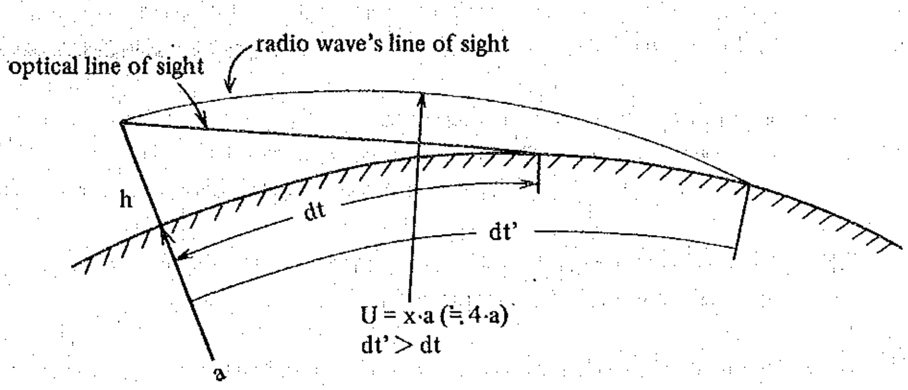
8. The factor of the effective earth radius

8-1 Radio wave propagation path in the standard atmosphere draws a loose arc of which radius is about 4 times longer than the earth's radius, and goes farther than the optical line of sight as shown by the picture below, and its refraction radius is given as below.



$$\therefore \quad U = x \cdot a \ \ [m] \qquad (x \fallingdotseq 4) \qquad (55)$$

U: radio wave refraction radius [m]
a: true earth radius [m]
x: factor of radio wave refraction radius
(≒ 4, in the standard atmosphere)

8-2 This means that, thinking of the radio wave propagation path in to a straight line, the earth should be smoothed more and its effective radius should be grown up similarly.
In this situation, the ratio of the effective earth and the true earth radius is called effective earth radius factor K and shown as the equation below.

$$\therefore \quad K = \frac{R}{a} = \frac{a\left(\frac{x}{x-1}\right)}{a} = \frac{x}{x-1} \qquad (56)$$

R: effective earth radius [m]
a: true earth radius [m]
x: factor of radio wave refraction radius
(≒ 4, in the standard atmosphere)
K: effective earth radius factor

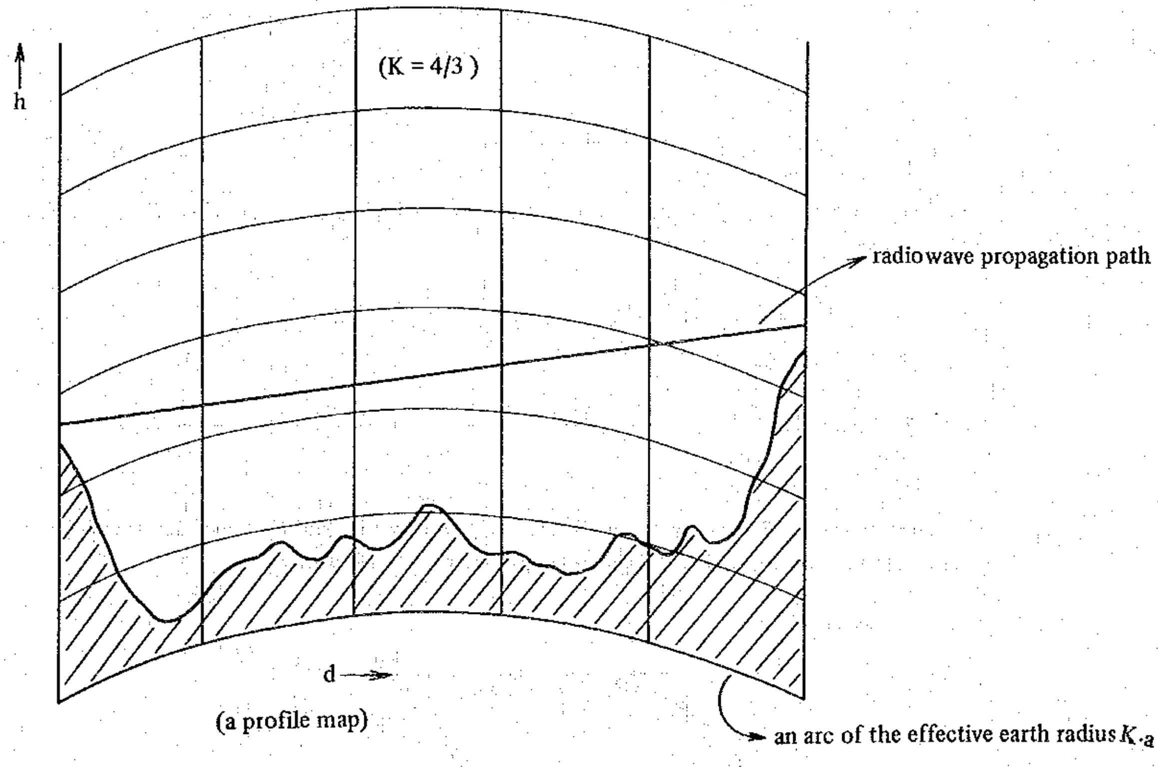
8-3 This effective earth radius factor K depends on the condition of the radio wave refractive index which is affected by the atmospheric conditions, and is calculated as next in the standard atmosphere.

$$K = \frac{R}{a} = \frac{x}{x-1} = \frac{4}{4-1} = \frac{4}{3} \quad \text{(standard value)} \qquad (57)$$

K = 4/3 is a standard value of the effective earth radius factor.

In Philippines, K = 4/3 ~ 3/2 may be given, but K = 4/3 should be used when the VHF propagation path is calculated (using the lowest value).

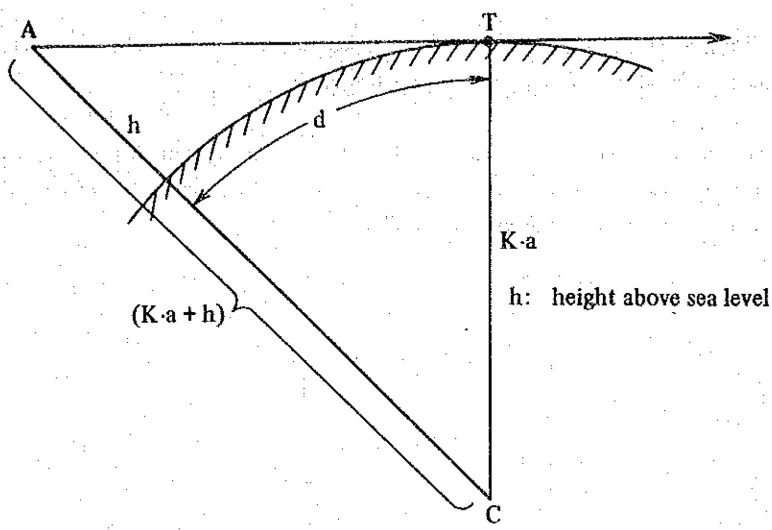
8-4 When the effective earth radius (= K · a) is used for a profile map, a radio wave propagation path is drawn into a straight line as shown below. Needless to say, this is very convenient for the calculation of the link budget on the VHF.



(a profile map)

9. The distance of radio propagation path (The line of sight distance)

9-1 The distance of the propagation path d which is shown by the picture below, is given as the equation below.



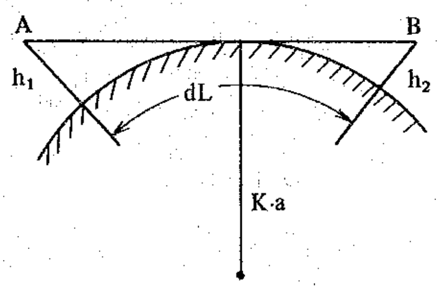
$$d = \sqrt{2Ka \cdot h} \quad [m] \qquad (58)$$

In the case of the standard atmosphere this d is calculated as below where K = 4/3 and a = 6370 [Km] are used.

$$d = \sqrt{2 \times 4/3 \times 6370 \times 10^3 \times h} \quad [m] = 4.12\sqrt{h} \quad [Km]$$
(K = 4/3)

$$d = 4.12\sqrt{h} \quad [Km] \quad (K = 4/3) \qquad (59)$$

When the height of the points A and B above sea level are h_1 and h_2 which are shown by the picture below, the distance of radio propagation path dL is given below.



