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Procedure for determination of territorial resources used by various types of transmitter emissions for radio licence fee calculation purposes

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1 Introduction

In all models for charging for use of the radio-frequency spectrum based on the transmitter emission's use of the multidimensional resource frequency/territory/time, it is necessary to determine the amount of territorial resources used by the emissions of every transmitter or network of transmitters. In automated spectrum management systems in which the process of frequency planning and frequency assignment to transmitters is carried out on the basis of complex and precise models for calculating radio-wave propagation conditions and the service areas of transmitters (or radio links), including through the use of digital topographical maps, such calculations do not present any difficulty and may be carried out automatically using the same models.

When the frequency planning and assignment process is not automated and is carried out manually on the basis of tables or graphs of geographical frequency separation, determining the territorial resources for the purposes of calculating fees for spectrum use becomes a separate task requiring some form of optimization with respect to the transmitters for the various classes of emission. A judicious trade-off between the accuracy and complexity of the calculations has to be found for the transmitters for each of the many different classes of emission, so that the calculations do not become excessively resource-consuming. The method set out below appears to fulfil these conditions to a large extent. It is based on extensive application of previously calculated tables and graphs. Its contents may also be used in developing the aforementioned automated calculation methods.

2 VHF/UHF sound and television broadcasting transmitters

### 2.1 Determination of service area radius

For sound and television broadcasting transmitters, the quantity of territorial resources used by the transmitter's emissions is perfectly expressed by the size of the transmitter's service area in km^2. If the relevant data have already been determined and are stored in the corresponding databases, they may be directly used to determine spectrum utilization fees. If the data are not available, calculations can be carried out on the basis of Recommendation ITU-R P.370, which contains radio-wave propagation curves and methods of using them to determine the distances at which the field strength takes on specific values adopted as minimum permissible values in accordance with Recommendation ITU-R BT.417.

The radio-wave propagation curves given as an example in Figures 1 and 2 (Figures 1a and 9 from Recommendation ITU-R P.370-7, respectively) represent field-strength values in the VHF and UHF bands in dB(μV/m) as a function of various parameters for land paths. They relate to transmitters with a power of 1 kW radiated by a half-wave dipole, and represent field-strength values exceeded

at 50% of locations (within any area of approximately 200 m x 200 m) and for 50% of the time. They correspond to different transmitting antenna heights and a receiving antenna height of 10 m. The curves are given for effective transmitting antenna heights between 37.5 m and 1 200 m. Intermediate values of transmitting antenna height may be obtained by linear interpolation. The curves correspond to a local terrain irregularity parameter of 50 m, in other words standard moderately rough terrain. For the purposes of this simplified method, it is proposed that these curves also be used for other types of terrain.

The effective height of the transmitting antenna h_{ef} is determined as its height over the average level of the ground between distances of 3 and 15 km from the transmitter in the direction of the receiver. The procedures for calculating the values of h_{ef} used to determine the service area radius are shown in § 2.2 below.

FIGURE 1a

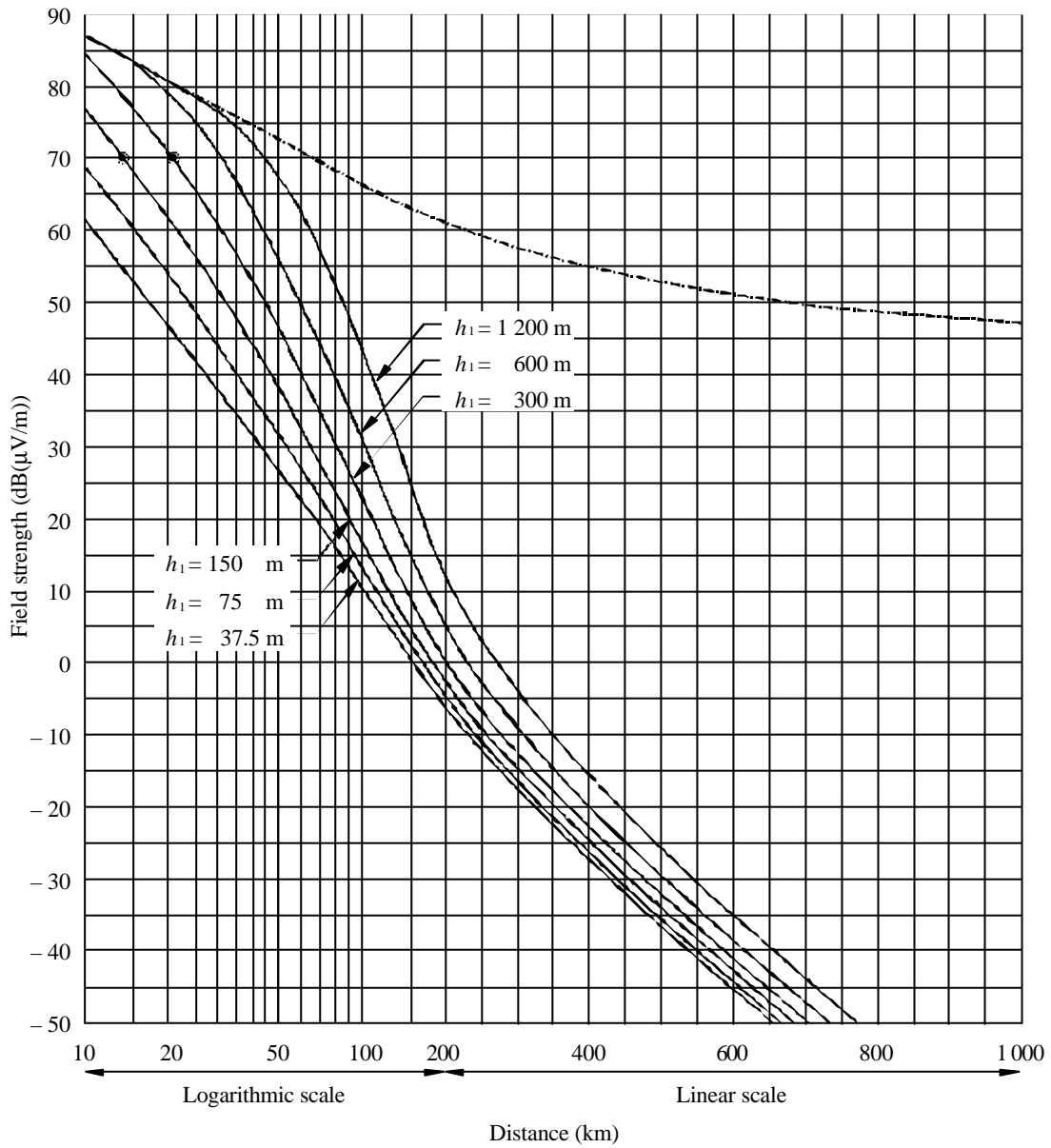**Field strength (dB(mV/m)) for 1 kW e.r.p.**
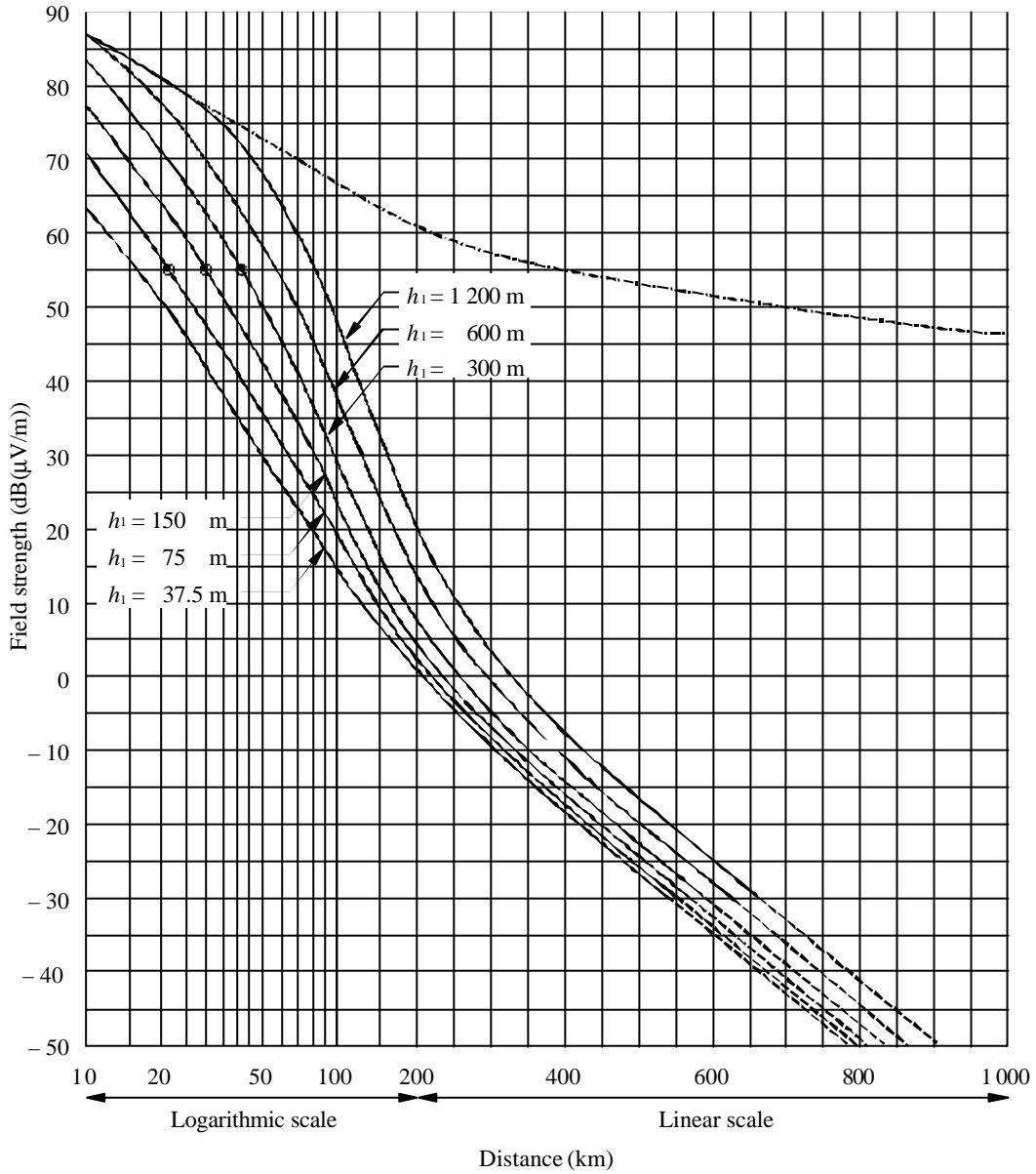
Frequency: 30-250 MHz (Bands I, II and III); land; 50% of the time;
50% of the locations; $h_2 = 10$ m; $\Delta h = 50$ m

