flat Earth, Smooth Earth, Rough Earth, etc. The height of trees should always be added to ground level heights of obstructions. Some timbered ridges "look" like knife-edges as frequency increases.

<u>EXAMPLE:</u>



EVALUATING LOSS FROM AN OBSTRUCTION:

Any signal, either reflected or refracted from an obstruction, arriving at the receiving antenna out of phase with the Direct Path signal will cause a loss.

This obstruction must be located within the "First Fresnel Zone" of the line of sight path. This zone is cigar shaped with the direct Line Of Site (LOS) path as it's axis. (Don't get upset the Fresnel Zone is nothing more than a piece of geometry!)

If an obstruction along our profile intrudes into the Fresnel Zone, the signal loss can be estimated from the appropriate curve on Fig.3 when "n" (the ratio of ray clearance to Fresnel Zone radius is known.) It is important to note that these calculations must take into account the earth bulge as well.

The Fresnel Radius at any point on the path is calculated as follows:-

$$F1 = 548 \times \sqrt{(d1 \times d2 / (f \times d))}$$

Where: F1 = metres

f in Mhz,

d1 & d2 in Km.

The ratio "N" of the ray clearance to Fresnel Radius is entered into Fig3 and the obstacle loss in dB is read off.

There are two cases;- Line of sight above Obstacle? (Fig.l) & Line of sight below Obstacle* (Fig.2).

EXAMPLE 1 (for a frequency of 150 Mhz.)

$$F1 = 548 \times \sqrt{(12 \times 8/ (150 \times 20))}$$

= 98 m

a = ray clearance

= +30m

N = a/F1 = 30/98

= + 0.31

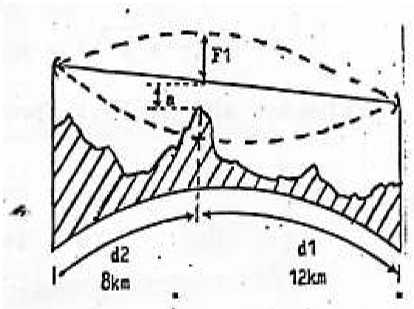


Fig 1

EXAMPLE 2

F1 = 98m (from previous eg.)

a = - 30 m

N = -a / F1

= -30 / 98

= -0.31

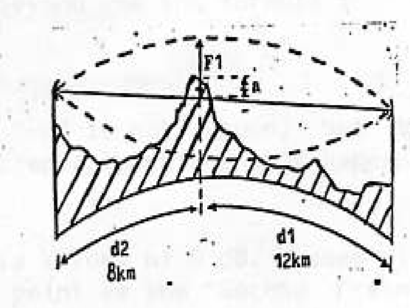


FIG 2

Enter "N" into Fig.3. Example 1 = -2.5 dB and Example 2 = -9.7dB.

Note: These are for true Knife Edge obstructions.

Now add obstruction loss to Free Space Loss:

FSL = 32.4 + 20 Log20 + 20 Logl50 = -101.9dB. + OL = Total Loss

OL = Obstical Log.

Now you know enough to start making mistakes!!

CALCULATION OF LOSSES:

For those people who want to convert "N" into -dB by calculator or computer instead of the graph at Fig.3, I refer you to the RSGB book. Amateur Radio Software, by Morris. This shows how to derive the answer to Fig.3 by Calculus, Computers are very good at Calculus, but hand calculators are not so hot and I personally find it impossible under any circumstances!

The following is a method which gives answers correct to within 0.5 dB fig.3 (however accurate it was in the first place!). I am unable to give credit to the author of this work as I have been unable to find it's origin.

As stated previously the curve of Fig.3 is derived by Calculus and cannot be duplicated on a simple calculator. By dividing the curve into two parts and using a different formula for each, the resulting accuracy is within plus or minus 0.5 dB.

First convert "n" to "v" by: $v = n \times \sqrt{2} \times -1$

(1) For values of "n" between +0.6 and -1.4 use the formula:

$$J(v) = 6.4 + 20 \text{ Log } (\sqrt{v^2 + 1} + v) \quad \text{dB.}$$

(2) For values of "n" for -1.4 and beyond use the formula:

$$J(v) = 13 + 20 \text{ Log } v \quad \text{dB.}$$

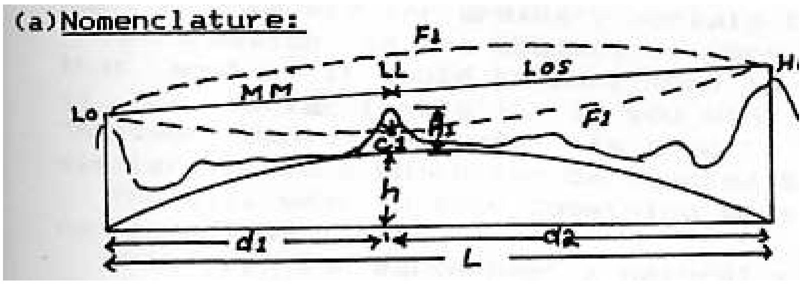
The upper limit of accuracy of "-n" is not known, but the value of loss in dB will become unacceptable before this happens.

NOTE:

A value of "n" = +0.6 equals a loss of 0 dB. Losses will begin to increase again beyond this point as the "Second Fresnel Radius is approached. (Do some more study!)

A word of warning here: Most paths have more than one obstruction and can be dealt with in a number of separate steps, the sum of all sections taken as the total loss.

For those with programmable calculators or computers, the following summary will allow you to see how to set up a program.



H1 & H2 in metres

L, d1 & d2 in Km.

LOS = Line of site.

Ci & h in metres.

