REPORT ITU-R F.2059

Antenna characteristics of point-to-point fixed wireless systems to facilitate coordination in high spectrum use areas

(2005)

Summary

This ITU-R Report provides information and results of comparative statistical studies on commercially manufactured point-to-point FWS antennas, from the perspectives of interference management and spectrum reuse potential within FS.

The use of a Monte Carlo methodology permits the derivation of quantitative estimates of spectrum utilization efficiency for point-to-point FWS antennas with widely varying characteristics. Through the statistical correlation of simulation results against individual antenna parameters and based on some simplifying assumptions, useful information is obtained about the role of such parameters in facilitating efficient spectrum use. For example, the antenna front-to-back ratio is shown to be a potentially useful estimator of spectrum reuse potential for the co-polar case. The results of simulation in the 7.5, 11 and 13 GHz point-to-point FWS bands are reported and analysed, with some preliminary conclusions drawn.

1 Introduction

Digital radio-relay systems and other point-to-point fixed wireless system (FWS) operate in the frequency bands between about 1 to 60 GHz, typically as constant bit-rate (2-155 Mbit/s) transport network elements complementing optic fibre and satellite transport media. The lower frequency (e.g. 4 and 6 GHz) bands have for many years supported long and medium haul radio-relay systems. More recently, given technology and global market developments, the higher microwave bands have experienced explosive growth, driven by the demand for cellular mobile backhaul and other new carrier networks. WRC decisions in favour of mobile/Global mobile personal communication by satellite (GMPCS) allocations has witnessed the displacement of many point-to-point fixed services from the 1-3 GHz bands placing further pressure on the remaining fixed allocations. Nevertheless, point-to-point FWS are a major user of the microwave radio spectrum and demand is expected to continue into the foreseeable future. Spectrum congestion is an ever increasing problem, especially in urban areas, with the potential reuse of microwave RF channels limited by interference related quality of service (QoS) considerations.

Point-to-point FWS mainly utilize highly directional, linearly polarized parabolic antennas. Within the fixed service interference environment, antenna radiation performance is a dominant factor in determining the extent of possible frequency reuse or “spectrum efficiency”. Accordingly, many administrations specify antenna performance standards for certification purposes, including “notional” radiation patterns and other criteria such as a minimum antenna size (parabolic reflector diameter). In practice, given the range of manufactured antenna products and the inherent variability of their radiation characteristics, the application of such minimum performance antenna standards is often problematic. For example, in some frequency bands, operators would prefer to deploy smaller and less visually intrusive antennas and tower structures, particularly in support of access networks around urban and environmentally conscious areas, but are constrained by requirements based directly or indirectly on a minimum antenna reflector size.

Annex 1 outlines the application of a Monte Carlo approach [1] to deriving estimates of the relative spectrum efficiency of different models of parabolic reflector antennas, with a view to comparing available models and developing an understanding of the preferred antenna radiation characteristics of point-to-point FWS antennas for use in high spectrum use areas. The use of manufacturers' digitized FWS antenna data facilitates the computer simulation of a homogeneous FWS interference environment, integrating a multidimensional problem space (antenna gain, co-polar and cross-polar envelope patterns) to a simple point estimate of the number of co-channel services that can theoretically be accommodated within a given area. The simulation is repeated for a sample population of serial production 7.5 GHz antennas, with parabolic reflector diameters within the range 0.6 up to 4.6 m. The simulation derived sampling distributions are then analysed using standard statistical methods. The methodology is similarly applied to other frequency bands, in this case the 11 GHz and 13 GHz fixed service bands and conclusions drawn.

Before considering the results of studies, the following sections review issues of interference management, commercial microwave antenna types and their radiation parameters.

1.1 Spectrum utilization efficiency

In elementary terms the antenna is a coupling device. Its principal purpose is to facilitate an efficient transfer of energy between a transmission line and the medium of "free" space. Ideally, as much as possible of the power generated at the transmitter should be directed at and arrive at its associated receiver(s). In practice, only a very small fraction is available at the receiver, with the bulk of the transmitted energy distributed into the environment as noise.