------------------ Free space

FIGURE 1

Radiowave propagation curves for the band 30-250 MHz

FIGURE 9

Field strength (dB(mV/m)) for 1 kW e.r.p.

Frequency: 450-1 000 MHz (Bands IV and V); land; 50% of the time;
50% of the locations; $h_2 = 10$ m; $\Delta h = 50$ m

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FIGURE 2

Radiowave propagation curves for the band 450-1 000 MHz

The limits of the service area are determined by the values of minimum usable field strength E_{mu} generally used for frequency planning purposes. These values are shown in Table 1.

TABLE 1

Values of minimum usable field-strength E_{mu}

Frequency band	<76 MHz (TV)	76-108 MHz (TV)	108-230 MHz (TV)	230-528 MHz (TV)	>528 MHz (TV)	< 108 MHz (sound)
Emu (dB(µV/m))	48	52	55	65	70	54

The service area radiuses R obtained from the curves in Figures 1 and 2 for various values of effective radiated power (e.r.p.) P_{ef}, effective height of the transmitting antenna h_{ef} and the minimum usable field-strength values given in Table 1 are shown in Tables 2 to 7 below. E.r.p. is determined as follows:

$$P_{ef} = P + G_t + \text{?} \ (dBW) \tag{1}$$

where:

$\quad\quad$ P $\ =$ transmitter power in dB referred to 1 W, i.e. in dBW

$\quad\quad$ G_t $\ =$ antenna gain referred to a half-wave dipole in dB

$\quad\quad$ η $\ =$ feeder losses in dB.

For the purposes of this method, it is proposed to take η = 0 for all cases.

It should be noted that with large powers and low antennas, and especially at low frequencies, the calculated service area radius exceeds the distance to the radio horizon. Since quality of service deteriorates significantly beyond the radio horizon, this means that any excessive transmitter power is used to no effect. The relevant distances to the radio horizon, where they are smaller than the service area radiuses, are indicated by the second values in the boxes in Tables 2 to 4.

It should be pointed out that the data in Figures 1 and 2 correspond, without any rescaling, to the data in the 30 dBW rows in Tables 2 to 7 (since 1 kW corresponds to 30 dBW). For example, the distances corresponding to points on the curves in the figures and which may be read off from the x-axis are printed in bold type in the relevant row in Tables 4 and 6.

TABLE 2

Service area radius in km for television at frequencies below 76 MHz , E_{mu} = 48 dB(μV/m)

h_{ef} (m) \ P_{ef} (dBW)	30	50	75	100	150	200	250	300	350	400	500
15.0	9.1	11.9	14.5	16.3	20.2	22.8	25.7	29.0	30.7	32.6	36.4
20.0	11.9	15.1	18.5	20.5	25.4	28.7	32.5	36.6	38.5	40.6	45.6
25.0	15.2	19.3	23.2	25.7	32.1	36.3	40.5	45.0	47.5	50.2	56.1
30.0	19.7	24.4	28.9	32.4	40.4	44.9	49.7	54.2	57.1	60.1	66.8
35.0	25.5	30.6	36.5	40.5	50.2	55.0	59.5	64.8	68.2	71.6	78.8
40.0	32.5	38.3	45.8	50.8	60.7	65.7	71.0	76.2	79.7	83.7	91.1
43.0	37.4/ 35.6	43.7/ 42.2	52.2/ 48.7	57.2/ 54.2	67.2/ 63.5	72.7/ 71.3	78.1	83.6	87.7	91.4	98.5
46.0	43.0/ 35.6	50.0/ 42.2	58.7/ 48.7	64.2/ 54.2	74.6/ 63.5	80.3/ 71.3	86.3/ 78.2	91.8/ 84.4	95.4/ 90.1	99.0/ 95.4	108.2/ 105.2
50.0	52.2/ 35.6	59.5/ 42.2	69.2/ 48.7	74.8/ 54.2	86.1/ 63.5	92.0/ 71.3	97.3/ 78.2	102.9/ 84.4	107.9/ 90.1	112.7/ 95.4	121.8/ 105.2
55.0	66.4/ 35.6	74.5/ 42.2	85.0/ 48.7	91.4/ 54.2	101.8/ 63.5	109.2/ 71.3	115.7/ 78.2	121.3/ 84.4	126.0/ 90.1	130.4/ 95.4	138.9/ 105.2
60.0	85.4/ 35.6	93.6/ 42.2	103.7/ 48.7	111.3/ 54.2	124.3/ 63.5	130.2/ 71.3	135.2/ 78.2	139.7/ 84.4	144.0/ 90.1	148.1/ 95.4	158.7/ 105.2