$$dL = \sqrt{2Ka}\,(\sqrt{h_1} + \sqrt{h_2}) \quad [m] \qquad (60)$$

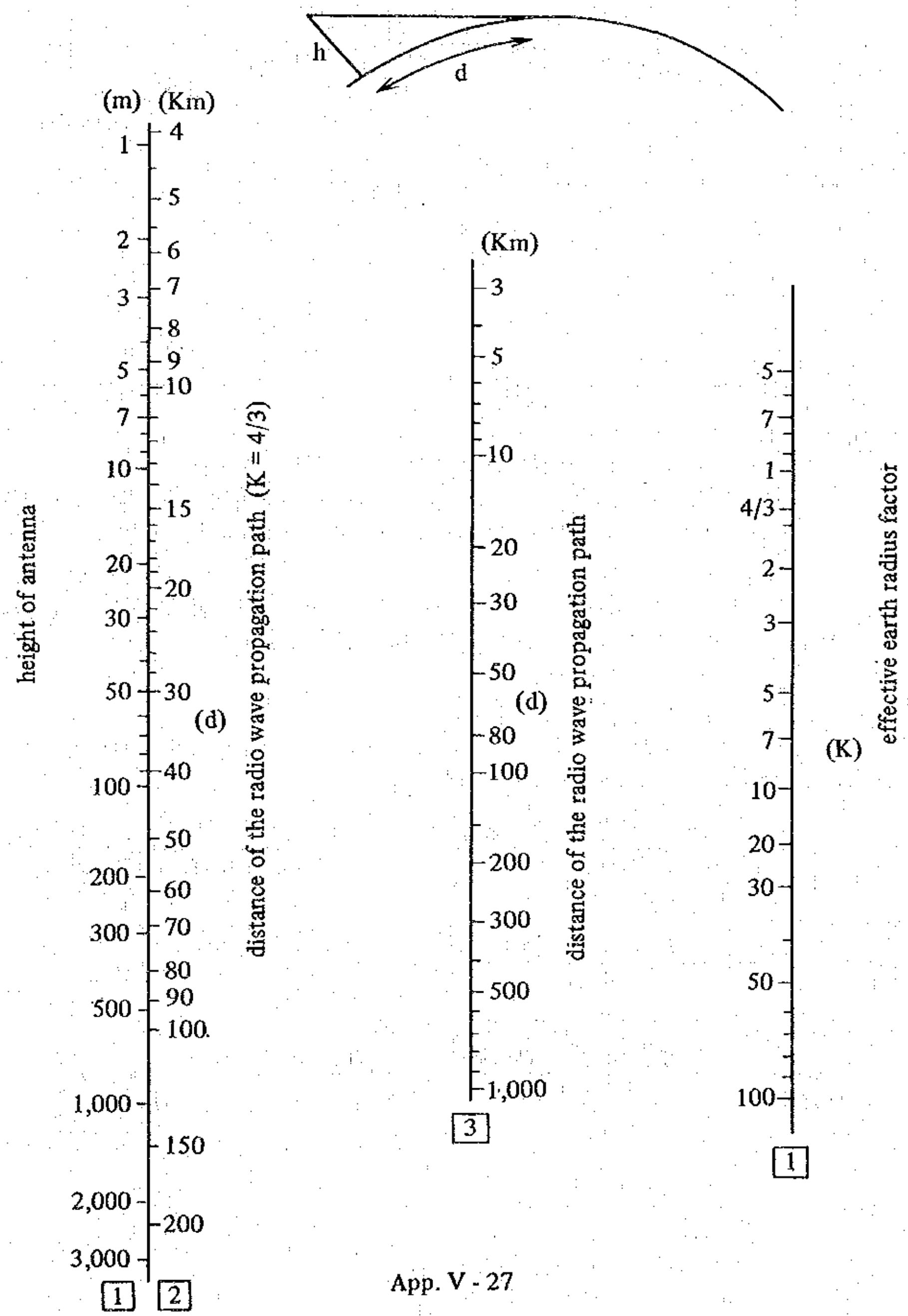
or

$$\therefore \quad dL = 4.12\,(\sqrt{h_1} + \sqrt{h_2}) \quad [Km] \quad (K = 4/3) \qquad (61)$$

9-2 The distance d is given also by the next nomogram.

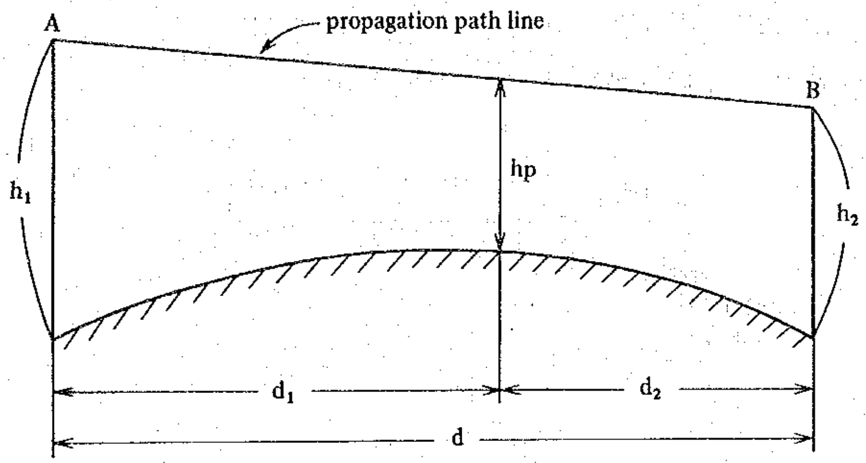
table (4)

Nomogram for the distance of radio propagation path



10. The propagation path height above sea level

10-1 The height of the propagation path above sea level between A and B which are shown by the picture below is given as the equation below.



$$hp = \frac{h_1 \cdot d_2 + h_2 \cdot d_1}{d} - \frac{d_1 \cdot d_2}{2Ka} \quad [m] \qquad (62)$$

hp:	the height of the propagation path between A and B [m]
h_1:	antenna height above sea level, at the point A [m]
h_2:	antenna height above sea level, at the point B [m]
d_1:	distance between the point A and the point wanted [m]
d_2:	distance between the point B and the point wanted [m]
d:	distance between A and B ($=d_1 + d_2$) [m]
K:	effective earth radius factor
a:	true earth radius (= 6370 [Km]) [m]

hp is also calculated as below, using K = 4/3.

$$\underset{(k=4/3)}{hp} = \frac{h_1 \cdot d_2\,[km] \times 10^3 + h_2 \cdot d_1\,[km] \times 10^3}{d\,[km] \times 10^3} - \frac{d_1\,[km] \times 10^3 \times d_2\,[km] \times 10^3}{2 \times 4/3 \times 6370 \times 10^3}$$

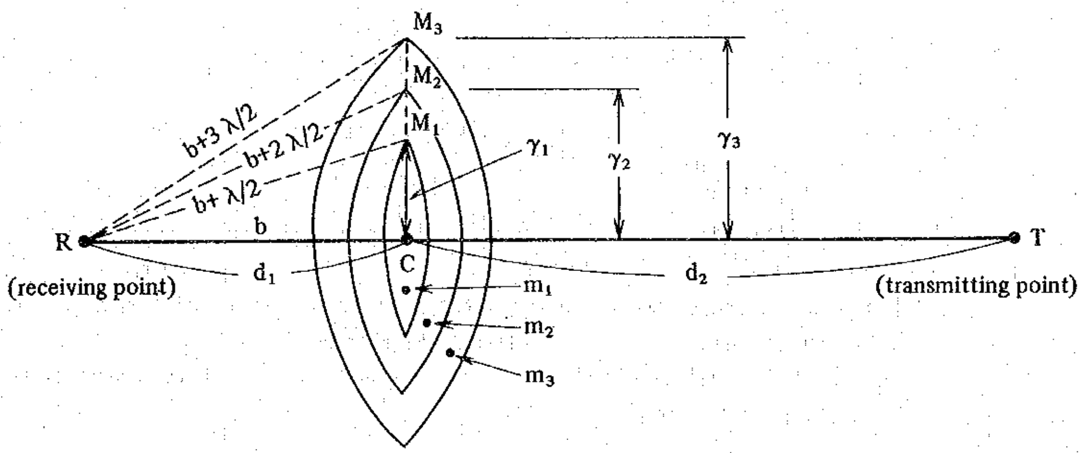
$$= \frac{h_1\,[m] \cdot d_2\,[km] + h_2\,[m] \cdot d_1\,[km]}{d\,[km]} - \frac{d_1\,[km] \cdot d_2\,[km]}{17} \quad [m]$$

$$\underset{(k=4/3)}{hp} = \frac{h_1\,[m] \cdot d_2\,[km] + h_2\,[m] \cdot d_1\,[km]}{d\,[km]} - \frac{d_1\,[km] \cdot d_2\,[km]}{17} \quad [m] \qquad (63)$$

11. Fresnel zone and the first fresnel zone radius

11-1 Zones of spherical wave front

11-1-1 The picture below shows an instantaneous situation of the spherical wave front. The distance between Mn (n=1, 2, 3 . . .) and the receiving point R are b + n · λ/2 (n=1, 2, 3 . . .) as shown by the picture.



11-1-2 It is said that the effect which is given to the receiving point R by the whole wave front, is shown by the total secondary effects those are given by all the points in the each zone (m_1, m_2, m_3 . . .) on the wave front.

11-1-3 Owing to the path difference of λ/2, every points within the first zone m_1 increase the effect to the receiving point R, but those within the second zone m_2 decrease it, and those within the third zone m_3 also increase it.

