Line-of-Sight Microwave Communications

by H. Schlager, OE 3 HSC

This article requires some knowledge of trigonometry of an oblique-angled triangle so that the flat surface profile can be corrected for by the curvature. The required terms »4/3 curvature of the earth« and »Fresnel zone« are to be described.

The triangle M, H 1, H 2 is determined by the three values $r + h_1$, $r + h_2$, and α (see **Fig. 1**). The angle α results from the arc F_1F_2 (= b), and the distance (QRB) of the two base points F_1 and F_2.

$$\alpha = \frac{QRB \times 360^\circ}{2 \times \pi \times r}$$

where: r = radius of the earth, to be explained later.

The straight line H_1 and H_2 is thus calculated according to cosine law as follows:

$$A = H_1H_2 = \sqrt{(r+h_1)^2 + (r+h_2)^2 - 2(r+h_1)(r+h_2)\cos\alpha}$$

It is now possible for the sum of the side lengths (circumference) of the triangle to be calculated, and this will be called circumference = 2 s:

$$s = \frac{(r + h_1) + (r + h_2) + A}{2}$$

Now, φ_1 is determined as the next calculation, using the chord formula:

$$\cos\frac{\varphi_1}{2} = \frac{s\,[s - (r + h_1)]}{A \times (r + h_2)}$$

All elements of the triangle are now determined that are required for further calculations. A general point (base point) F can be calculated that is spaced b from base point F_1, as well as the height h of the radio beam, and other things.

From the value $b' = F_1F$ the following will result:

$$\alpha' = \frac{b' \times \alpha}{b}$$

From the rule »the sum of angles = 180°«, the following will result:

$$\varphi = 180^\circ - (\alpha' + \varphi_2)$$

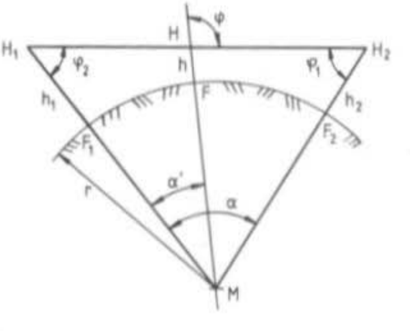

Fig. 1:
Trigonometry of the oblique-angled triangle H_1H_2 = A; F_1F_2 = b; F_1F = b'

With this and sine law it is now possible for the unknown side of the small triangle H_1MH to be calculated:

$$\frac{h + r}{\sin \varphi_2} = \frac{h_1 + r}{\sin \varphi}$$

$$h = \frac{(h_1 + r) \sin \varphi_2}{\sin \varphi} - r$$

THE TERM 4/3 THE EARTH CURVATURE

The propagation of electromagnetic waves in space and in a homogene atmosphere is a straight line.

The value of the relative dielectric constant varies with increasing height in the air layers near to the surface. One will find a gradient of the reflective index (ΔN) that is dependent on the temperature, and even more on the humidity.

The anomalities of this refractive index are responsible for the tropospheric over-the-horizon communication, which is so useful on the 2 m band.

The value of ΔN is (usually) negative, which means that it is normally more humid near the surface and decreases with height.

This gradient is found in the equation for the effective diameter of the earth (1):

$$r_{eff} = r_{geom.} \times k, \quad \text{where}$$

$$k = \frac{1}{1 + 6.37 \times N \times 10^{-3}}$$

According to CCIR, ΔN does not differ greatly from -40, which means that k is 1.34, which corresponds to 4/3, and r_{eff} = 8488 km.

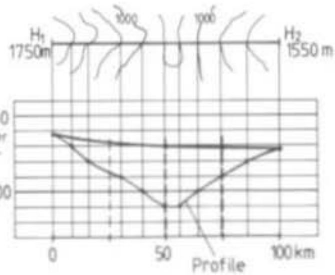

Fig. 2:
The points of intersection are now transferred from the lines of height on the map with the aid of additional lines onto the mm-paper

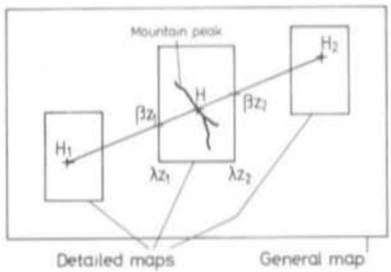

Fig. 3:
Detailed maps should be obtained for the critical points of the communication path

THE PROFILE OF A COMMUNICATION PATH

This is commenced by obtaining a map with a scale of approximately 1 : 500 000. There are some maps available which are only provided with lines of height, and lakes. A line is now drawn between the two required points (projection in the sectional plane). A page of mm-paper is now fixed approximately 1 to 2 cm from this line.