TABLE 3

Service area radius in km for television in the frequency band 76-108 MHz, E_{mu} = 52 dB(μV/m)

h_{ef} (m) \ P_{ef} (dBW)	30	50	75	100	150	200	250	300	350	400	500
15.0	7.3	9.6	12.2	13.5	16.8	18.9	21.3	24.1	25.4	26.9	30.1
20.0	9.5	12.6	15.2	17.1	21.2	23.9	27.0	30.3	32.2	34.1	38.1
25.0	12.6	16.0	19.3	21.5	26.6	29.9	34.1	38.1	40.1	42.5	47.8
30.0	16.1	20.2	24.2	26.9	33.7	37.9	42.3	46.8	49.3	52.2	58.1
35.0	20.7	25.5	30.2	33.9	42.1	46.9	51.6	56.2	59.1	62.4	69.0
40.0	26.8	32.1	38.1	42.5	52.3	57.0	61.8	67.1	70.5	73.9	81.2
43.0	31.0	36.7	43.8	48.7	58.5	63.4	68.7	74.0	77.4	81.0	88.6
46.0	35.7/ 35.6	42.8/ 42.2	50.0/ 48.7	55.1/ 54.2	65.0/ 63.5	70.2	75.7	80.8	85.0	88.9	96.0
50.0	43.0/ 35.6	50.0/ 42.2	58.7/ 48.7	64.2/ 54.2	74.6/ 63.5	80.3/ 71.3	86.3/ 78.2	91.8/ 84.4	95.4/ 90.1	99.0/ 95.4	108.2/ 105.2
55.0	54.8/ 35.6	62.3/ 42.2	72.0/ 48.7	77.6/ 54.2	89.1/ 63.5	94.9/ 71.3	100.0/ 78.2	106.6/ 84.4	111.5/ 90.1	116.3/ 95.4	125.2/ 105.2
60.0	69.6/ 35.6	77.9/ 42.2	89.2/ 48.7	94.5/ 54.2	106.3/ 63.5	113.4/ 71.3	119.6/ 78.2	125.0/ 84.4	129.6/ 90.1	134.0/ 95.4	142.3/ 105.2

TABLE 4

Service area radius in km for television in the frequency band 108-230 MHz,
E_{mu} = 55 dB(μV/m)

h_{ef} (m) P_{ef} (dBW)	30	50	75	100	150	200	250	300	350	400	500
15.0	5.9	8.2	10.4	11.8	14.5	16.3	18.4	20.9	22.1	23.3	26.1
20.0	8.3	10.7	13.4	14.0	18.5	20.8	23.5	26.5	28.0	29.5	33.2
25.0	10.6	13.8	16.8	18.8	23.3	26.2	29.5	33.4	35.3	37.3	41.7
30.0	13.9	17.6	**21.2**	23.6	**29.1**	33.1	37.2	**41.4**	43.8	46.3	52.0
35.0	17.9	22.3	26.5	29.4	37.0	41.3	45.9	50.4	53.2	56.1	62.4
40.0	23.1	28.0	33.3	37.2	45.9	50.9	55.6	60.0	63.5	66.9	73.8
43.0	26.8	32.1	38.1	42.5	52.3	57.0	61.8	67.1	70.5	73.9	81.2
46.0	31.0	36.7	43.8	48.7	58.5	63.4	68.7	74.0	77.4	81.0	88.6
50.0	37.4/ 35.6	43.7/ 42.2	52.2/ 48.7	57.2/ 54.2	67.2/ 63.5	72.7/ 71.3	78.1	83.6	87.7	91.4	98.5
55.0	47.4/ 35.6	54.8/ 42.2	63.8/ 48.7	69.2/ 54.2	80.0/ 63.5	86.2/ 71.3	91.9/ 78.2	96.9/ 84.4	100.7/ 90.1	105.7/ 95.4	115.0/ 105.2
60.0	60.1/ 35.6	68.0/ 42.2	77.7/ 48.7	84.2/ 54.2	95.2/ 63.5	100.8/ 71.3	107.8/ 78.2	114.0/ 84.4	118.8/ 90.1	123.3/ 95.4	132.0/ 105.2

TABLE 5

Service area radius in km for television in the frequency band 230-528 MHz,
E_{mu} = 65 dB(μV/m)

h_{ef} (m) P_{ef} (dBW)	30	50	75	100	150	200	250	300	350	400	500
15.0	3.0	3.9	5.0	5.9	8.0	9.7	11.3	12.8	13.3	14.0	16.0
20.0	3.9	5.3	7.0	8.1	11.1	12.6	14.1	16.0	17.1	18.2	21.0
25.0	5.3	7.2	9.5	10.9	13.8	15.5	17.8	20.1	21.6	23.2	26.7
30.0	7.1	9.5	12.2	13.7	17.3	19.5	22.2	25.1	26.9	28.7	32.7
35.0	9.4	12.2	15.0	17.0	21.4	24.1	27.3	30.6	32.7	34.8	39.2
40.0	12.0	15.0	18.8	21.0	26.1	29.4	33.1	37.0	39.2	41.6	46.7
43.0	13.6	17.3	21.3	23.8	29.4	33.1	37.0	41.1	43.6	46.1	51.2
46.0	15.4	19.6	24.2	26.9	33.0	37.0	41.2	45.6	48.1	50.7	56.1
50.0	18.7	23.5	28.4	31.6	38.5	43.0	47.4	51.8	54.5	57.3	63.3
55.0	23.8	29.1	35.0	38.6	46.5	51.0	55.6	60.0	63.3	66.7	73.3
60.0	30.5	36.4	42.8	47.0	55.1	59.8	64.9	70.0	73.3	76.7	83.8

TABLE 6

Service area radius in km for television at frequencies above 528 MHz, E_{mu} = 70 dB(μV/m)

h_{ef} (m) P_{ef} (dBW)	30	50	75	100	150	200	250	300	350	400	500
15.0	2.3	3.0	3.7	4.2	5.6	6.2	7.1	9.5	10.1	10.4	11.2
20.0	3.0	3.9	5.0	5.9	8.0	9.7	11.3	12.8	13.3	14.0	16.0
25.0	3.9	5.3	7.0	8.1	11.1	12.6	14.1	16.0	17.1	18.2	21.0
30.0	5.3	7.2	9.5	10.9	**13.8**	15.5	17.8	**20.1**	21.6	23.2	26.7
35.0	7.1	9.5	12.2	13.7	17.3	19.5	22.2	25.1	26.9	28.7	32.7
40.0	9.4	12.2	15.0	17.0	21.4	24.1	27.3	30.6	32.7	34.8	39.2
43.0	10.8	13.9	17.3	19.3	24.1	27.2	30.6	34.4	36.5	38.8	43.7
46.0	12.5	15.8	19.5	22.0	27.2	30.6	34.3	38.3	40.6	43.1	48.1
50.0	14.7	18.8	23.2	25.8	31.8	35.6	39.7	44.1	46.6	49.1	54.5
55.0	18.7	23.5	28.4	31.6	38.5	43.0	47.4	51.8	54.5	57.3	63.3
60.0	23.8	29.1	35.0	38.6	46.5	51.0	55.6	60.0	63.3	66.7	73.3

