Communications Research Centre

SHARING CRITERIA IN THE 406.1–410 MHZ BAND BETWEEN THE RADIO ASTRONOMY SERVICE AND THE MOBILE SATELLITE AND LAND MOBILE SERVICES: CALCULATION OF INTERFERENCE RANGE

by

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(Radio and Radar Branch)

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1. In the last line of the Abstract (Page 1) replace "500" by "650".

2. In the third line of Section 3 (Page 6) replace "72" by "54".

3. Insert the following new paragraph at the end of Section 4.2 (Page 9): –

Recent information suggests that the ARO radio telescope has sidelobe gains (at about 55° off the main beam) that may be as high as +10 dBi at 408 MHz. Use of this figure in the calculations rather than -10 dBi (Table 1), would increase the required losses by 20 dB, and the interference ranges by about 200 km for all percent times of interference.

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ABSTRACT

Calculations were made of the minimum separation distance required to permit sharing of the 406.1–410 MHz band by the radio astronomy service and the mobile satellite and land mobile services. Based on assumed characteristics for the systems and using median-path-loss values, this distance was found to vary from about 200 to 500 km, depending on band loading by the mobile services. If interference can be tolerated for less than 50 percent of the time, separations greater than 500 km may be required.

1. INTRODUCTION

As part of the analysis of the briefs and other documentation relating to the establishment of Canadian spectrum policy for the 406–960 MHz band, an assessment was required of possible sharing criteria in the 406.1–410 MHz band for the radio astronomy service with mobile satellite uplink and land mobile stations. Accordingly, this study of the propagation aspects was undertaken.

CCIR Report 224-3, Table 1 (see Reference 1) states that in the 408 MHz radio astronomy band, an interference level with noise power above -203 dBW or with noise power flux spectral density greater than -255 dB relative to 1 W/m^2.Hz is considered harmful. These levels appear to be valid, based on the assumptions given (see Appendix A).

If typical characteristics for an interfering transmitter and for a radio astronomy receiving system are assumed, then the minimum path losses necessary to avoid harmful interference may be calculated. Calculations of path loss as a function of distance can then be used to determine the probable interference range for the given systems.

Two propagation models were used to estimate path loss: the Longley-Rice irregular terrain model[2] and the CRC detailed model[3]. The irregular terrain model is characterized by the use of a median terrain irregularity parameter Δh, and predicts values of path loss typical of communication links whose antennas are "randomly to well" sited. The detailed model requires the actual path terrain profile in order to calculate the path loss appropriate to a specific propagation path. The results of these path loss calculations are shown in Section 2.

A comparison of the above calculations indicated that the detailed model was the better one to use for a path having a receiving site designed to minimize interference, such as a radio astronomy observatory. The interference ranges discussed in Section 3 are therefore based on the detailed calculations.

2. PATH LOSS CALCULATIONS

The path loss or basic transmission loss used here is as defined in References 4 and 5 (and see Appendix B). The results discussed below were derived from both the irregular terrain model and the detailed terrain model. All calculations of path loss are for 50 percent of the locations and also for 50 percent of the time, i.e. median path loss, unless otherwise indicated.

In all calculations, a frequency of 408 MHz and a conductivity of 0.005 S/m have been used. For the frequency and antenna heights used here, the conductivity was found to have a negligible effect. The receiving antenna height used was 30 m, corresponding approximately to the height of the antenna at Algonquin Radio Observatory, assumed typical of radio astronomy receiving sites. The transmitting antenna heights used here are those assumed for the interfering systems (2 m for the land mobile station and 30 m for the mobile satellite earth station).

2.1 IRREGULAR TERRAIN MODEL

The irregular terrain model was used to assess the effect of terrain and antenna height on path loss. Both antennas were assumed to have the same polarization. Figure 1(a) shows the increase in path loss as the transmitting antenna height is lowered. This is particularly evident at low heights. Figure 1(b) shows median path loss as a function of distance for several terrain types. The differences are not large for the terrains shown, and are negligible beyond 110 km.