The line-of-sight orientated to the curvature of the earth is now inserted into the straight profile as a dot approximately every 25 km (**Figure 2**).

All points should be checked at which the radio beam is in the vicinity of the profile. This requires the study of more detailed maps (approx. 1 : 50 000) from which the exact position of H_1, H, and H_2 can be determined. These maps provide lines of height every 20 m.

It is best to provide a great circle through H_1 and H_2 and to study the exact path of the radio beam on the more detailed maps. It is thus possible for the actual height above ground to be determined.

GREAT CIRCLE

The equation for determining the width β_z of a point on the great circle from H_1 (λ_1, β_1) to H_2 (λ_2, β_2) with the point of intersection on the meridian λ_z is:

$$\beta_z \;=\; \text{arc tg} \frac{\text{tg}\,\beta_2 \times \sin(\lambda_z - \lambda_1) - \text{tg}\,\beta_1 \times \sin(\lambda_z - \lambda_2)}{\sin(\lambda_2 - \lambda_1)}$$

An example is given in **Figure 3**.

The height above ground for H can be read off from the map.

FRESNEL ZONES

Fading of the signal due to multipath propagation is well-known in mobile communication. Similar effects are also observed when a signal from a fixed station at location H_1 is not only received on the direct path to location H_2, but also, partially, via a reflection. This will cause a complete cancellation of the signal when the signals are of equal amplitude and opposite phase.

This means that it is not only necessary for direct line-of-sight conditions to be present between transmitter and receiver, but also to ensure that there are no reflections present with a path difference of $\lambda/2$ (or odd multiples of this).

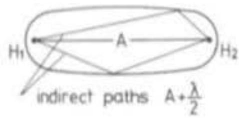

Fig. 4:
The Fresnel zone is an ellipse around the radio beam from H_1 to H_2

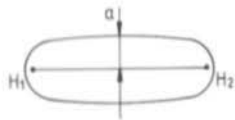

Fig. 5:
The critical spacing a is calculated according to equation 2

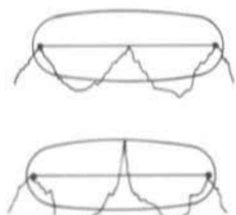

Fig. 6:
Anything protruding into the Fresnel zone will cause additional losses

The geometrical location (the assumed joining) of all these points is an ellipse around the radio beam, whose focal points are H_1 and H_2. This zone is called Fresnel zone (see **Fig. 4**).

The spacing »a« of the ellipse around the radio beam can be approximately given for any point of the path by the following (see **Figure 5**):

$$a = 548 \times \frac{b' \times (b - b')}{[b' + (b - b')] \times f}$$

with a in m, b in km, f in MHz.

Anything protruding into this ellipse will increase the path loss by 6 dB on approaching the first Fresnel zone (see **Figure 6a**) up to the radio beam, and by 16 dB when cutting the radio beam **(Figure 6b)**.