TABLE 7

Service area radius in km for sound broadcasting at frequencies below 108 MHz, E_{mu} = 54 dB(μV/m)

h_{ef} (m) P_{ef} (dBW)	30	50	75	100	150	200	250	300	350	400	500
15.0	6.3	8.6	11.0	12.4	15.1	17.1	19.3	22.0	23.2	24.4	27.4
20.0	8.7	11.3	13.9	15.4	19.3	21.8	24.5	27.7	29.3	31.0	34.8
25.0	11.3	14.5	17.7	19.6	24.3	27.4	30.9	35.0	36.9	38.9	43.6
30.0	14.5	18.5	22.2	24.6	30.5	34.7	38.8	43.2	45.6	48.2	54.1
35.0	18.8	23.3	27.7	30.8	38.7	43.1	47.8	52.3	55.2	58.1	64.6
40.0	24.2	29.3	34.8	38.8	48.0	53.0	57.6	62.4	65.9	69.2	76.3
43.0	28.2	33.6	39.7	44.5	54.4	59.1	64.1	69.5	72.8	76.2	83.7
46.0	32.5	38.3	45.8	50.8	60.7	65.7	71.0	76.2	79.7	83.7	91.1

2.2 Determination of effective antenna height

As already stated, the effective height of the transmitting antenna h_{ef} is defined as its height over the average level of the ground between distances of 3 and 15 km from the transmitter in the direction of the receiver (see Figure 3), i.e.:

$$h_{ef} = h_s - h_{av} \tag{2}$$

where:

h_s = antenna height above sea level (i.e. the height of the antenna mast plus the altitude of the antenna site above sea level)

h_{av} = average level of the ground between distances of 3 and 15 km from the transmitter.

It should be borne in mind that what is significant is not the physical height (mast height) but the effective height of the antenna, since antennas are often installed on hilltops as high as or even much higher than the mast itself (see Figure 3).

The average level of the ground between distances of 3 and 15 km from the transmitter is determined from topographical maps (preferably with a scale of 1:200 000 or 1:500 000). Height readings must be taken from the maps in the given direction at intervals of 1 or 2 km between distances of 3 and 15 km from the transmitter, and the average level of the ground is calculated as the sum of all the readings divided by the number of readings.
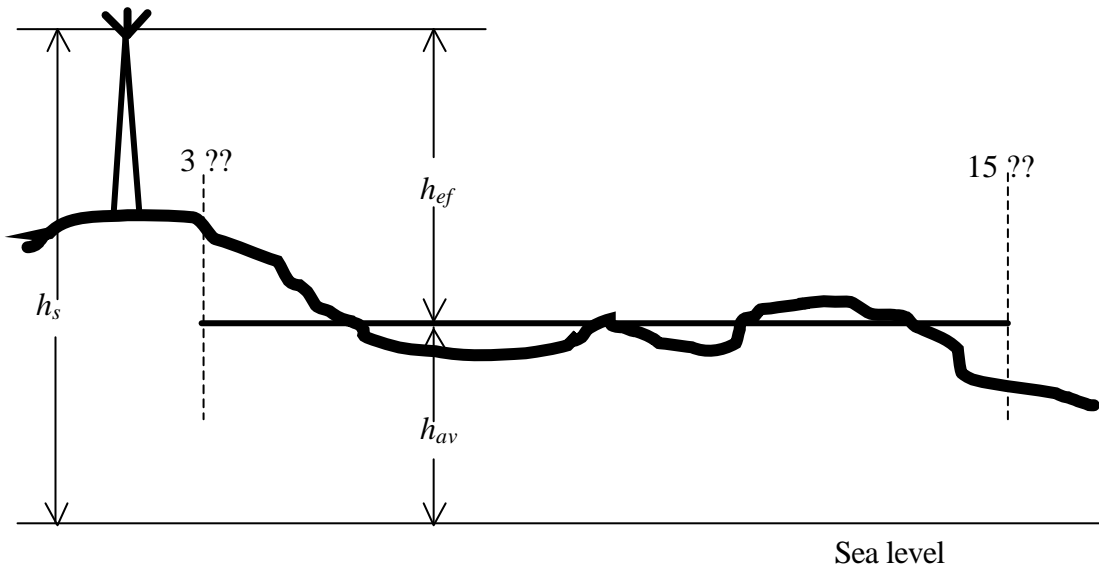
FIGURE 3

Determination of effective antenna height

Obviously, even with omnidirectional transmitting antennas, the actual service area will usually not be circular, since the average level of the ground between distances of 3 and 15 km from the transmitter in the different directions, and hence the corresponding effective antenna heights, will vary. Nevertheless, for the purposes of this method, a circular service area based on the effective antenna height calculation in one direction may be assumed in most cases. If an administration wishes to improve the accuracy of calculations in cases where the terrain profile in different directions from the antenna varies significantly, calculations may be carried out in relation to a particular average value of effective antenna height determined from four values obtained from the average levels of the ground in the longitudinal and latitudinal directions. An illustrative example of such calculations is given in Table 8.

TABLE 8

Example of effective antenna height calculation for very rough terrain

No.	Distance of the reading from the antenna (km)	Ground height readings (m)			
		North	South	East	West
1	3	250	240	300	240
2	4	240	220	300	220
3	5	220	180	290	200
4	6	230	180	280	170
5	7	240	160	270	160
6	8	260	140	260	180
7	9	260	120	250	200
8	10	280	120	230	250
9	11	280	110	220	250
10	12	280	100	210	240
11	13	290	100	200	200
12	14	300	80	200	180
13	15	320	60	200	140
	Sum of readings (S_d), m	3 450	1 810	3 210	2 630
	Effective heights ($S_d/13$), m	265	139	245	202
	Average effective height (h_{ef}), m	213			

2.3   Determination of service area

Having calculated the radius of the service area (R in km) by the methods set out in §§ 2.1 and 2.2 above, the service area can obviously be calculated as:

$$S = \pi R^2 \left(km^2\right) \tag{3}$$

It can happen that the service area contains two (see example in Figure 4) or even three (see example in Figure 5) segments belonging to different categories for the purposes of spectrum usage fees. Such a situation may also arise on a country's border with other countries. The simplified method described below may be used to calculate the areas of the different segments of the service area belonging to different fee categories.