11-1-4 The radius of n th zone γ_n (n=1, 2, 3 . . .) are called the n th fresnel zone radius and are given by the equation below.

$$\gamma_n = \sqrt{n \cdot \lambda \frac{d_1 \cdot d_2}{d}} \quad [\text{m}] \quad (n=1, 2, 3 \ldots \quad d=d_1+d_2) \qquad (64)$$

From the equation (64), the first fresnel zone radius is given by n=1, as the equation below.

$$\gamma_1 = \sqrt{\lambda \frac{d_1 \cdot d_2}{d}} \quad [\text{m}] \qquad (65)$$

(the first fresnel zone radius)

The inside zone of each radius is also called the n th (n=1, 2, 3 . . .) fresnel zone.

11-2 Mixed effects by each zone

11-2-1 The field strength at the receiving point is in proportion to the area of the n th zone and in inverse proportion to the distance between the zone and the receiving point.

11-2-2 If the mixed effects by each zone are expressed by S,

$$S = m_1 - m_2 + m_3 - m_4 \dots\dots$$

$$= \frac{1}{2}m_1 + (\frac{1}{2}m_1 - m_2 + \frac{1}{2}m_3) + (\frac{1}{2}m_3 - m_4 + \frac{1}{2}m_5) + \dots\dots$$

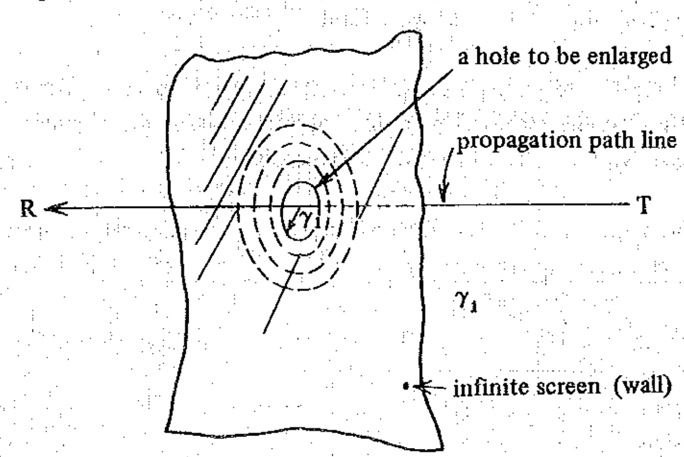
11-2-3 Because the area of each zone is nearly the same value ($m_1 = m_n \quad n=2, 3 \dots\dots$), the equation below is given.

$$\therefore \quad S \doteqdot \frac{1}{2}m_1 \qquad (66)$$

11-2-4 The equation above means that the mixed all effect by the propagation wave front is 1/2 as much as the effect m_1 only by the 1st fresnel zone.
This also means that the effect only by the 1st fresnel zone is 2 times as much as the effect by all the wave front.

11-3 Diffraction by a simple screen

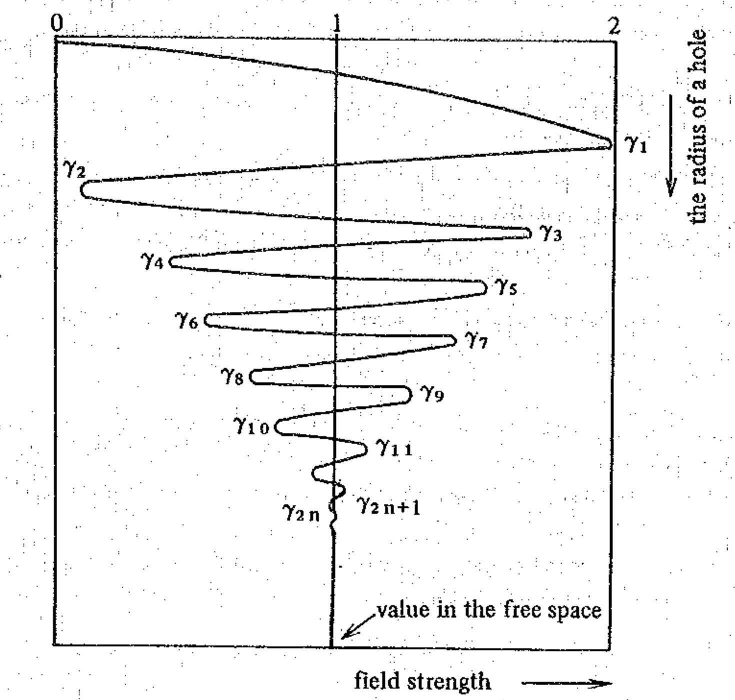
11-3-1 If a hole was made in a infinite screen or wall and was enlarged, the field strength should be grown up little by little and become the maximum value when the radius of the hole was equal to the 1st fresnel zone radius γ_1 .



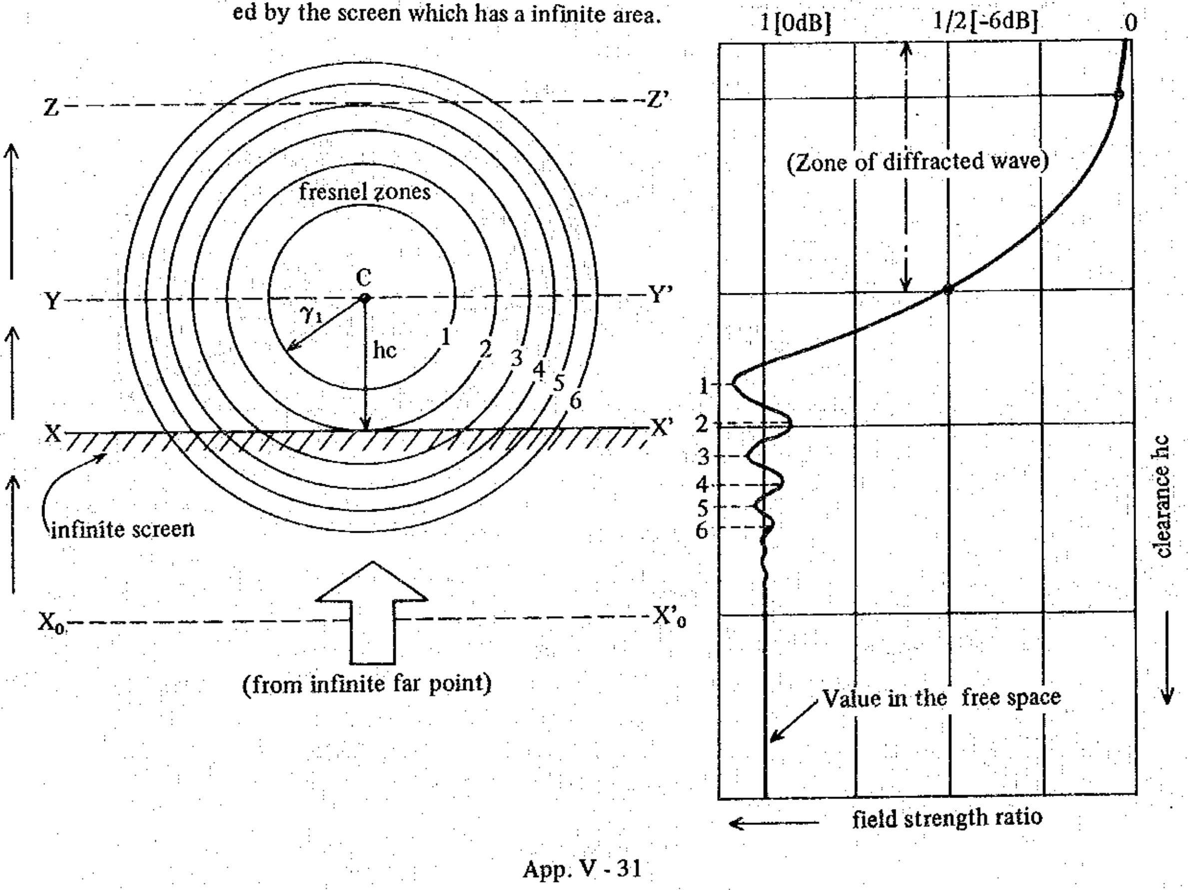
At this time the receiving field strength becomes twice than that in the free space.

If the radius of the hole was grown up to the 2nd fresnel zone radius γ_2, the receiving field strength should become to the first minimum value.

The picture below shows these status.



11-3-2 The picture below shows a situation when the wave propagation path is about to be covered by the screen which has a infinite area.



In the picture, the transmitting point is at the back of the paper, and the straight edge of the screen approaches to the center C on the wave propagation path.