This radiated noise power manifests itself as interference, potentially "denying" access to the spectrum by other services, out to a distance where the noise power is sufficiently diminished to permit the receiver of another service to operate without unacceptable degradation of its grade of service (GoS). In accordance with Recommendation ITU-R SM.1046 – Definition of spectrum use and efficiency of a radio system, such *spectrum denial* is sometimes expressed as the product of geometric space (area/ volume), bandwidth and time. In this case, the time term can be ignored, since we assume constant bit rate FWS, so $T = 1$:

$$U = B.S \qquad \{\ \mathrm{MHz}\ .\ \mathrm{m}^2\ \} \tag{1}$$

where:

U: represents an area bandwidth product, i.e. the spectrum space occupied by a fixed service system and denied to other services

B: radio-frequency bandwidth of the system

S: area of the potentially denied spectrum.

Transmitters and receivers already in operation both deny spectrum to other new services – existing transmitters potentially interfere with and deny spectrum to the receivers of proposed new systems and existing receivers are susceptible to interference from and therefore deny spectrum to the transmitters of new systems.

For conceptual purposes and for terrestrial fixed services of arbitrary bandwidth[1], the area S may be represented as being bounded by a geographic power density contour (Fig. 1), determined by,

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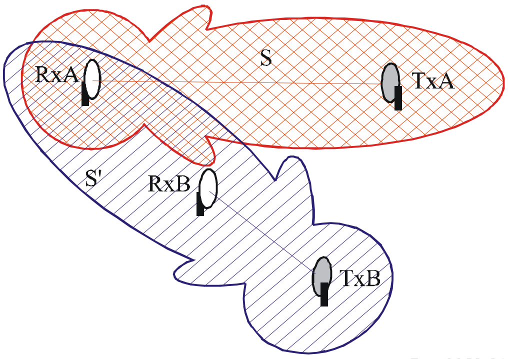
[1] For the purposes of this document we are principally interested in the term "S", so all wanted and unwanted signals are assumed to be co-channel and the radio-frequency bandwidth term "B" need not be considered.

inter alia[2], by the susceptibility of the victim receiving system to interfering emissions (i.e. receiver sensitivity and the required grade of service). In principle this is somewhat analogous to the establishment of a coordination area.

FIGURE 1

Spectrum denial area "S"



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The degree of unwanted interference signal coupling is proportional to:

- the absolute and relative ($G_t(\theta)$, $G_r(\theta)$) azimuth relationships;
- the antenna discrimination, including co-polar and cross-polar components;
- the radial distance (d) between the interference source and victim; and
- additional losses ($l_m(\theta)$ due to terrain obstruction on the interference path.

In practice, for homogeneous fixed services operating within the same frequency band, the standard deviations of parameters such as transmit power, feeder losses and receiver interference threshold are small and for many purposes these parameters are often approximated with constants (See Recommendation ITU-R F.758 – Considerations in the development of criteria for sharing between the terrestrial fixed service and other services.). Potential interference path distance d and relative antenna azimuths θ are predetermined by the locations dictated by the respective communication and siting requirements of the interfering and potentially interfered with services. However, the radiation pattern envelope ($G(\theta)$) is unique to each antenna and the standard deviation of the gain patterns between different models of FWS antennas typically extends to orders of magnitude.

In conclusion, it is generally accepted that the use of directional antennas with high off-axis discrimination reduces the overall levels of interference, reduces the area "S", and increases the potential reuse capacity of the available RF spectrum space.

1.2 Point-to-point FWS antennas

For point-to-point FWS using parabolic antennas, it is well known that the directive gain is proportional to aperture, i.e. reflector diameter [2]. Figure 2 demonstrates this relationship, using sample data of 141 different 7.5 GHz parabolic antennas.

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[2] In addition to the system gain parameters.