The actual curved edges of the different segments in the service area are approximated with straight lines plotted such that the areas of the different segments lying either side of the approximation line are roughly equal (see Figures 4 and 5). The approximation line between segments S_2' and S_3 in Figure 5 must run along the radius of the service area, as shown in Figure 5.
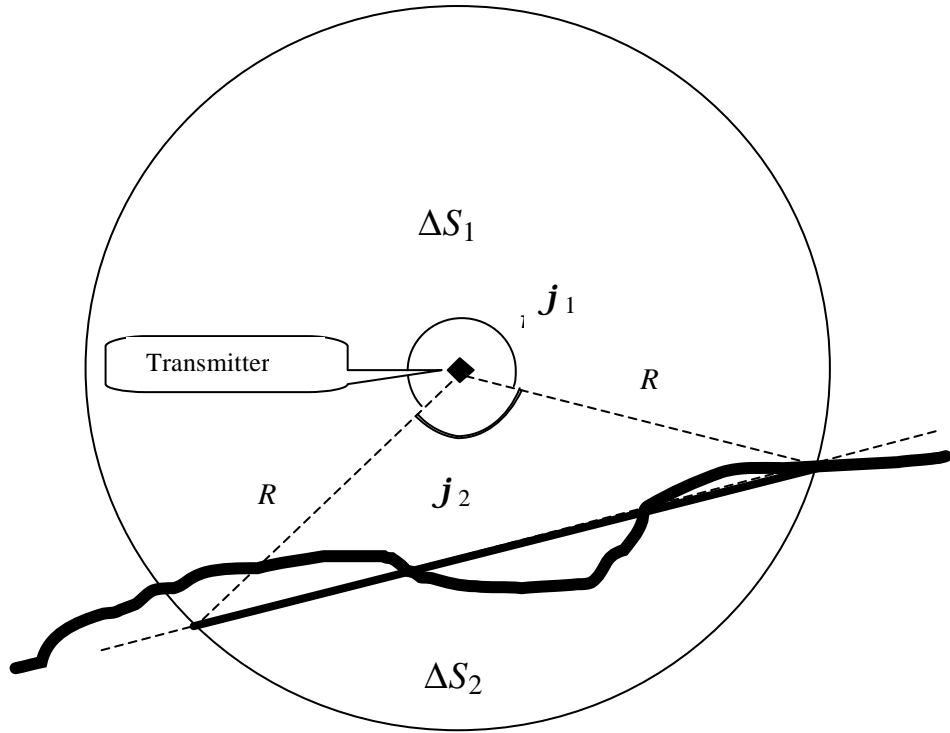
FIGURE 4
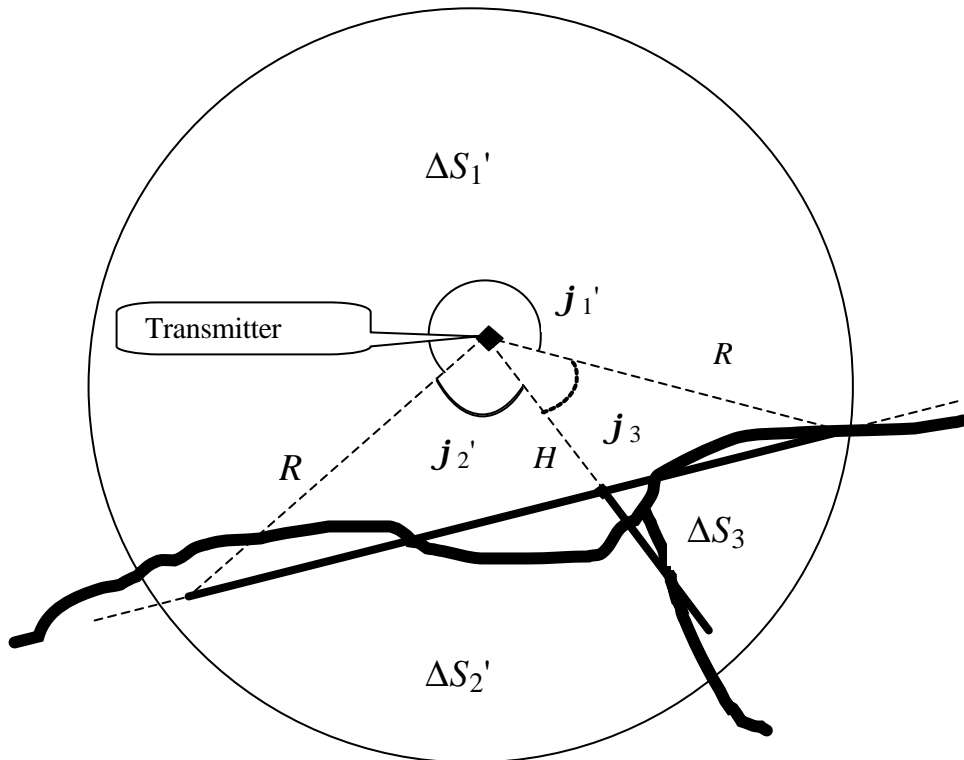
Example with two different segments in the service area

FIGURE 5

Example with three different segments in the service area

The area ΔS_2 of segment S_2 for the case with two segments (Figure 4) is determined by:

$$\Delta S_2 = \frac{R^2}{2}\left(\frac{\pi\varphi_2}{180} - \sin\varphi_2\right) \tag{4}$$

where:

φ_2 = angle of the corresponding sector (see Figure 4),

while the area ΔS_1 of the segment S_1 is determined by:

$$\Delta S_1 = \pi R^2 - S_2 \tag{5}$$

With three segments (Figure 5), the segments S_2' and S_3 of the total sector ($S_2' + S_3$) have the following areas, respectively:

$$\Delta S_2' = \frac{R^2}{2}\left(\frac{\pi\varphi_2'}{180} - \Psi\sin\varphi_2'\right) \tag{6}$$

$$\Delta S_3 = \frac{R^2}{2}\left(\frac{\pi\varphi_3}{180} - \Psi\sin\varphi_3\right) \tag{7}$$

$$\Psi = \frac{H}{R}$$

where:

H = distance from the transmitter to the intersection of the approximation lines (see Figure 5) in km

φ_2' and φ_3 = angles of the respective sectors (see Figure 5) in degrees,

then:

$$\Delta S_1' = \pi R^2 - \Delta S_2' - \Delta S_3 \tag{8}$$

As an example, we shall calculate the relative areas of the three segments for the case depicted in Figure 5. In this figure, $\varphi_2' = 88°$, $\varphi_3 = 39°$ and $\Psi = 0.51$.

Then, from (6), (7) and (8), it follows that: $\Delta S_2' = 0.51R^2, \Delta S_3 = 0.18R^2, \Delta S_1' = 2.45R^2$.

3   Transmitters in the land mobile service

3.1   Basic calculation method

The method follows the radio-wave propagation models known as the modified Okumura-Hata model, the basis of which is set out in Recommendation ITU-R P.529-2. The model assumes the presence of homogeneous urban buildings within the service area, no line-of-sight visibility between the transmitter of the base station and the mobile personal receiver, and transmitting and receiving antenna heights within the range 20-200 m (although in most cases 40-100 m) and 1.5-10 m, respectively.

Considering, for the purposes of this method, that feeder losses in the transmitting and receiving antennas are 0, the signal power P_r (in dB relative to 1W) at the receiver input may be represented as follows:

$$P_r = P_t + G_t + G_r - L(R), \text{ dBW} \tag{9}$$

where:

P_t = transmitter power, dBW

G_t = transmitter antenna gain, dB

G_r = receiver antenna gain, dB

L(R) = transmission losses between the receiver and transmitter, dB.

In order to provide the required signal quality at the edge of the service area, the following condition must be met:

$$P_r = P_{min} + k_f s$$

where:

P_{min} = minimum power of the received signal, equal to the sensitivity of the receiver in dBW

k_f = signal fade tolerance for a given signal quality degradation time

σ = r.m.s. value of signal fluctuations in dB.