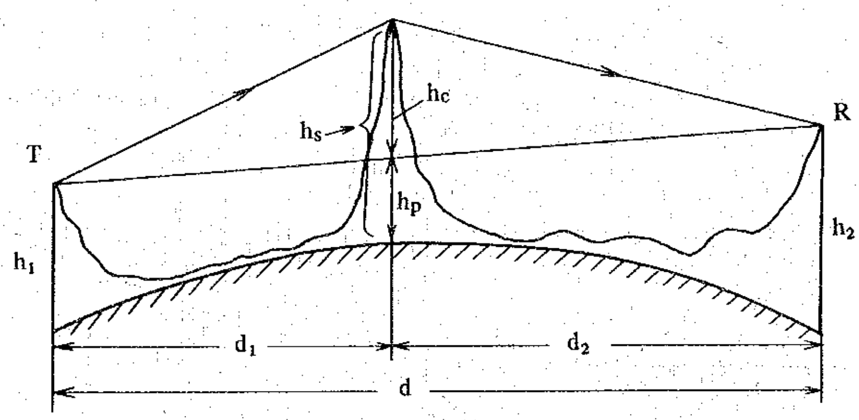
Under these conditions, the receiving field strength should be shown as the graph on the right in the picture above.
According to the graph, if the straight edge passed through the border of the 1st fresnel zone, the receiving field strength decreased suddently and became 1/2 times as much as that in the free space, when the edge touches the radio wave propagation path.

If the edge passed through the radio wave propagation path and moved above, the receiving field strength also decreased suddently and turned in to zero in the limit of covering.

The receiving field strength to be shown after when the straight edge of the screen passed through above the propagation path, is caused only by the diffracted wave, and such a zone in which there is only diffracted wave, is called the Zone of diffracted wave.

The distance between the propagation path and the edge of the screen is called the Clearance, hc.

11-4 Clearance and Clearance factor



a profile map for an example

11-4-1 The clearance hc is expressed by the next equation.

$$hc = \left\{ \frac{h_1 d_2 + h_2 d_1}{d} - \frac{d_1 \cdot d_2}{2ka} \right\} - hs \quad [m] \qquad (67)$$

(This tem is same as the propagation path height hp shown by the equation (62).)

hs: height of the mountain by which the propagation path between T and R is shut off.

11-4-2 When the effective earth radius factor K = 4/3, hc is calculated below using the equation (63).

$$\underset{(k=4/3)}{hc = hp - hs} = \left\{ \frac{h_1[m] \cdot d_2[km] + h_2[m] \cdot d_1[km]}{d[km]} - \frac{d_1[km] \cdot d_2[km]}{17} \right\} - hs[m] \quad [m] \qquad (68)$$

11-4-3 The clearance hc to the 1st fresnel zone radius ratio is called the Clearance factor U.

$$U = \frac{hc}{\gamma_1} \qquad (69)$$

hc: clearance

γ_1: the 1st fresnel zone radius at the point of an obstacle

U: clearance factor

According to the equation (67), (69), the clearance hc and the clearance factor U takes the plus/minus value.

i.e. $U > 0$ $(hc > 0)$ .... with in the line of sight

$U = 0$ $(hc = 0)$ .... skimming the line of sight

$U < 0$ $(hc < 0)$ .... out of the line of sight (with in the diffraction zone)

11-5 Diffraction loss and Clearance factor

The diffraction loss Ld is given by the table (5).

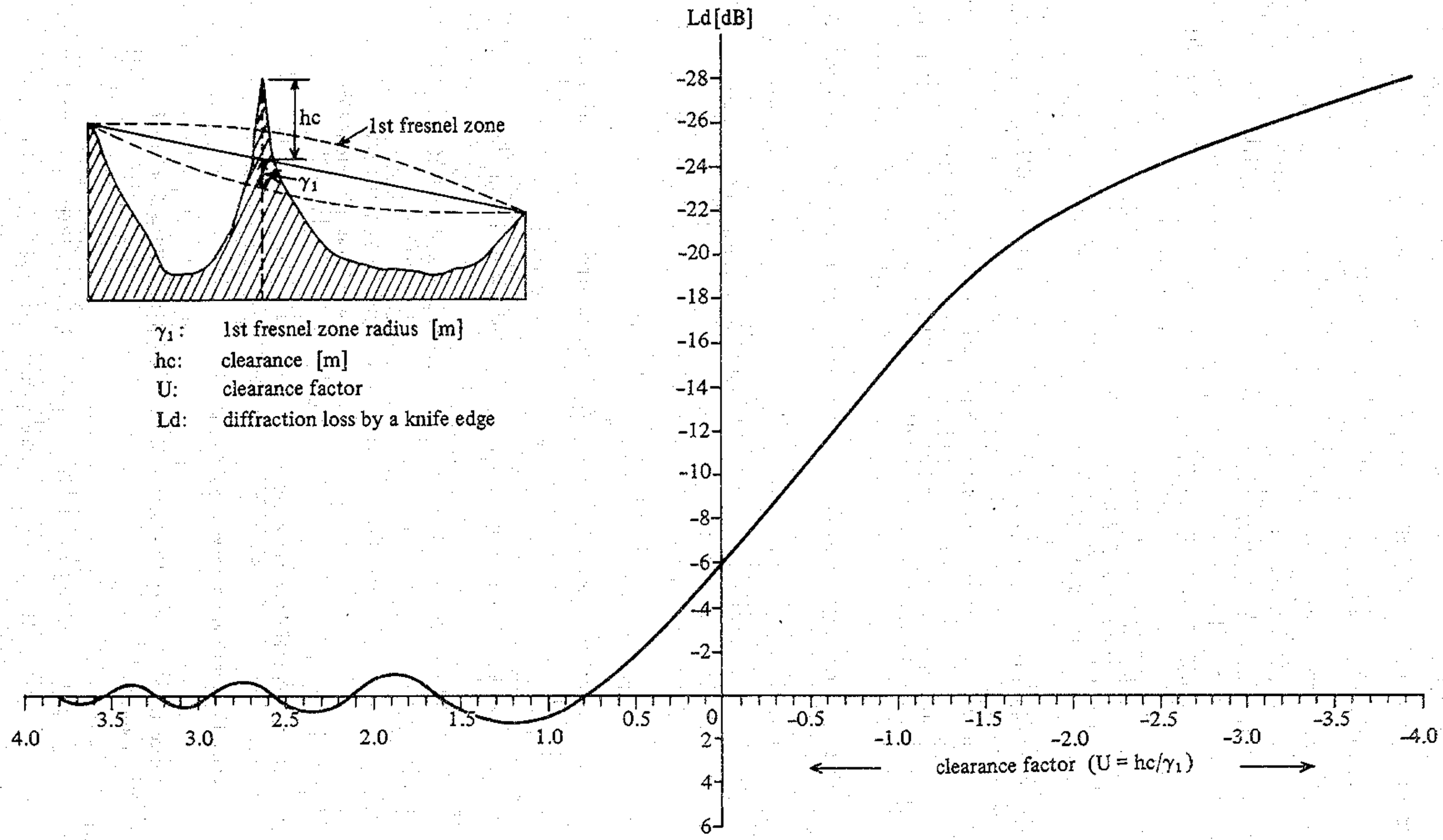
Within the deep diffraction zone such as $W < -1$, the diffraction loss Ld is also given by the equation below.

$$Ld = 20 \log |U| + 16 \quad [dB] \quad (U < -1) \qquad (70)$$

U: clearance factor $(= hc/\gamma_1)$

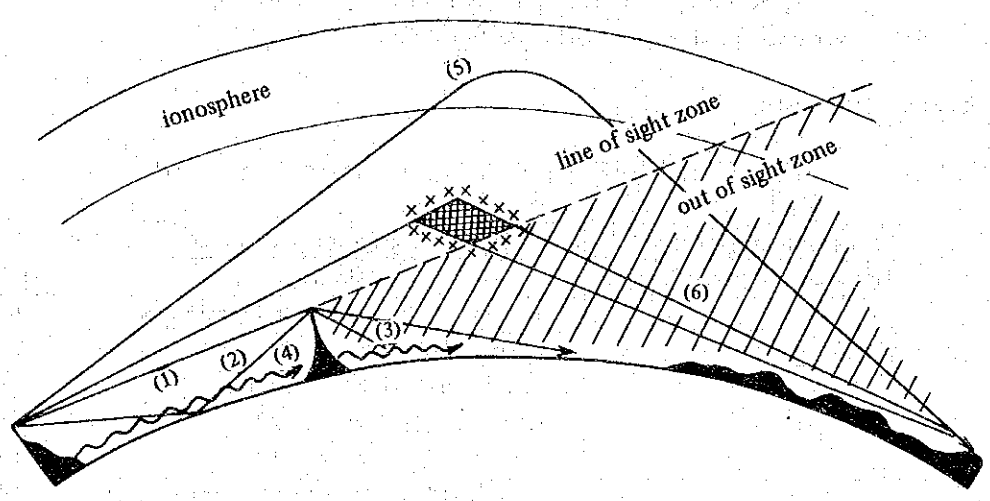
Diffraction loss caused by a mountain ridge (knife edge)

table (5)



12. Propagation modes

12-1 The picture below shows the physical propagation modes of radio waves.