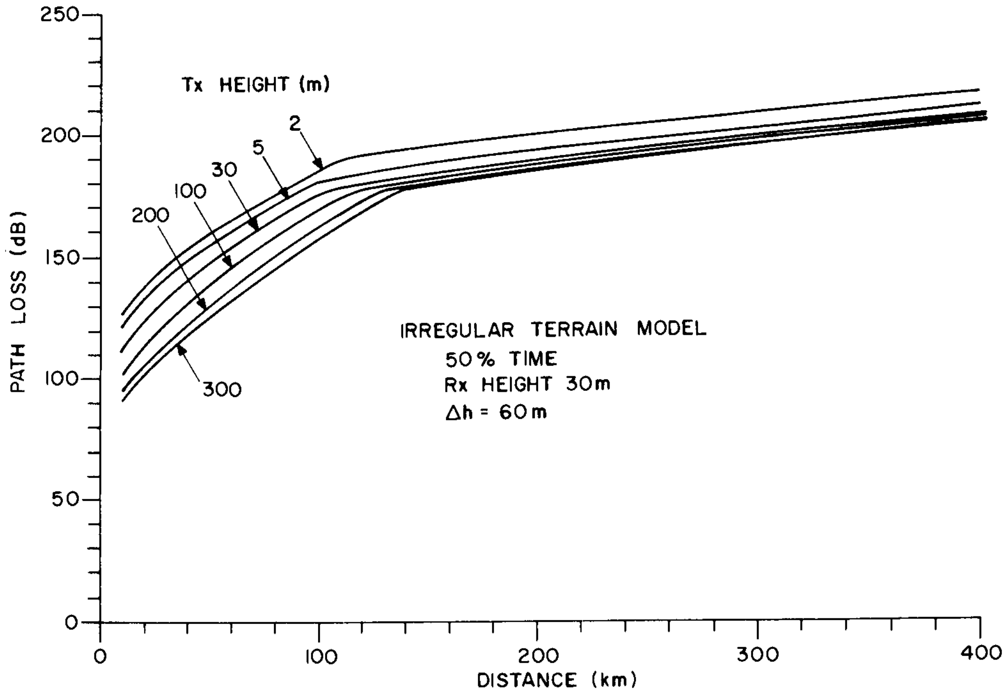
2.2 DETAILED TERRAIN MODEL

In order that the detailed terrain model might be used for a representative path, the terrain profile from Algonquin Radio Observatory (ARO) through Toronto was scaled from topographic maps (Figure 2). This profile includes earth curvature and standard atmospheric refraction.

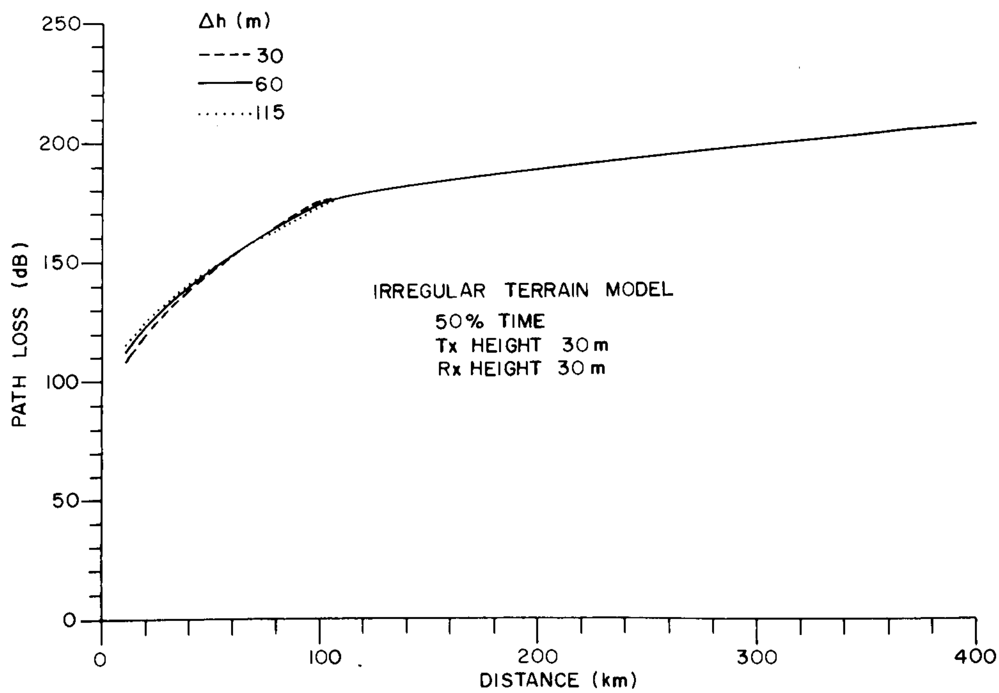
Figure 3 shows path losses calculated for the above path using this model, assuming the receiver is at ARO, for a number of transmitting antenna heights. As the antenna height is increased, the loss decreases and its variation with range becomes smoother.