FIGURE 2

Diameter (m) vs. gain (dBi)

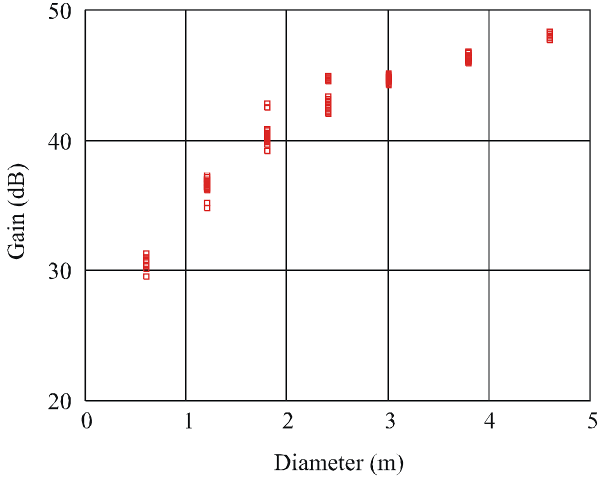
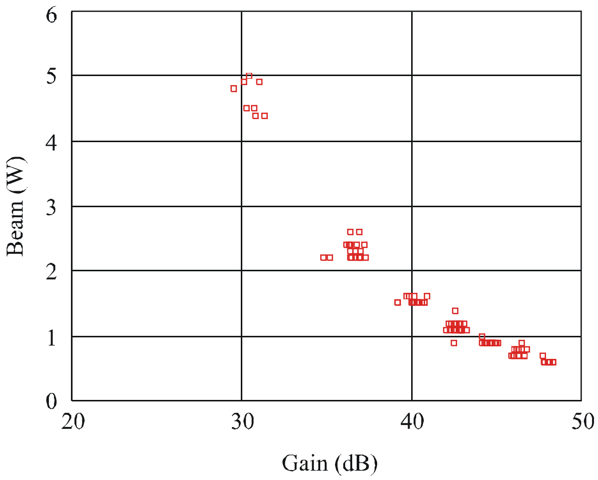


FIGURE 3

Gain (dBi) vs. beamwidth (degrees)



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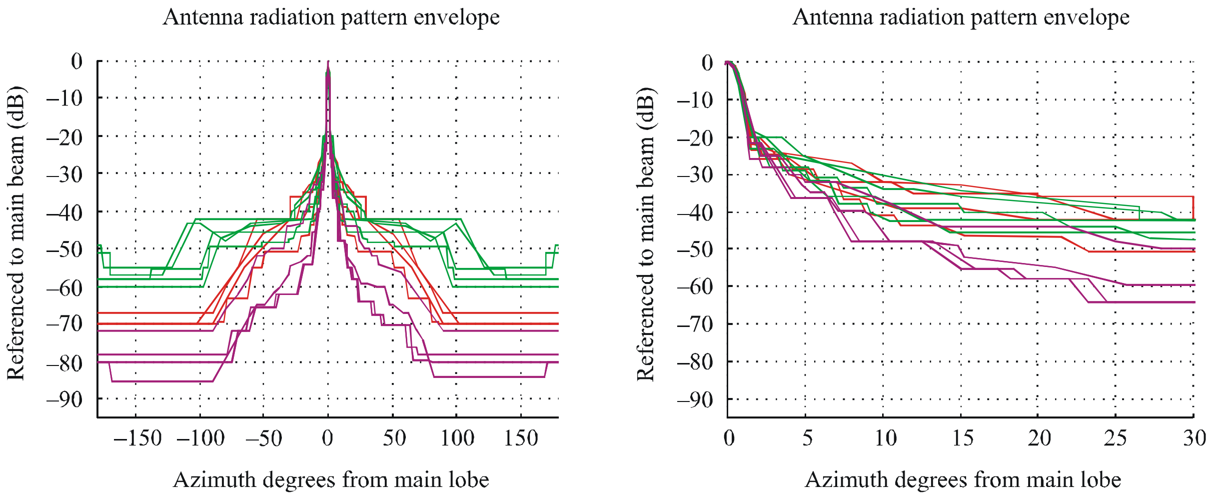
Similarly, the behaviour of on-axis gain vs. half power beamwidth is relatively well conditioned (Fig. 3), with the statistical variation including some deliberate antenna design tradeoffs. Accordingly, the behaviour of these parameters is easily approximated using established mathematical models. However, whilst recognizing that the side-lobe patterns of antennas of different sizes are strongly influenced by the ratio of the antenna diameter to the operating wavelength (D/λ), per Recommendation ITU-R F.699 – Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz, for actual production antennas the off-axis co-polar and cross-polar radiation levels of different antenna models are not so predictable. Once outside of the 3 dB beamwidth[3], differences often extend to orders of magnitude, even for models of the same physical aperture (Fig. 4).