(b) MM = (HI-LO)/(L*1000) This is the Tan gradient of LOS.
(c) h = (dl*d2/(12.75*K)) The Earth Bulge in metres. (K=?)
a convenient variation is h=(L – d1) * d1 / (12.75 * K))

(d) LL = (MM *(d1 * 1000)) + LO LL = height of LOS (ASL) at d1.
(e) Fl = 548 * (d1 * d2 / (L * f)) Fl = Fresnel Radius at LL. f=MHz
(f) Cl = (LL – h – Fl) = clearance between F11 & Mean Sea Lev.

Note: if C1 is positive, then F1 is above ground lev. However if earth's surface H1 above Sea Lev. is greater than positive clearance, then a "Path obstacle" intrudes the Fresnel Zone.

The section across the map is now examined in say 10 Km. segments and any ground level height less than +C1 isdisregarded. However any feature with a height greater than C1 intrudes the Fresnel Zone and is evaluated as follows:

(g) H = MM * (OD * 1000) + L0 – H1 OD = obstacle distance from low end
H = obstacle intrusion into F1.
H1 = height of obstacle ASL.

(h) H/F1 = The ratio used to obtain loss in dB from either Graph or calculations. If loss is to be calculated, use:
(i) First convert H/F1 to "v" by: $v = H/F1 * \sqrt{2* -1}$
(j) For values of H/F1 between +0.6 & -1.4 use the formula:

$J(v) = 6.4 + 20 \text{ Log } (\sqrt{v^2 + 1} + v)$ dB.

and for values of H/F1 of -1-5 and beyond, use:

$J(v) = 13 + 20 \text{ Log } v$ dB.

Try Amateur Radio Software for ideas.

CONCLUSIONS:

I think that you will agree that the subject is too complicated to be expressed simply, so I have simplified it as I much as possible for ordinary mortals to understand.

Information on the subject is very hard to get, but I fancy that most of it would be published in one of Bullington's books if one could locate it. If you want to put it on computer, "Amateur Radio Software" is good to start on as it has some similar versions which can be adapted to any type of computer.

You will want to know something more about the "K" factors of earth radius. Briefly, the earth has a natural radius of about 6336 Km., which is K = 1. Due to atmospheric refraction you can see a little way over the horizon — therefore the earth appears to have become flatter, or the radius increased by about K = 1.1. This varies widely with atmospheric conditions to the point where "Optical ducting" takes place and you see a MIRAGE!

Atmospheric refraction also bends radio waves over the horizon. The average increase in apparent earth radius is about K = 1.33. However , the atmosphere varies from hour to hour, giving ranges of less than normal horizon range, to ducts many thousands of Km. in length.

Now if an amateur gets greater than 50% of a voice contact, he is happy; but less than 100% for 99.97%. of the time for a commercial digital link is an economic disaster, so professional people use factors of as low as K = 0.8 around the North Coast here and I understand that in North Queensland they use K = 0.6 in places. I imagine that Packet links will need this consideration.

To make practical use of the path losses you are going to calculate I recommend that you Read Lindsay Lawless" excellent article on Receiver Sensitivity and Signal Strengths,(A,R- Aug. 1987, P48.) Also the articles on Signal Enhancement by Aircraft.

At my QTH in Goonellabah there are a number of distant stations which I can communicate with regularly and which have reliable signals Just above the noise. I have used these as standards, and have found that the calculated signal losses along these various paths fit the actual signals most of the time.

So far I have only dealt with classical "knife edged " obstacles. I am collecting material on obstacles of other shapes and sizes, but so far have not found a way to substitute a mathematical solution to the graphs which I have. Strangely most of our timber-crested obstacles around here behave like sharp crested ones!

I did have working programs in both a Sharp 1401 and an old North Star computer. The battery died in one and the system died in the other. I have not got around to re-installing in either the 1401 or my present computer.

NOTES ON Tx. POWER and Rx. SENSITIVITY:

There is Positive gain from Transmitter Power and Antenna Gain. There is Negative loss from Feed Lines, Free Space Loss and Obstacle Loss. What the receiver hears is governed by Receiver Sensitivity in uV and the Signal Strength in uV arriving at the input terminals. This is further limited by the Thermal Noise coming from the sky. The signal you are listening for must be above the thermal noise level. I advise you to read a bit about these subjects.

Hereunder are a few notes on converting total dB loss to uV. and vice versa.

Tx. Power in dB:= 10Log(W / 0.001) or 10Log(W * 10^3) Where: W= watts

Rx. Sensitivity:

$$E\ uV = \sqrt{(R*10^{-3})*Log^{-1}(-dB/10)*10^{6}}$$

Note: Log^{-1} = Inverse Log

Where: R=Rx. input impedance in ohms,
-dB=total loss in dB between Tx & Rx
E uV=signal volts across Rx. input.

ALSO: Total path loss which will give X uV input at Rx. =

$$-dB = 10Log\left(\frac{(EuV*10^{-6})^{2}}{R*10^{-3}}\right)$$

Note; 50 ohm * 10^-3 = 0.05, etc.

EXAMPLE: Potential allowable path loss between Tx & Rx, with a receiver input impedance of'50 ohms jand sensitivity of 0.2 uV.

$$10\ Log\left(\frac{(0.2*10^{-6})^{2}}{0.05}\right)$$

= -120.96dB

And: Actual uV at Rx for a path loss of say -90.98dB:

$$EuV = \sqrt{0.05*Log^{-1}(-90.98/10)*10^{6}}$$

Note: Log^{-1} = Inverse Log.

= 6.316 uV.

I hope you have a lot of Joy experimenting with this.

Is Expressed Better as: $10^{6}\sqrt{0.05*[Log^{-1}(-90.98/10)]}$