For 50% of the time $k_f = 0$; for 95% of the time $k_f = 1.65$. For common urban areas, σ fluctuates within the range 6-8 dB. Taking it, as with broadcasting, that the service area is determined by the 50% of the time criterion, then $k_f = 0$, the product $k_f \sigma$ becomes 0, and:

$$P_r = P_{min} \tag{10}$$

Equating the right-hand sides of equations (9) and (10) in order to satisfy the signal reception quality condition at the edge of the service area, we obtain:

$$P_t + G_t + G_r - L(R) = P_{min}$$

or:

$$L(R) = P_t + G_t + G_r - P_{min} \tag{11}$$

According to the modified Okumura-Hata propagation model, for the median value of signal field strength (i.e. for 50% of the time):

$$L(R) = u + x \log R \tag{12}$$

where υ and ξ are coefficients in dB, the magnitudes of which depend on frequency and transmitter and receiver antenna heights. For common urban areas:

$$x = 44.9 - 6.55 \, log \, h_t \tag{13}$$

$$u = 65.55 - 6.16 \, log \, f + 13.82 \, log \, h_t + a_r(h_r) \text{ for } f \leq 1 \text{ GHz} \tag{14}$$

$$u = 46.3 - 33.9 \, log \, f + 13.82 \, log \, h_t + a_r(h_r) \text{ for } f \geq 1.5 \text{ GHz} \tag{15}$$

where:

f = working frequency, MHz

h_t = effective height of transmitting antenna, m

h_r = effective height of receiving antenna, m

$$a_r(h_r) = (1.1 log f - 0.7)h_r - (1.56 log f - 0.8), dB$$

In accordance with Recommendation ITU-R P.529-2, the effective height of the transmitting antenna is determined in accordance with the method given in Recommendation ITU-R P.370, in other words we follow the method described in § 2.2 above. However, bearing in mind that nowadays base stations in the mobile service are not so powerful and that the corresponding service areas are thus smaller, for the overwhelming majority of cases in towns located on flat terrain the effective heights of the transmitting antennas may be approximated to their heights above the ground level at their location. In accordance with Recommendation ITU-R P.529-2, the antenna height of a mobile or portable station is taken as its height above ground.

Following equations (11)-(15), the radius of the service area R may be calculated as:

$$R = 10^{\left(\frac{z - \vartheta}{\xi} \right)} \qquad (16)$$

where:

z is an easy to calculate generalized energy parameter in dB, determined by:

$$z = P_t + G_t + G_r - P_{\min} \qquad (17)$$

Graphs for the functions $R = f(z)$ calculated using equations (16) and (17) for frequencies below 1 GHz and above 1.5 GHz are given in Figures 6-7 and 8-9, respectively. Figures 6 and 8 relate to transmitter antenna heights (h_t) of 40 m, and Figures 7 and 9 to heights of 100 m. In all the figures, line 1 relates to receiving antenna heights (h_r) of 1.5 m, line 2 to heights of 10 m. Line 2 also makes it possible to use these graphs also for calculations in relation to fixed VHF/UHF radio systems and with "point-to-area" programme distribution systems, with community receiving antennas installed on building roofs. Line 3 plots the functions for free-space propagation conditions. These lines may be used for calculations relating to short fixed VHF/UHF radio links with line-of-site. For other values of antenna height within the above ranges, the service area radius can be obtained from the graphs in Figures 6 to 9 by interpolation.

A few typical values of the parameters in equation (17) for a range of land mobile radiocommunication systems, including digital enhanced cordless telecommunications (DECT) and private mobile radio (PMR) are given in Table 9.

TABLE 9

Parameters for different systems

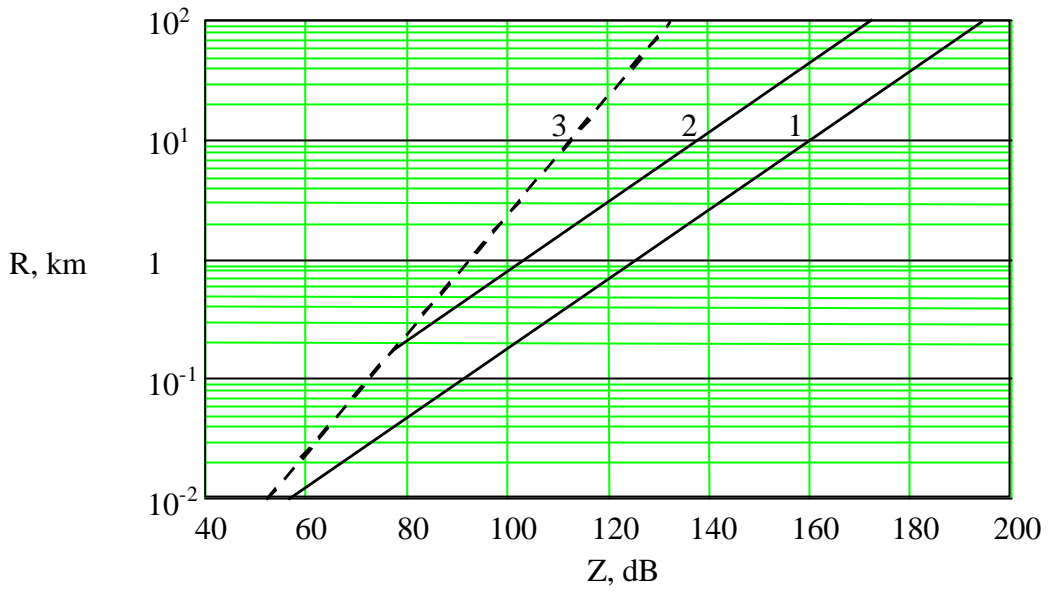| Parameter/system	CDMA	GSM	AMPS	NMT	DECT	PMR
Transmitting antenna gain (G_t), dB	13	18	17	10-17	3	6-15
Receiving antenna gain (G_r), dB	0	0	0	6	3	3-6
Receiver sensitivity ($P_{\min}$), dBW	−147	−138	−146	−115	−112	−110

FIGURE 6

**Calculated service area radius for frequencies below 1 000 MHz, h_t = 40 m
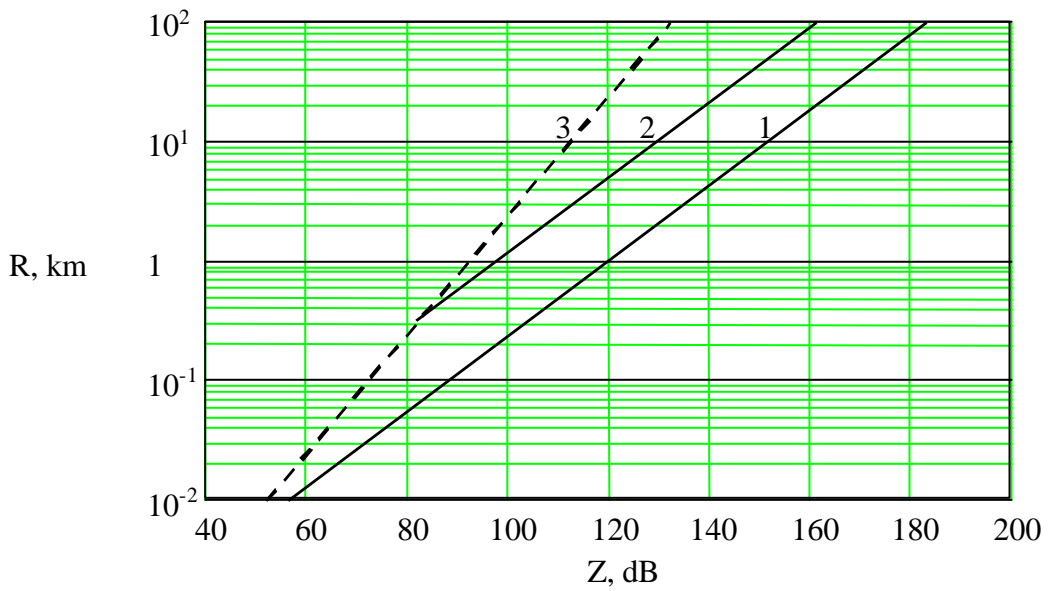1: h_r = 1.5 m, 2: h_r = 10 m, 3: free-space propagation**