2.3 COMPARISON OF MODELS

It is to be expected that the path losses calculated using the irregular terrain model, which represents "typical" communication link paths, should differ from those calculated using the detailed terrain model for a particular path. The curves of Figure 4 show results from the two models for a transmitting antenna height of 30 m.



(a) Comparison of losses for various transmitting antenna heights



(b) Comparison of losses for various values of terrain roughness

Figure 1. Irregular Terrain Model Calculations of Path Loss as a Function of Distance

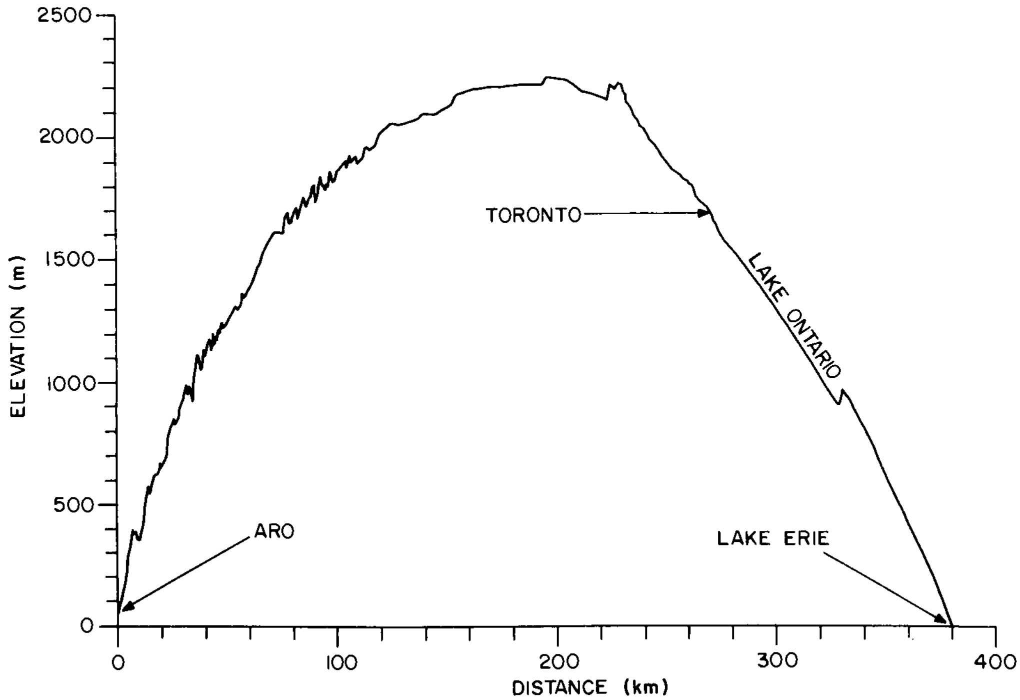


Figure 2. Path Profile for Detailed Terrain Model Calculations

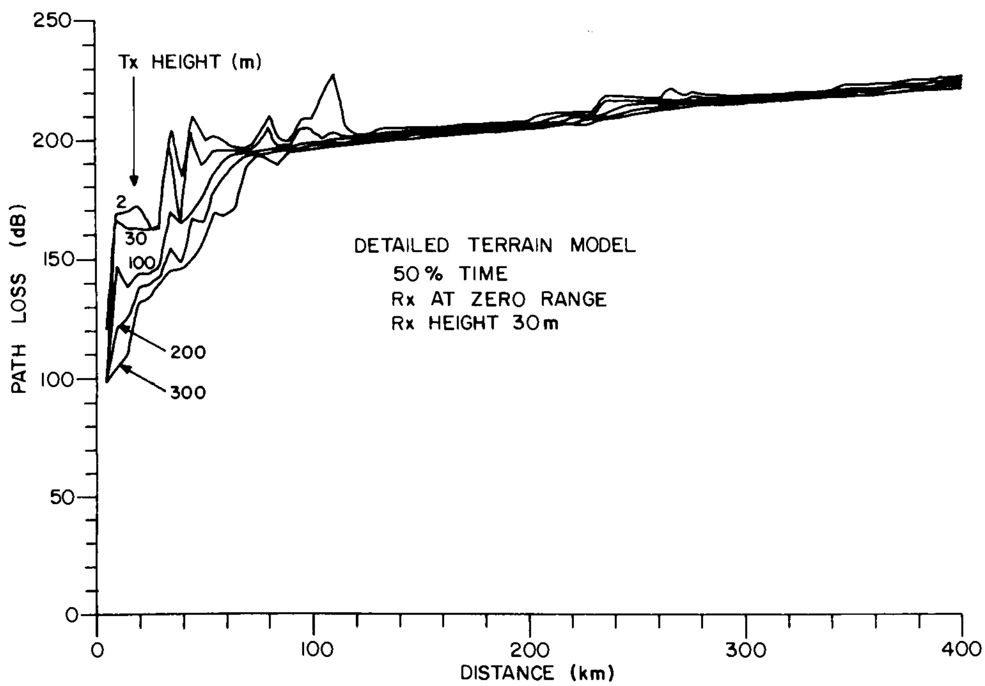


Figure 3. Detailed Terrain Model Calculations of Path Loss as a Function of Distance, for Various Antenna Heights. ARO is at the Origin.