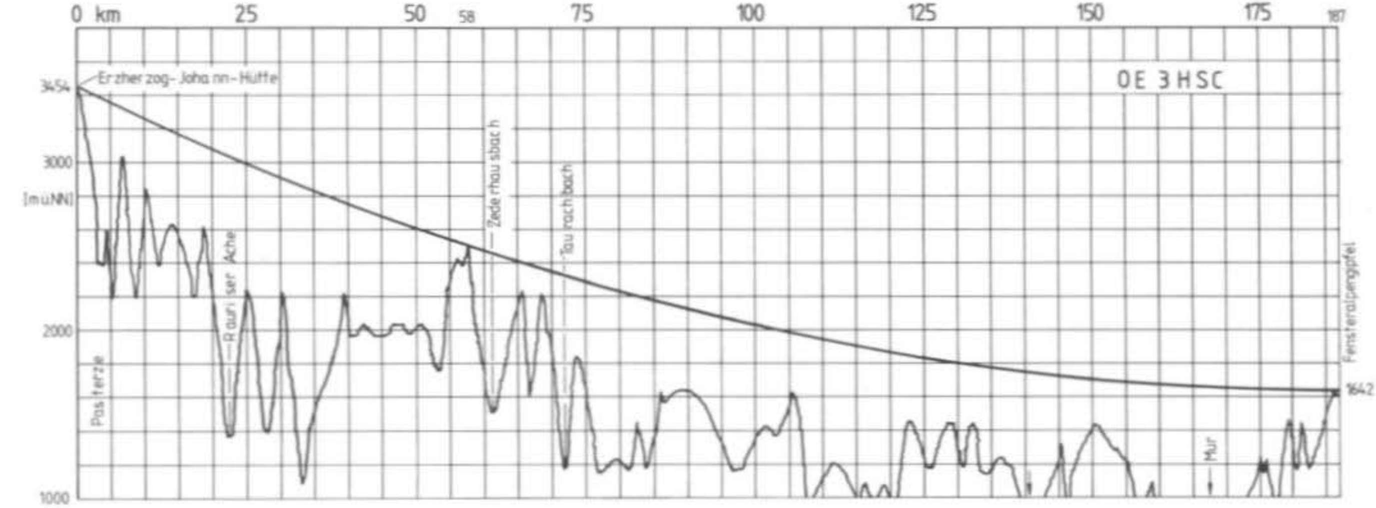

Fig. 7: Profile of a radio path from the Grossglockner to Fensteralpen-Gipfel in Austria

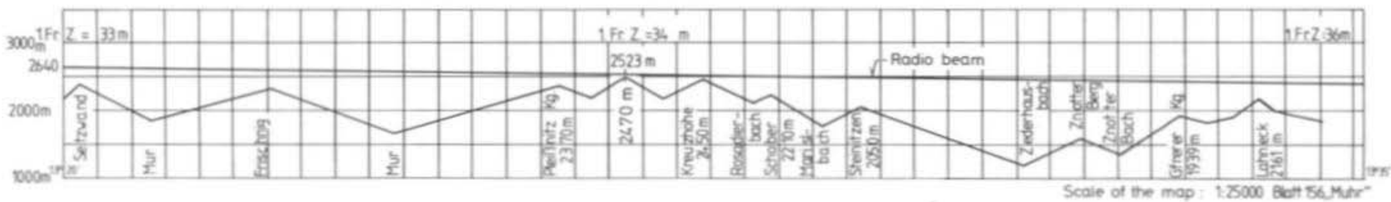

Fig. 8: At 58 km, the height between the radio beam and the mountain amounts to 53 m

These values are additional losses that must be taken into consideration on calculating the path loss along the communication path.

FINAL NOTES

The given calculations can be made easiest using a programmable calculator. Programmed cards for the HP 41 c can be provided at cost. Finally, the author would like to show this calculation in the form of a practical example: Profile and Fresnel zone consideration of a communication path in Austria for 10 GHz communication over 187 km: This is from the Erzherzog-Johann-Hütte on the Grossglockner to Fensteralpengipfel in OE 6. Both points are readily accessible using a cable railway, or road.

One will see in **Figure 7** that one part of the path is in the direct vicinity of the radio beam between 13°20' and 13°35' East.

With the aid of the equation given in the section »Great Circle«, the points of intersection of the great circle (determined by H_1 and H_2) were determined for the meridians 13°20' and 13°35'. These were 47°07'55" and 47°09'15". These coordinates have been marked in the detailed map **(Figure 8)** and joined with a pencil line. This allows the fine profile of this section of the path to be drawn, and indicates that the first Fresnel zone is not affected. The height of the radio beam amounts to 2523 m, and the height of the mountain is 2470 m according to the map. This means that there is a spacing of 53 m between the radio beam and the mountain peak.

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