(1): direct wave
(2): ground reflected wave
(3): diffracted wave
(4): surface wave
} ground wave

(5): ionospheric (reflected, scattered) wave
(6): tropospheric scattered wave
} space wave

12-2 The useful propagation mode of each frequency band is shown by the table below.

propagation modes \ frequency bands							micro wave		millimeter wave
		VLF	LF	MF	HF	VHF	UHF	SHF	EHF
ground wave	direct wave	×	×	×	△	◎	◎	◎	◎
	reflected wave	×	×	×	×	△	○	○	○
	diffracted wave	×	×	△	△	○	△	×	×
	surface wave	◎	◎	◎	△	△	×	×	×
space wave	ionospheric reflected wave	△	○	○	◎	△	×	×	×
	ionospheric scattered wave	×	×	×	△	△	×	×	×
	tropospheric scattered wave	×	×	×	×	○	△	△	×

12-3 Propagation path forms are classified as below.

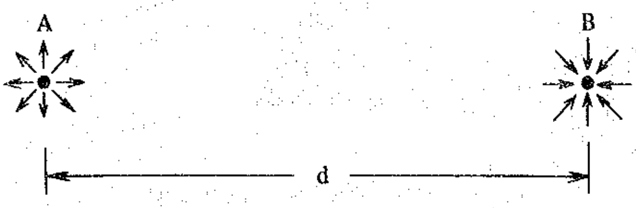
1. Free space propagation path (direct wave only)
2. Interference propagation path (direct wave + reflected wave)
3. Diffraction propagation path (diffracted wave only)
4. Scattering propagation path (tropospheric scattered wave only)
5. Mixing propagation path (combination of others)

13. Propagation path models

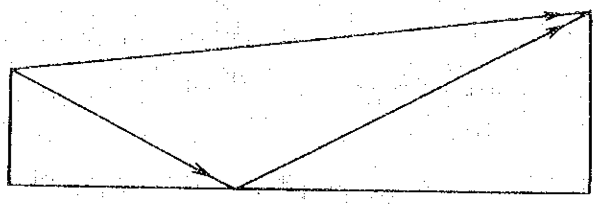
Propagation path models of VHF band is classified as the next table and pictures below.

zone	form of propagation path	kind of propagation path model	No. of picture
in sight	free space propagation path	free space type	(1), (19)
	interference ***	smooth and plane ground reflection type	(2)
		rough and plane ground ***	(3)
		smooth and spherical ground ***	(4)
		rough and spherical ground ***	(5)
		multi path reflection type ***	(6)
out of sight	diffraction ***	smooth and spherical ground diffraction type	(7)
		rough and spherical ground ***	(8)
		knife edge diffraction type	(9)
		circular top ridge ***	(10)
		multi ridge ***	(11)
		slant ridge ***	(12)
		multi diffraction type	(13)
	scattering ***	tropospheric scattering type	(14)
transition	mixing *** / tangent ***	near the horizon type	(15)
		near the ridge type	(16)
–		diffraction, reflection type	(17)
		scattering, diffraction type	(18)

⟨ pictures of propagation path models ⟩

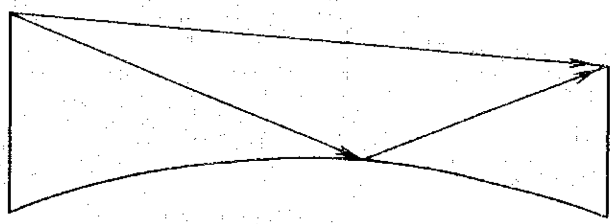


(1) free space model



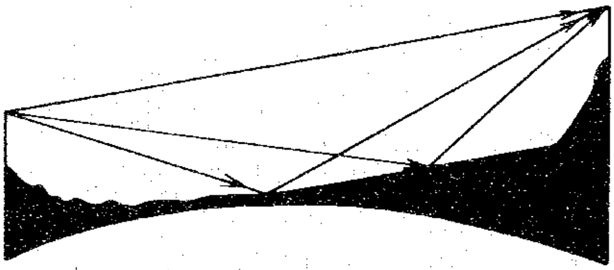
(2) smooth and plane ground reflection model

(3) rough and plane ground
reflection model

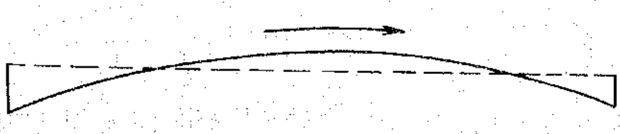


(4) smooth and spherical ground
reflection model

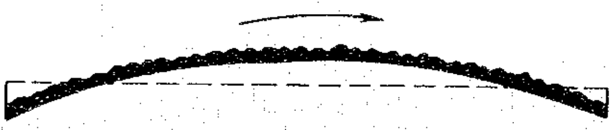
(5) rough and spherical ground
reflection model



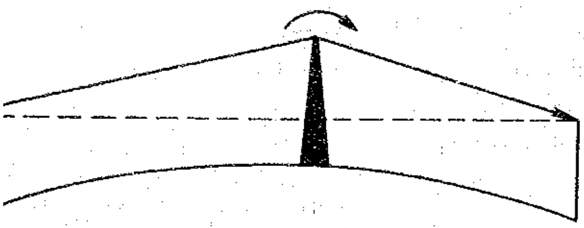
(6) multi path reflection model



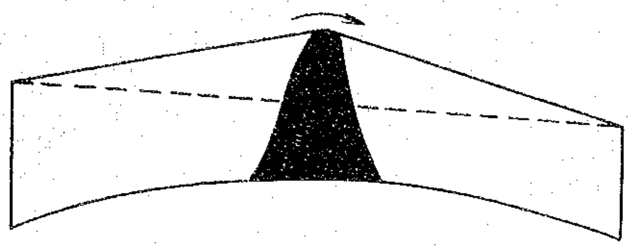
(7) smooth and spherical ground
diffraction model



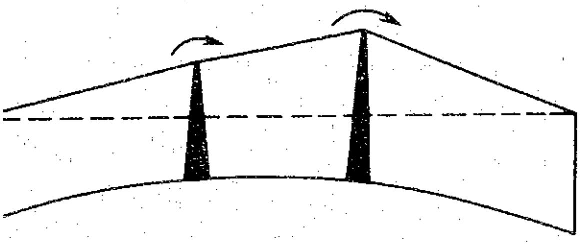
(8) rough and spherical ground
diffraction model



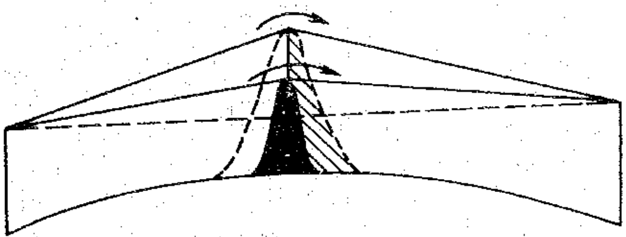
(9) single knife edge diffraction model



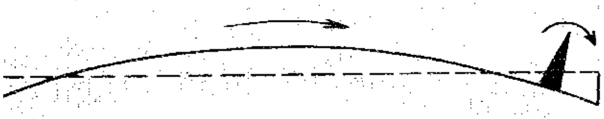
(10) single circular ridge diffraction model