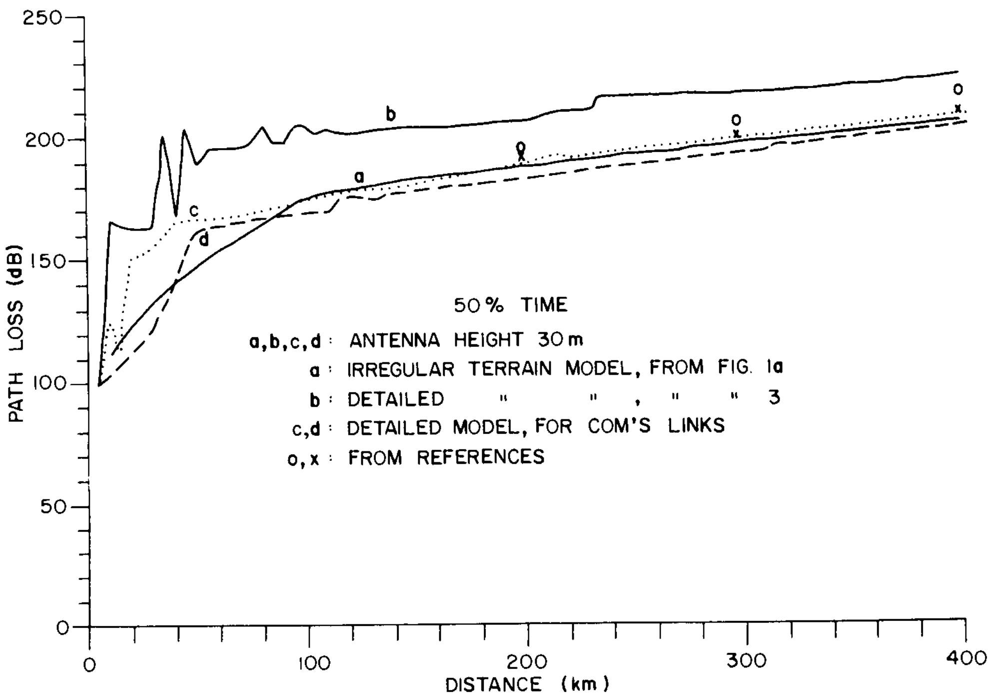


Figure 4. Comparison of Path Losses Calculated from Several Models

Compare curve "a" (irregular terrain, $\Delta h = 60$ m) with curve "b" (detailed). The losses obtained from the detailed calculation are the greater. This is due to the good site shielding afforded the Algonquin Radio Observatory site by local hills. At distances greater than about 150 km, the difference in loss between the two models is about 20 dB. This is to be expected, since the tropospheric scatter (the dominant propagation mode at these distances) path loss is a function of the elevations of the local horizons as seen by transmitter and receiver. The better the site shielding due to hills, the higher the elevation of the local horizon, and the higher the resulting path loss at great, as well as short, distances.