FIGURE 7

**Calculated service area radius for frequencies below 1 000 MHz, h_t = 100 m
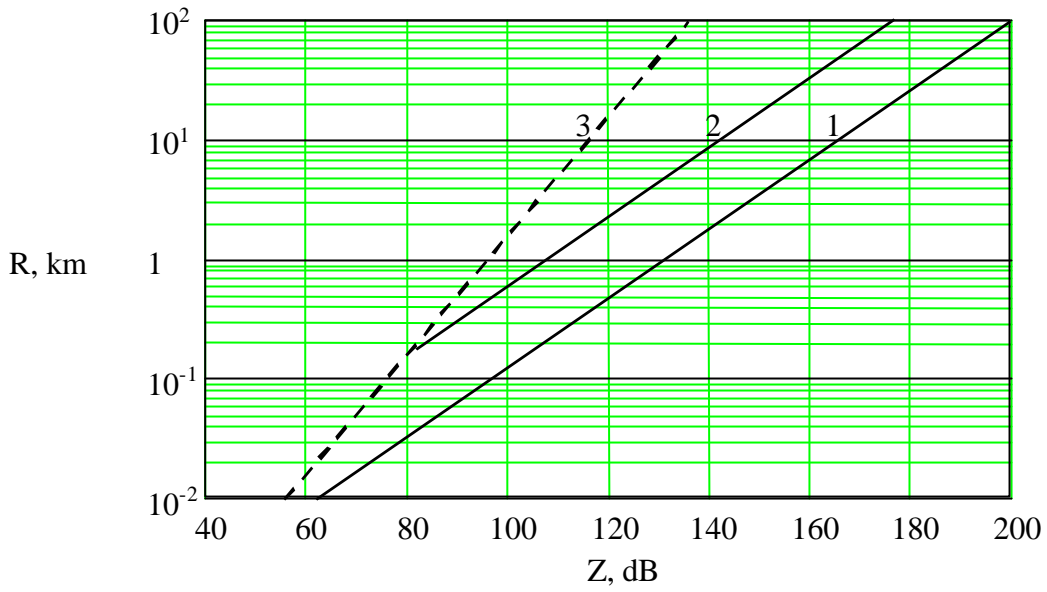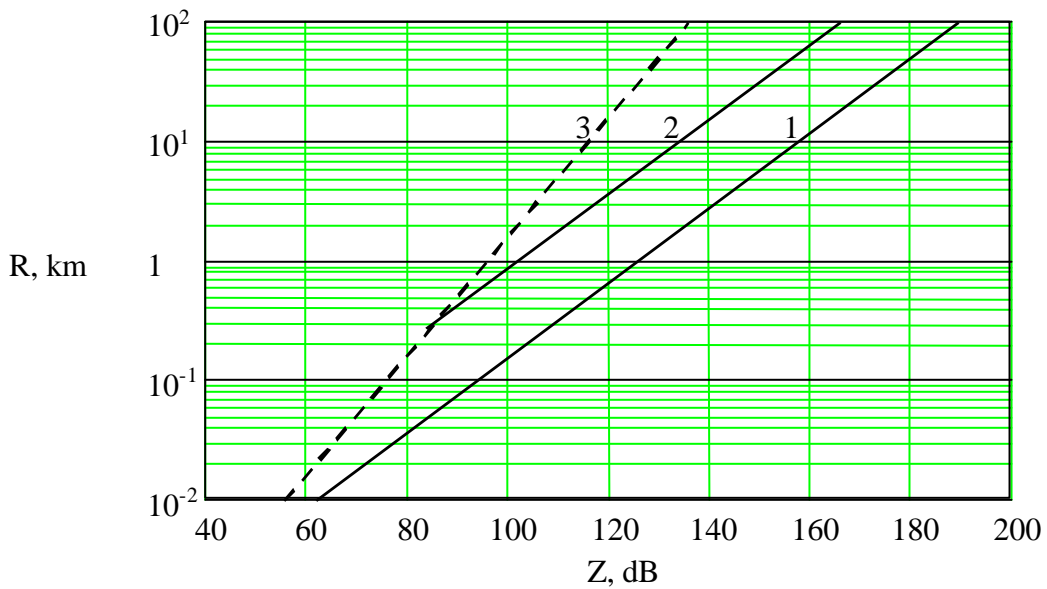1: h_r = 1.5 m, 2: h_r = 10 m, 3: free-space propagation**

FIGURE 8

Calculated service area radius for frequencies below 1 500 MHz, $h_t = 40$ m
1: $h_r = 1.5$ m, 2: $h_r = 10$ m, 3: free-space propagation

FIGURE 9

Calculated service area radius for frequencies below 1 500 MHz, $h_t = 100$ m
1: $h_r = 1.5$ m, 2: $h_r = 10$ m, 3: free-space propagation

3.2   Calculation method

With the graphs in Figures 6-9, the calculation method becomes extremely simple. All we have to do is substitute in equation (17) the corresponding parameters from the national frequency assignment database (or, failing this, from Table 9), and compute the corresponding service area radius R for the calculated value of the parameter z directly on one of the graphs according to antenna height and working frequency. Given that the service areas of base stations in the land mobile service, and particularly in cellular systems, are relatively small, they are usually circumscribed within a single spectrum licence fee category. The area of the service area may thus usually be calculated from the simple equation (3).

4   Transmitters in the maritime mobile service

4.1   Basis for the calculation method

In accordance with the provisions of Recommendation ITU-R P.616, the service areas of coast and ship stations in the VHF band operating in the frequency band 156-174 MHz (Appendix S18 of the Radio Regulations) may be determined from the radio-wave propagation curves in Recommendation ITU-R P.370 - in other words on the same basis as for broadcasting (see § 2.1 above). The technical characteristics of the equipment are set out in Recommendation ITU-R M.489-2.

For ship stations with a non-directional transmitting antenna, the area of the service area (S) is given by:

$$S = \pi \, R_s{}^2 \ (\text{km}^2)$$
(18)

where:

R_s: Radius of the circular service area determined from the propagation curves in Recommendation ITU-R P.370 for the 30-250 MHz band; sea; 50% of the time; 50% of the locations (Figure 1b in Recommendation ITU-R P.370-7).

It should be pointed out that in this specific case the curves are the same for both cold and warm sea. The transmitting and receiving antenna heights may be considered to be equal to their actual height above sea level. To simplify use of the curves in Recommendation ITU-R P.370, the receiving antenna heights may be taken as 10 m in all cases. Nevertheless, it should be noted that to ensure equal radiocommunication conditions between coast and ship stations in both directions, the receiving antennas of the coast stations have the same height as the transmitting antennas. When calculating the actual heights of receiving antennas, corrections have to be introduced in accordance with the methods set out in Recommendation ITU-R P.370. For calculations specific to sea paths, it is also possible to use a universal correction factor of –5 dB for all distances.

For ship stations using non-directional antennas, it may be considered that half of the circular service area with a radius R_s, the actual service area itself, lies over the sea, and the other half with a radius R_l over land, such that:

$$S = 0.5 \, \pi \, (R_s{}^2 + R_l{}^2) \, (\text{km}^2)$$
(19)

where:

R_l: Radius of the area covered by the emission and lying over dry land, calculated from the radio-wave propagation curves in Recommendation ITU-R P.370 for the frequency band 30-250 MHz; land; 50% of the time; 50% of the locations (Figure 1a in Recommendation ITU-R P.370-7, reproduced in Figure 1 above).

For the land portion of the area, the effective antenna height is determined as indicated above for broadcasting (see § 2.2).

Since the maritime mobile service is one of the safety of life services, it must enjoy a high level of reliability. Thus, the minimum useable field strength at the edge of the service area is taken as 30 dB above the standard receiver sensitivity (2.0 μV in accordance with Recommendation ITU-R M.489-2), i.e. E_{mu} = 36 dB (μV/m).