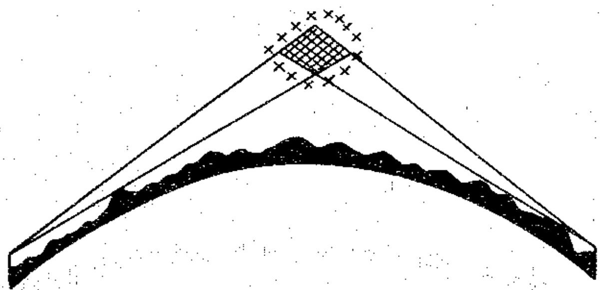
(11) multi ridge diffraction model



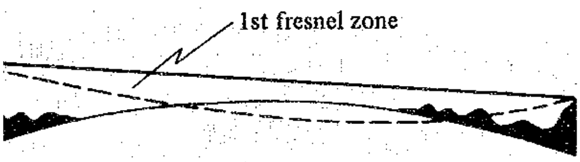
(12) slant ridge diffraction model



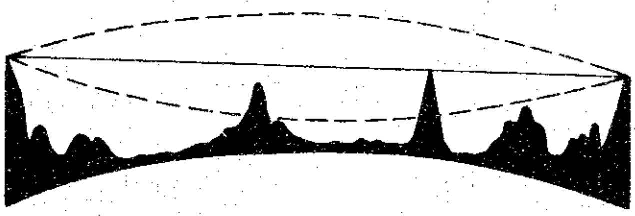
(13) multi diffraction model



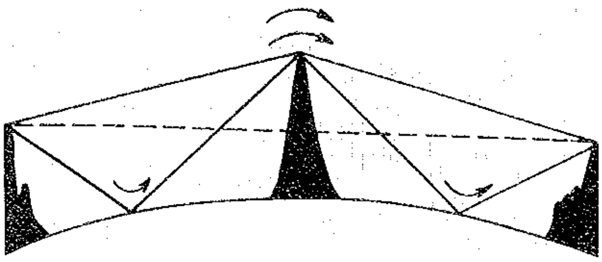
(14) tropospheric scattering model



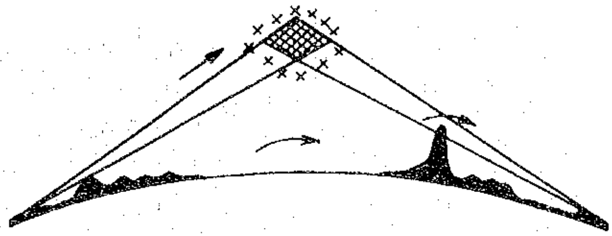
(15) near horizon model



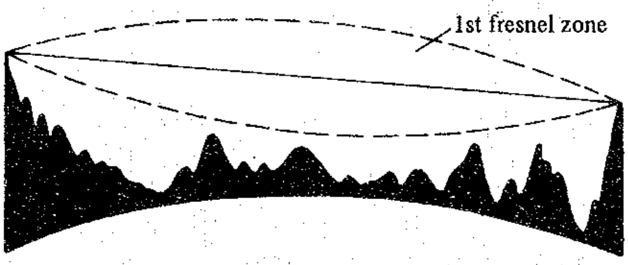
(16) near ridge model



(17) diffraction, reflection model



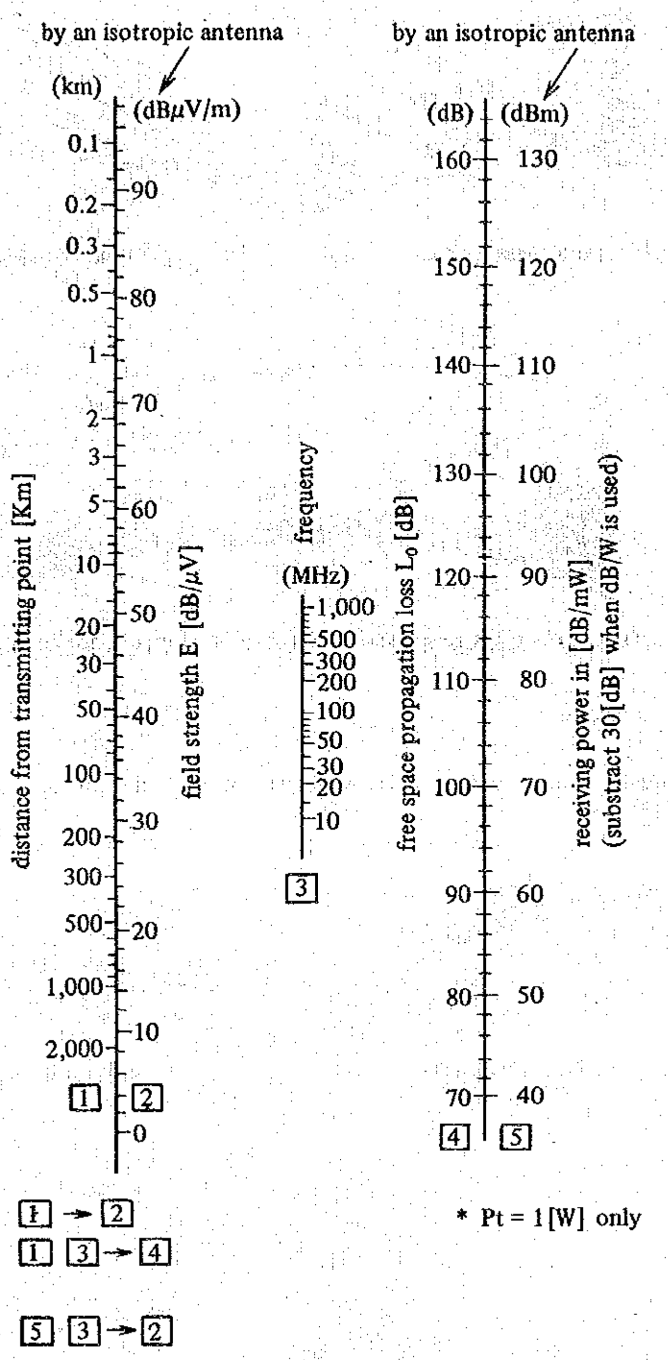
(18) scattering, diffraction model



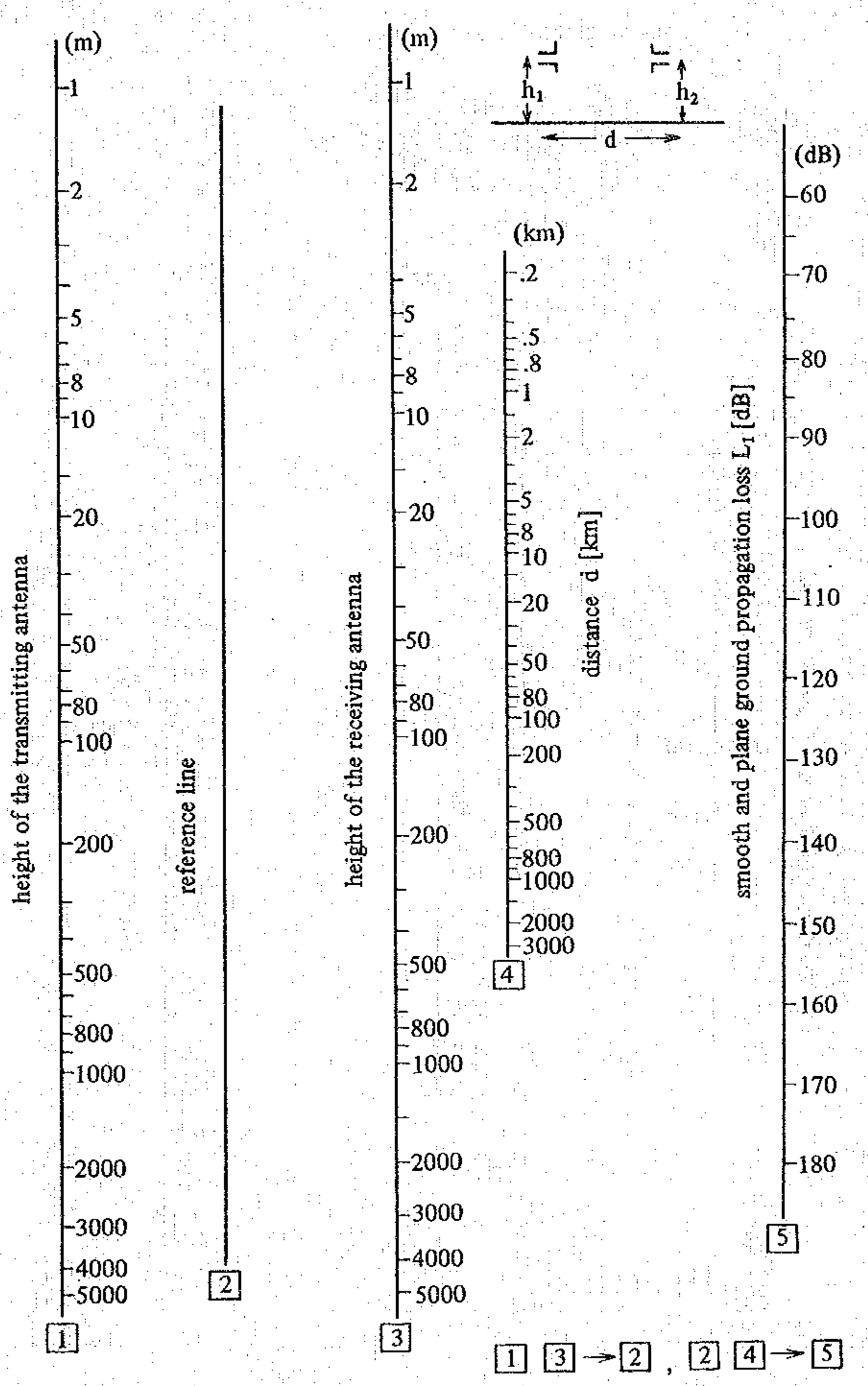
(19) effective free space model (no reflection and no diffraction)