As a cross-check upon the predictions of the detailed program, some path profiles more typical of communication links were chosen. These paths are extensions of those used by CRC for UHF propagation tests. In these cases, the transmitting antenna was situated on relatively high ground, clear of local obstructions. Path losses for these paths are shown by dashed curves "c" and "d" in Figure 4. The results are consistent with the predictions of the irregular terrain model for these types of paths.

Path loss data for long communication paths in the 385–505 MHz frequency range were extracted from Reference 6. A graph of these data indicated that one might expect the losses shown by (X) in Figure 4. Field strengths given in Figure 9 of Reference 7 were used to derive the losses shown by (O). The latter apply to 450–1000 MHz over land with $\Delta h = 50$ m, $h_T = 37.5$ m, $h_R = 10$ m. As expected, the path losses obtained from these two sources fall close to the values predicted by the irregular terrain model and below those predicted by the detailed model for a "shielded" antenna site.

In summary, the above results show that good site shielding of radio observatory sites may provide up to an additional 20 dB of path loss at large distances, compared to the values predicted under the assumption that the antennas at both ends of the propagation path are reasonably well sited from a communications point of view. For this reason, the predictions of the detailed model, rather than those of the irregular terrain model, were used in deriving the interference ranges presented in Section 3.

2.4 TIME VARIABILITY AND POLARIZATION EFFECTS

All of the path losses discussed above refer to median levels, i.e. the path losses that will be exceeded 50 percent of the time. Figure 5 shows a comparison of these calculations with those for smaller fractions of the time. The 10 percent curve shows about 20 dB less loss at 200 km, the difference decreasing to about 13 dB at 400 km. For shorter periods, the losses are further decreased: the corresponding differences are 39 and 25 dB for the 0.1 percent curve.

The above path losses were calculated for vertically polarized antennas. At short ranges, polarization mismatch can provide up to 3 dB additional loss for vertical/circular, or 20 dB for vertical/horizontal antennas. These increased losses may not be achievable in the region beyond about 100 km, due to depolarization of the signal by tropospheric scatter effects. In any case, the polarisation of the radio astronomy antenna may vary with antenna orientation. Therefore such losses have not been included in the consideration of interference range.

3. INTERFERENCE RANGE

The characteristics assumed for the radio astronomy receiving systems, and for the interfering transmitters, are given in Table 1. The antenna gains shown for the mobile satellite uplink and for the receiver are for side- and backlobe gains, about 10 and 72 dB respectively below the main-beam gains. These gains were used since it was assumed that there would be no main-beam coupling.

Based on these characteristics and the tolerable interference levels, the equations of Appendix C were used to obtain the minimum necessary path losses given in Table 2. L_b is the path loss required if a single transmitter is not to add more than -203 dBW to the 406.1–410 MHz band and L_b^1 is the path loss required if the whole band were assigned to mobile systems (one user per channel). L_b^1 is much larger than L_b due to the large difference in bandwidth between transmitter and receiver.