On the basis of the above parameters and tolerances and assuming a gain of 6dB for all antennas, the radiuses of sea and land areas were calculated for different values of transmitter power from 10 to 50 W (maximum carrier power of coast station transmitters in accordance with Recommendation ITU-R M.489-2) and different effective antenna heights in Recommendation ITU-R P.370-7. The results of the calculations are shown in Table 10. The data for effective antenna heights of 9.5 and 19 m were obtained by graphical approximation, which is quite acceptable for the purposes of this method.

For coast stations located on the banks of rivers or relatively narrow lakes, the whole service area may be calculated as being over land, i.e.:

$$S = \pi\, R_l{}^2\ (km^2) \tag{20}$$

When directional transmitting antennas are used, the concept of "service sector" may be employed, as defined in Recommendation ITU-R F.162-3 (see § 6 below).

For HF radio links, the area covered may be calculated only within the boundaries of a country's territorial waters (usually 200 miles, i.e. around 360 km).

TABLE 3.2

Radiuses of sea and land areas (in km) for transmitters in the
maritime mobile service in the band 156-174 MHz

P(W)	H_{ef} (M) paths	9.5	19	37.5	75	150	300
10	land	11	16	21	28	37	50
	sea	19	25	33	43	55	72
20	land	13	18	23	32	44	57
	sea	21	28	37	50	62	80
30	land	15	20	26	34	45	61
	sea	23	30	41	54	68	87
40	land	17	22	28	36	48	64
	sea	25	32	47	57	72	92
50	land	18	23	30	38	50	66
	sea	26	33	46	60	76	96

4.2   Calculation method

For a known transmitter power and transmitter antenna height above sea level, the service area radius over the sea can be determined directly from Table 10. For intermediate values, linear interpolation can be used. For a known radius, the area of the service area of a ship station and the sea portion of the service area of a coast station can be calculated using equations (18) and (19). To determine the radius of the land portion of the service area of a coast station, it is first necessary to

determine the effective antenna height above the average level of the ground, as described in §2.2 above. In this case, the procedure can be simplified by calculating the average level of the ground only in one direction, perpendicular to the averaged coastline. After calculating the area of the land portion, the total area is determined using equation (19).

5   Transmitters in the aeronautical mobile, radionavigation and radiolocation services

All the above services involve radiocommunication (or localization) with high-flying aircraft. This results in large service areas, the limits of which are determined by the distances to the radio horizon. Taking into account the refraction of radio waves in the Earth's atmosphere, the distance to the radio horizon (R_g) may be calculated using the equation:

$$R_g = 4.14 \sqrt{h_t} + \sqrt{h_r} \text{ (km)} \tag{21}$$

where:

h_t: height of the transmitting antenna above the average level of the ground (on the Earth or on the aircraft), m

h_r: height of the receiving antenna over the average level of the ground (on the Earth or on the aircraft), m

With an aircraft altitude of 10 000 m and an antenna height on the ground of 15 m, equation (21) gives a distance to the radio horizon of the order of 430 km. Beyond the radio horizon the field strength falls sharply, as can clearly be seen from the curves in Recommendation ITU-R P.528. Therefore, in this specific case, the radius of the service area may be taken as being equal to the distance to the radio horizon irrespective of the transmitter power and receiver sensitivity.

In these services, non-directional transmitting antennas are widely used. In cases where directional transmitting antennas are used (mainly in radionavigation and sector radiolocation), the concept of "service sector" in accordance with Recommendation ITU-R F.162-3 may be used (see § 6 below).

Since these services are safety of life services and the overall spectrum resource they occupy for the purpose of calculating spectrum licence fees is usually significantly reduced through the application of appropriate coefficients, it is hardly advisable to contemplate subdividing the service area into different portions belonging to different spectrum utilization fee categories. The category corresponding to the largest portion in terms of area may be adopted for the whole area.

A similar approach to determining the territorial resources occupied may also be adopted for maritime radionavigation and radiolocation, using in equation (21) a target height of about 10 m as the receiving antenna height.

6   Transmitters in the fixed service

Today, all fixed radiocommunication systems, such as HF/VHF radio links and UHF/SHF radio-relay links, use directional and highly directional antennas. Thus, in this case the area covered by the transmitter emission can be calculated using the "service sector" concept set out in Recommendation ITU-R F.162-3. According to that recommendation, the service sector for HF fixed radio links using directional antennas is very close to twice the angular width of the main beam of the antenna radiation pattern. Given the similar physical basis involved, for the purposes of this method this concept may be used for fixed radiocommunications in other frequency bands as well, including radio-relay links.

Thus, if the angular width of the antenna radiation pattern θ is known (from the national frequency assignment database, reference documentation or on request from the system operator or user), the area used by an emission S_f may be determined by:

$$S_f = \pi L_c^2 \, (\theta/180), \text{km}^2 \tag{22}$$

where:

θ: width of antenna radiation pattern in degrees at half power (–3 dB)

L_c: length of the radio link, km

Fixed radio links, especially radio-relay, are carefully planned, and the planning methods are very complex. To improve the reliability of communications, extremely high fading margins are employed. In view of this and in order to avoid complex calculations, for the purposes of this method it is proposed to use as the length of the area occupied by the emission the actual distance between transmitter and receiver, i.e. the length of the radio link L_c, and for radio-relay, the length of the hop between two repeaters. The overall territorial resource used by the radio-relay link will be equal to the sum of the areas used by each constituent hop. In calculating the spectrum resource used by the emission, it is necessary to bear in mind that transmission is bidirectional and the fact that different hops may have different emission bandwidths on account of branch lines.

Here again, it is also possible to adopt the principle of subdividing the overall area into portions with different spectrum fee categories, as put forward for broadcasting in §2.3. However, this has a lot less impact here, since the areas occupied by transmitter emissions are smaller. Nevertheless, if an administration wishes to improve the accuracy of the calculations somewhat, the following equations can be used for cases where the area crosses two portions the boundary of which runs perpendicular at a distance L_b from the transmitter:

$$S_1 = \frac{\theta}{180} \cdot \pi \cdot L_b{}^2$$

$$S_2 = \frac{\theta}{180} \cdot \pi \cdot \left(L_c{}^2 - L_b{}^2\right)$$

For international HF communications, the areas covered may be calculated only within the national territory.

7   Earth stations operating with satellite communication systems

As with the terrestrial fixed service addressed in § 6 above, the "service sector" concept contained in Recommendation ITU-R F.162-3 (see § 6 above) can be used to determine the areas used by emissions from the transmitters of earth stations in satellite communication systems.

For earth stations, it is extremely difficult to arrive at an accurate determination of the distance L_e in equation (22). Therefore, it is suggested that these distances be determined on the basis of the coordination distances agreed upon during the process of coordination of the frequency assignments with ITU-R. If these data are not available, one may use the universal coordination distances of 350 km for VSAT stations and 750 km for all other stations. In many cases, it may also be possible to use the values agreed between the administration and the relevant operators.

8   Conclusion

This document sets out a general approach to determining the amount of territorial resources used by a transmitter emission, illustrated with specific calculation methods for the whole range of most frequently employed classes of emission. By analogy, methods can also be developed for other cases not covered here.

Also in the case where a frequency assignment relates only to a receiver requiring protection, it is still possible to calculate the amount of territorial resources within which it is not possible to locate another transmitter operating on the same frequency and in the same direction. In this case, on the basis of the principle of reciprocity, the receiver is replaced by a transmitter and antenna with typical characteristics for the type of service in question.

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