14. Other useful Nomograms

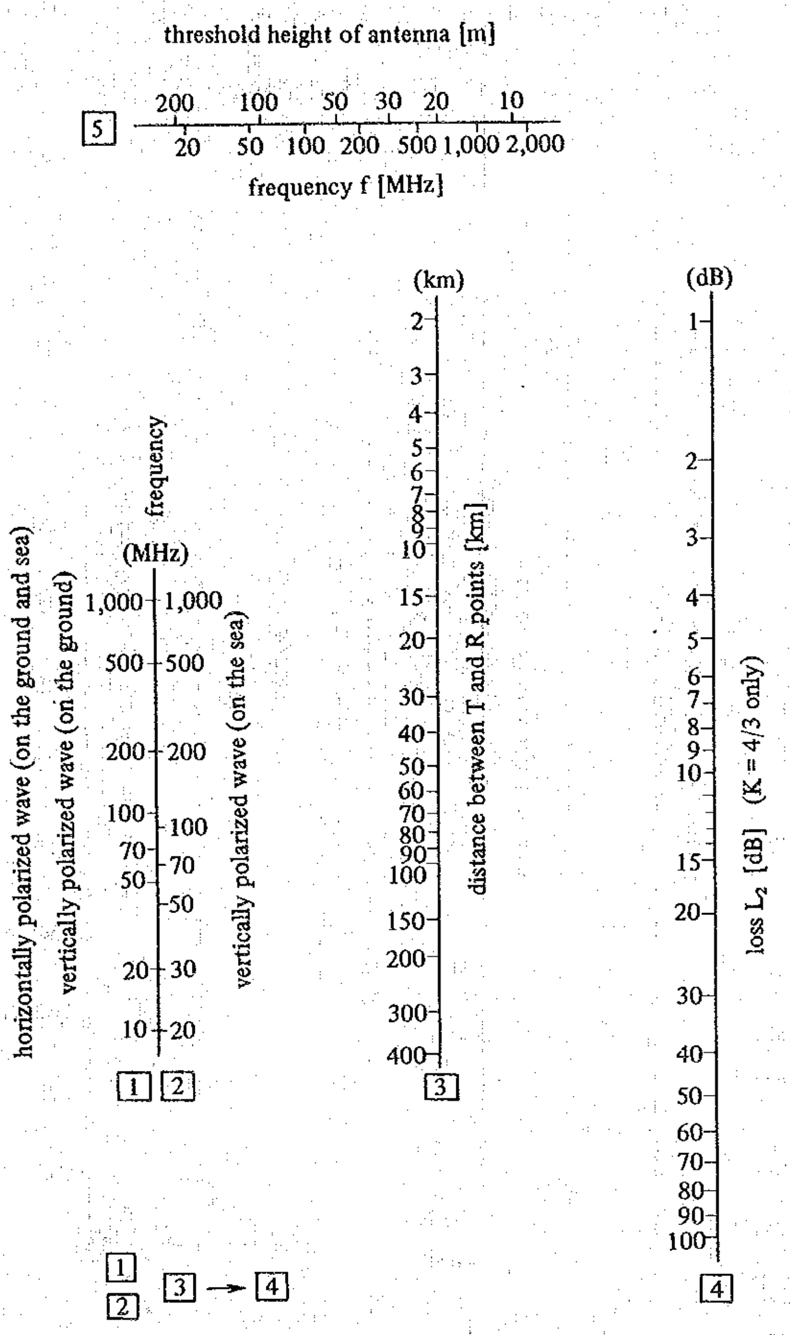
When we calculate the link budget, it is helpful to use such the nomograms as shown by the table (6) to (12).



Nomogram for the free space propagation loss L_0 [dB] and field strength E [dB/μV] by the transmitting power of 1 [W]

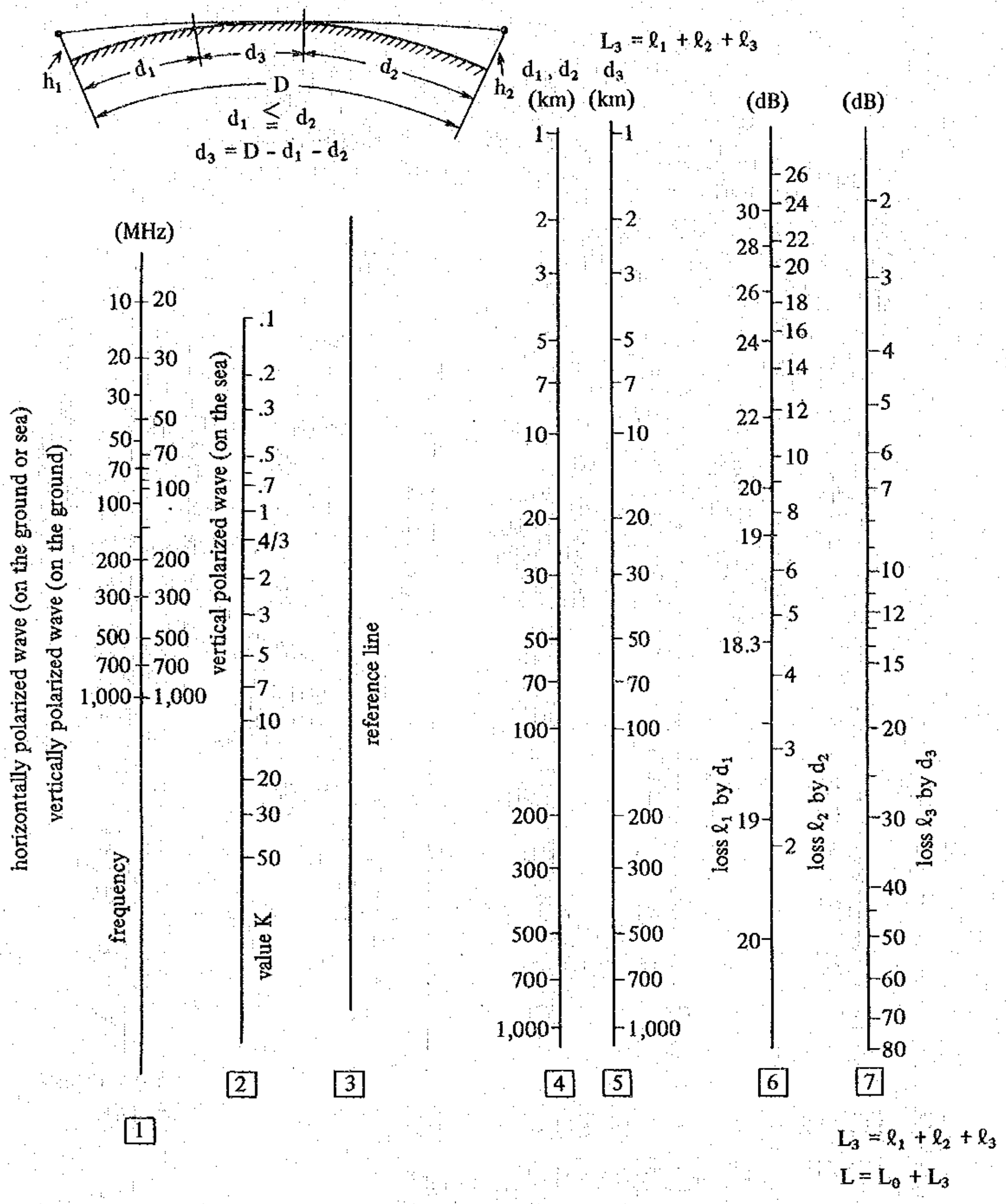


Nomogram for the smooth and plane ground propagation (in sight) loss L_1 [dB]