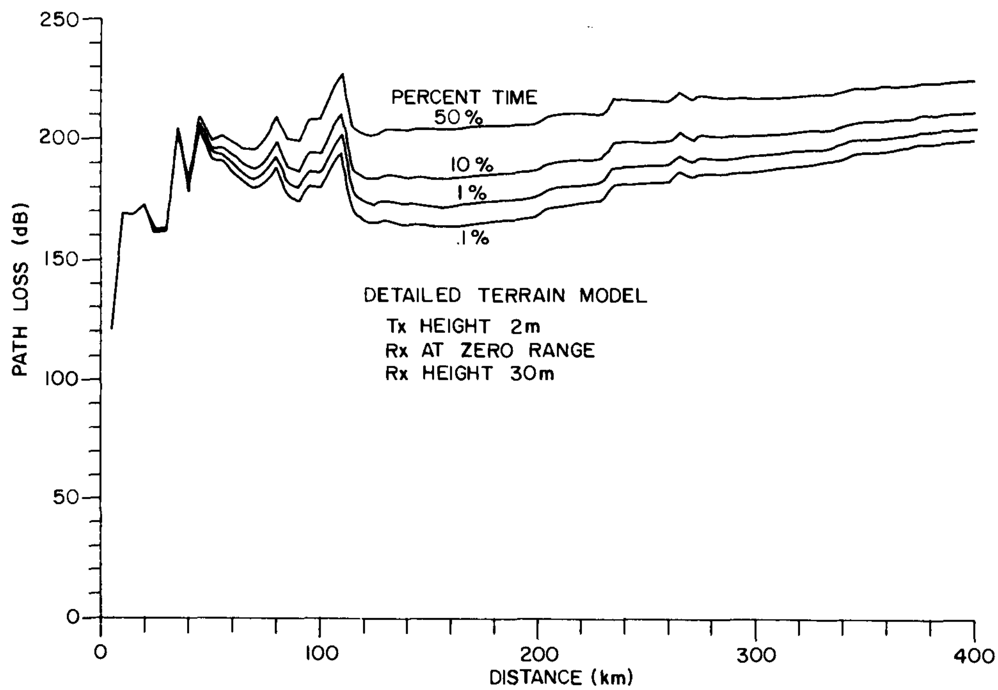


Figure 5. Comparison of Path Losses Expected for Various Percentages of Time. Path Loss is Less Than Ordinate for Indicated Percentage of Time.

The required losses are almost the same for both assumed interfering systems, and so values of $L_b = 210$ dB and $L_b^1 = 234$ dB were chosen for comparison with the path loss calculations. Table 3 shows the distances at which these losses may be expected for several transmitting antenna heights, obtained from the detailed median path loss curves of Figure 3. The variation of range with antenna height is small (10–20 percent), and so interference ranges (50 percent time) of 210 km for 210 dB and of 525 km for 234 dB are reasonable estimates for antenna heights less than 50 m.

These distances increase to approximately 375 km and 615 km respectively if the specified interference levels are not to be exceeded more that 10 percent of the time. The determination of an acceptable percent time of interference is of prime importance in determining the corresponding interference ranges. Figure 6 shows a plot of interference ranges as a function of acceptable percent time of interference. These ranges were obtained from extrapolated path loss calculations for a 2 m transmitting antenna. They will be somewhat greater for higher antennas (see Table 3). The shaded area indicates the variation in interference range due to changes in band loading.

TABLE 1

Assumed Transmitting and Receiving System Characteristics

System	Antenna Type	Height (m)	Polarization	Gain (dBi) G_T	Power (dBW) P_T	Band width Δf (MHz) Δf_T
Transmitter						
Mobile Satellite Earth Station	Helix	30	RHC	3 (Sidelobe)	14 (25W)	.016
Land Mobile Station	Dipole	2	Vertical	4	14 (25W)	.025
Receiver				G_R		Δf
46-m Radio Telescope, ARO	Para-boloid	30		-10 (Backlobe)		3.9
(45° 57′ 19″ N Lat. 78° 04′ 23″ W Long.)						

TABLE 2

Required Path Losses (See Appendix C)

Transmitter	P_T (dBW)	P_H (dBW)	G_T (dBi)	G_R (dBi)	Δf (MHz)	Δf_t (kHz)	L_b (dB)	L_b^1 (dB)
Mobile Satellite Earth Station	14	-203	3	-10	3.9	16	210	234
Land Mobile Station	14	-203	4	-10	3.9	25	211	233

$$L_b = P_T - P_H + G_P$$

$$L_b^1 = L_b + 10 \log (\Delta f/\Delta f_T)$$

$$G_P = G_T + G_R$$

TABLE 3

Interference range (km) as a function of transmitting antenna heights, for path losses of 210 and 234 dB. Calculations are for a receiving antenna height of 30 m, 50 percent time.

	Path Loss	
Transmitting Antenna Height (m)	210 dB	234 dB
	Interference Range (km)	
2	205	516
30	214	529
100	232	551
200	238	562
300	242	574

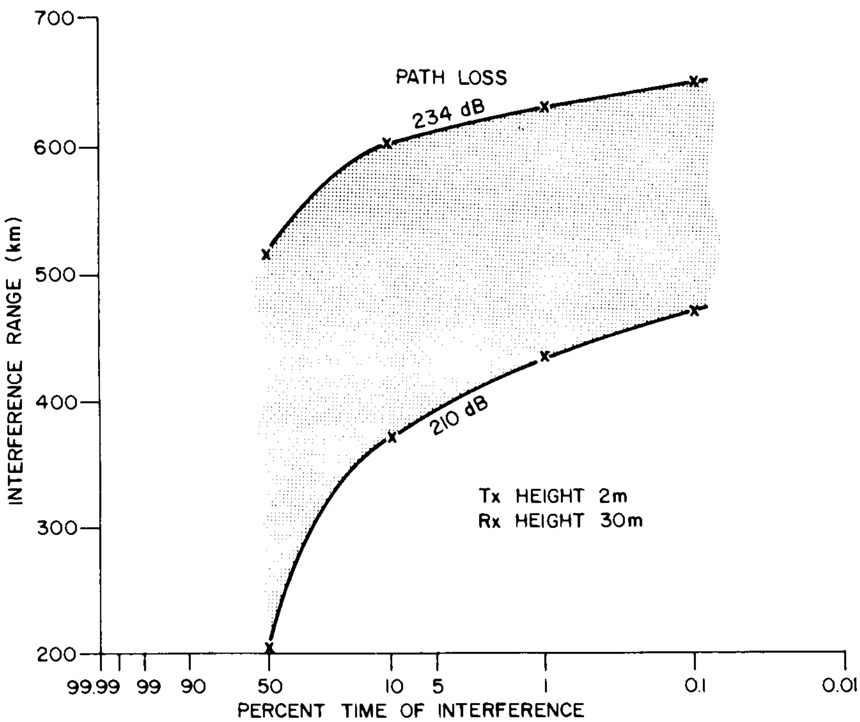


Figure 6. Interference Range as a Function of Acceptable Percent Time of Interference, for Two Values of Path Loss.

4. CONCLUSIONS

Estimates have been made of path loss at 408 MHz, and of the corresponding sharing criteria for the radio astronomy service with the mobile services. The following conclusions may be drawn from the results.

4.1 PATH LOSS

At the shorter ranges, reflections and diffraction over obstacles are the dominant factors in the propagation, and so the effects of the terrain and antenna heights predominate. In general, at distances less than 60 km, the path loss increases with either increased terrain roughness or decreased antenna height.

Beyond 110 km, the effect of terrain roughness on path loss is much less. Also, except for antennas near the ground, the loss changes only slowly with antenna height. It is in this distance range that path losses increase to the 200-plus dB necessary for sharing. The dominant propagation mode here is tropospheric forward scatter. For small percentages of the time, tropospheric ducting may be important. During such periods, the path loss will be less and the corresponding interference range will be greater. Such effects are accounted for, in a statistical sense, in the derivation of the interference ranges expected less than 50 percent of the time.

4.2 INTERFERENCE RANGE

The establishment of an interference range as the sharing criterion for the radio astronomy and mobile services is made difficult by the time variability of the path loss. However, the results of Section 3 suggest that, for 50 percent of the time, a range of about 210 km is required for a single mobile transmitter in the 406.1–410 MHz band. If it is anticipated that a large part of the band would be assigned to the mobile services, the required range is about 525 km. If interference levels in excess of -203 dBW can be tolerated for only a very small fraction of the time, the interference ranges can easily exceed 650 km.

5. REFERENCES

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2. Longley, A.G. and P.L. Rice, *Prediction of Tropospheric Radio Transmission Loss Over Irregular Terrain – A Computer Method – 1968*, ESSA Technical Report ERL 79-ITS 67, July 1968.

3. Palmer, F.H., *Review of Propagation in the 470–890 MHz Band With Emphasis on Land Mobile and Cellular Systems*, CRC Report 1288, February 1976.

4. *The Concept of Transmission Loss in Studies of Radio Systems, Recommendation 341*, p. 82, **Vol. I** of XIIIth Plenary Assembly, CCIR, Geneva 1974.

5. *Transmission Loss in Studies of Radio Systems, Report 112*, p. 85 ibid.

6. Longley, A.G., R.K. Reasoner and V.L. Feller, *Measured and Predicted Long-Term Distributions of Tropospheric Transmission Loss*, Telecommunications Research and Engineering Report 16 (OT/TRER 16), July 1971.

7. *VHF and UHF Propagation Curves for the Frequency Range from 30 MHz to 1000 MHz, Recommendation 370-2*, p. 116, **Vol. V** of XIIIth Plenary Assembly, CCIR, Geneva 1974.

APPENDIX A

Allowable Interference to Radio Astronomy in the 408 MHz Band

Note: See Appendix D for units.

The *allowable noise power* due to interference (see Reference 1) is:

$$P_H = kT \sqrt{\Delta f/2t} \ / \ 10$$

Therefore for $T = 125$ K, $\Delta f = 3.9$ MHz, $t = 2000$ s,

$P_H = 5.39 \times 10^{-21}$ W, or, in decibels,

$P_H = -202.69$ dBW.