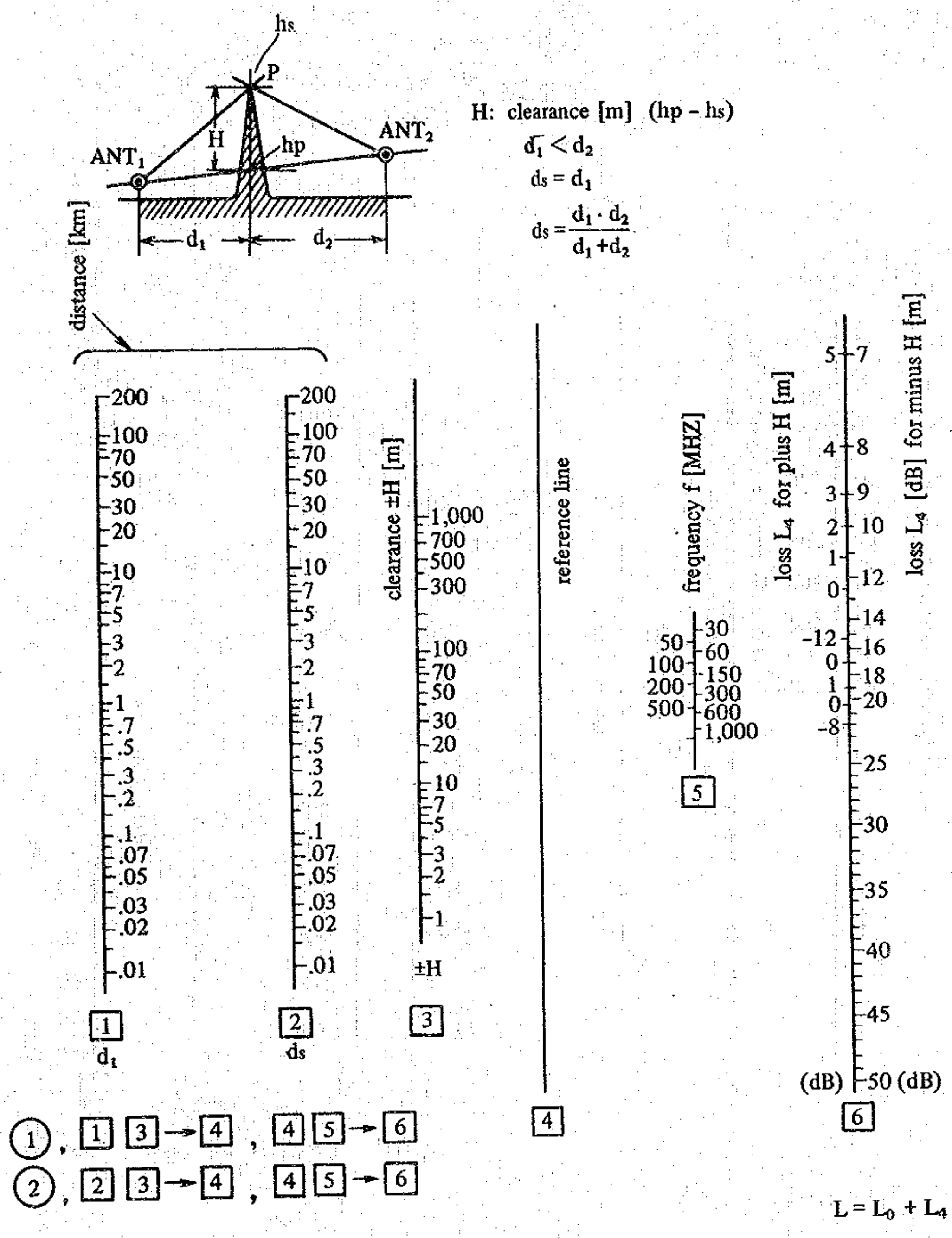


$L = L_0 + L_2$

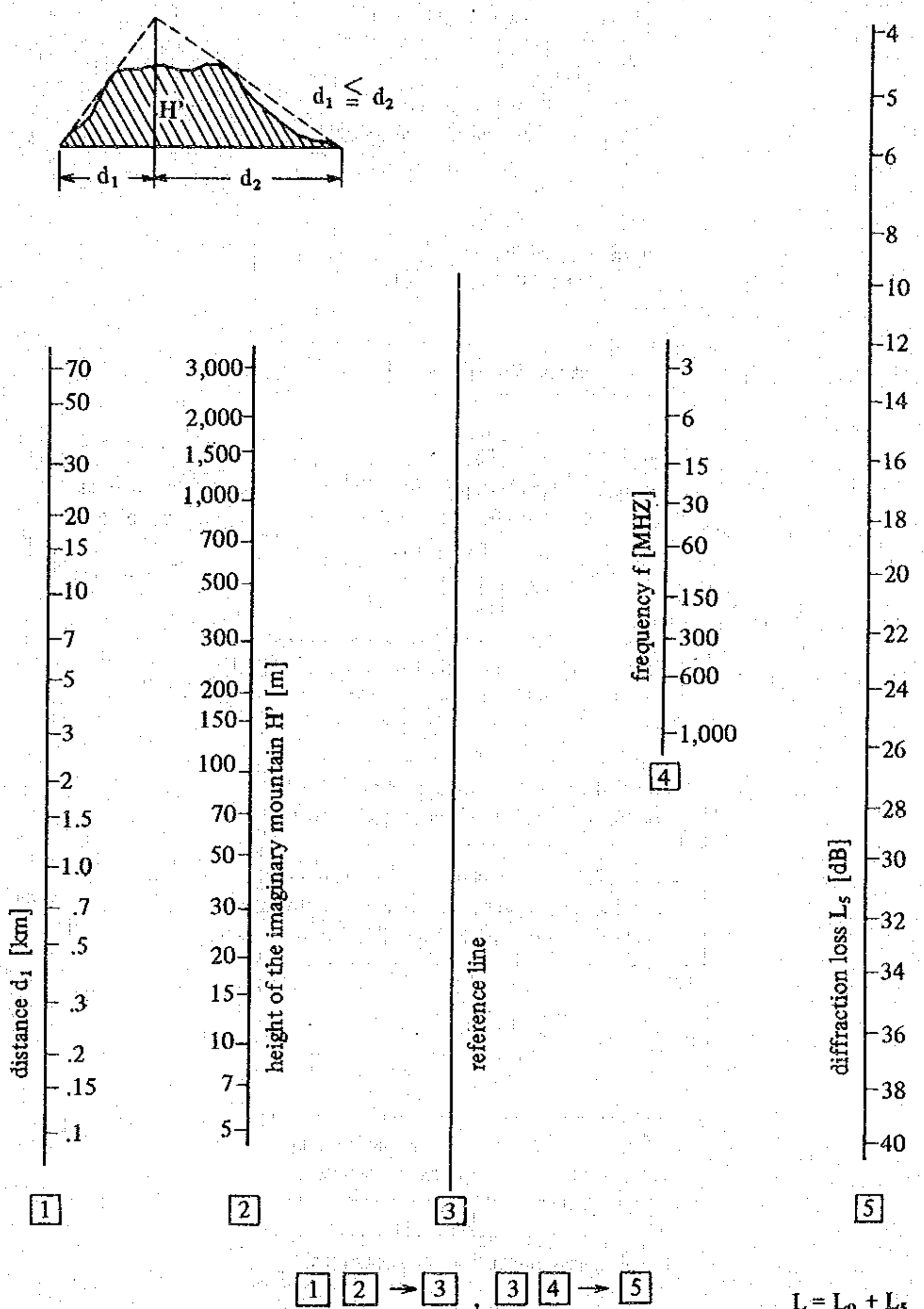
Nomogram for additional loss L_2 [dB] on the spherical ground propagation (in sight) table (9)



Nomogram for additional loss L_3 [dB] on the smooth spherical ground propagation path (out of sight)



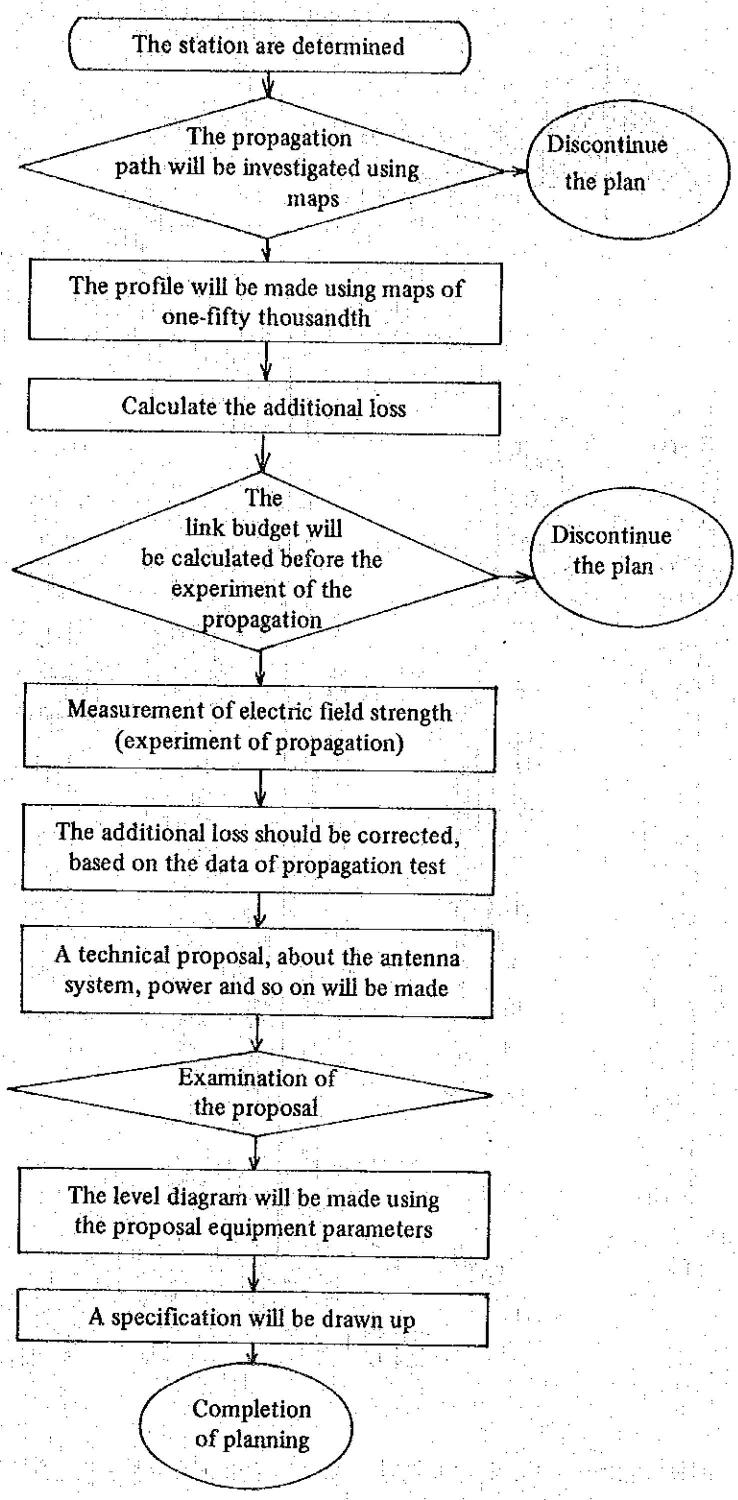
Nomogram for the diffraction loss L_4 [dB] by a knife edge



$L = L_0 + L_5$

Nomogram for the diffraction loss by a lengthy top mountain propagation path

Flow diagram for an arrangement of a circuit planning table (12)



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