The corresponding *noise power spectral density* is

$$P_H^1 = P_H - 10 \log \Delta f,$$

and the *noise power flux spectral density* is

$$S_H = P_H^1 - 10 \log (c^2/4\pi f^2)$$

$$= P_H + 13.67 - 65.91 \text{ at } 408 \text{ MHz}$$

$S_H = -254.93$ dB relative to 1 W/m^2. Hz

APPENDIX B

Path Loss, and Received Power

B1. PATH LOSS

The definition of *path loss* or basic transmission loss L_b used here is that of CCIR Recommendation 341[4], i.e. the ratio in decibels of the power radiated from the transmitting antenna to the power available from the receiving antenna into a matched load, assuming both antennas to be lossless and isotropic. The *transmission loss* L includes the *path antenna gain* G_p, i.e. $L = L_b - G_p$, and so is generally less than the path loss.

The *system loss* L_s of a radio circuit is the ratio of the power input P_T at the antenna terminals to the power P_A available from the receiving antenna. It therefore includes all losses except transmission line losses:

$$L_S = P_T - P_A = L + L_c,$$

where L_c is the combined loss of the antenna circuits. In the present study, $L_c = 0$, therefore

$$L_b - G_P = L = L_s = P_T - P_A,$$

and so the *available power*

$$P_A = P_T - L_B + G_P.$$

The corresponding *power spectral density* is $P_A^1 = P_A - 10 \log \Delta f_T$.

APPENDIX C

Required Path Loss

The path loss L_b that must be exceeded, if the noise power due to interference added to the band is to be less than P_H, is given by equating P_H and P_A (see A. and B.):

$$P_H = P_A = P_T - L_b + G_P \quad .$$

Therefore,

$$L_b = P_T - P_H + G_P \, . \tag{1}$$

Similarly, the minimum path loss L_b^1, if the allowable noise power spectral density is not to be exceeded, is given by equating P_H^1 and P_A^1.

$$P_H^1 = P_A^1 = P_A - 10 \log \Delta f_T$$

$$P_H - 10 \log \Delta f = P_T - L_b^1 + G_P - 10 \log \Delta f_T$$

$$L_b^1 = P_T - P_H + G_P + 10 \log (\Delta f / \Delta f_T)$$

$$L_b^1 = L_b + 10 \log (\Delta f / \Delta f_T) \, . \tag{2}$$

This would be the loss required if the 408 MHz band were subject to interference on all frequencies.

The above equations 1 and 2 were used in the calculations for Table 2.

APPENDIX D

Glossary

Symbol	Parameter	Unit
c	Velocity of light	m/s
f	Wave frequency	Hz
G_P	Path antenna gain	dBi*
G_R	Receiving antenna gain	dBi
G_T	Transmitting antenna gain	dBi
h_R	Receiving antenna height	m
h_T	Transmitting antenna height	m
K	Boltzmann's constant, 1.3806×10^{-23}	J/K
L	Transmission loss	dB
L_b	Path loss or basic transmission loss	dB
L_b^1	Path loss for spectral density	dB
L_c	Antenna circuit loss	dB
L_s	System loss	dB
P_A	Available power at receiver	dBW
P_A^1	Available power spectral density	dB(W/Hz)**
p_H	Noise power	W
P_H	Noise power	dBW
P_H^1	Noise power spectral density	dB(W/Hz)
P_T	Transmitter antenna power input	dBW
R	Interference range	km
S_H	Noise power flux spectral density	dB(W/m^2 . Hz)***
t	Receiver integration time	s
T	Total noise temperature at receiver	K
Δf	Receiver bandwidth	Hz
Δf_T	Transmitter bandwidth	Hz
Δh	Median terrain irregularity parameter	m

* *Decibels relative to an isotropic antenna*
** *Decibels relative to one watt per hertz*
*** *Decibels relative to one watt per square metre per hertz*

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8. **ABSTRACT:**

Calculations were made of the minimum separation distance required to permit sharing of the 406.1–410 MHz band by the radio astronomy service and the mobile satellite and land mobile services. Based on assumed characteristics for the systems and using median-path-loss values, this distance was found to vary from about 200 to 500 km, depending on band loading by the mobile services. If interference can be tolerated for less than 50 percent of the time, separations greater than 500 km may be required.

9. **CITATION:**

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