FIGURE 4

Comparison of co-polar RPEs for a number of STD/HP/UHP 1.8 m dish antennas



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[3] It should be emphasized that the cross-polarization is strongest in the main beam and can also be relatively strong in the side lobes, depending upon the particular type of antenna used.

For the antenna designer, the challenge is to derive an optimum combination of parabolic reflector and feed. The reflector cannot intercept all of the energy radiated by the feed, as maybe desired for maximum gain. The lost power can be considered as a *spillover loss*, given by integrating the power patterns of the feed over the angular region outside of that subtended by the reflector. Other losses account for non-uniform illumination, non constant phase of the aperture field and cross-polarization loss, collectively referred to as the aperture efficiency. Commercial model designs are based around obtaining either maximum gain or a reduction in side lobes in exchange for a slight decrease in gain. Increased illumination at the periphery of the reflector surface increases the diffraction field and side-lobe levels. Special techniques, such as RF absorbent "shrouds", are often employed to suppress the diffraction field and thus reduce the average magnitude of side lobes. The best of these designs represent years of development and exhibit dramatically reduced back and side-lobe levels in comparison to standard models. Optimized cross-polar feed systems provide further benefits in terms of additional interference immunity, to the extent that co-channel cross-polar operation on the same RF path is now a routine technique, particularly on long-haul circuits.

1.3 Commercial FWS antenna specifications

Manufacturers' catalogues usually list families of electrically similar parabolic FWS antenna models within the range of industry standard apertures. For the purposes of this study, *three* categories are defined [3], based on the manufacturers nominal model designations (see Table 1), STD – standard, HP – high performance and UHP – ultra-high performance, shown in Fig. 3 as green, red and magenta respectively.

- *Frequency band* – Usually aligned with relevant ITU-R Recommendations detailing radio-frequency (RF) channel arrangements.
- *Model type* – Manufacturers generic model type typically including (but not limited to) the following generic descriptors.

TABLE 1

Commercial antenna model types

Model name	**Description** (see Note)
Grid parabolic	Grid reflector parabolics, useable range limited to the range 0.4-2.7 GHz. Small to medium capacity systems, inherently good cross-polar performance and low wind loading
Standard	Unshielded, low cost, solid parabolic antennas. Average side-lobe performance. *F*/*B* ratio of the order of 40-55 dB
High performance	Deep or shrouded dish offering improved side-lobe suppression and *F*/*B* ratio of the order of 70 dB
Ultra high performance	Shrouded antennas with optimal feed arrangements, very high side-lobe suppression and *F*/*B* ratios in excess of 80 dB

NOTE – Dual beam and multiband antennas are not considered in this study.

- *Diameter* – The diameter of the parabolic reflector (in metres). Commonly manufactured sizes include antennas of 0.3, 0.6, 1.2, 1.8, 2.4 3.0, 3.7 and (in some bands) 4.6 m.
- *Gain* – The mid-band gain of the antenna (dBi). Additional figures may be given for the top and bottom limits of the operating frequency range.

- *Beamwidth* – Nominal half power beamwidth of the main antenna beam at the –dB points at the midland frequency.
- *Cross-polar discrimination* – The ratio of the co-polar main beam signal response to the maximum cross-polar signal response, within the region bounded by twice the 3 dB beamwidth;
- *Front-to-back (F/B) ratio* – The ratio of the response of the highest peak in the region 180 ± 40 to the main beam response. Production antennas do not normally exceed the rated values by more than 2 dB; and
- *Radiation pattern envelope* – The relative distribution of radiated power as a function of direction (azimuth) in space is the radiation pattern envelope (RPE) of an antenna. The RPE is most commonly referenced as a ratio relative to the main beam (dB) over the full range of azimuths from 0° to 360°, or 0° to 180° for antennas with symmetric patterns. The RPEs of commercially available fixed service antennas represent the envelope peaks of a measured sample of manufactured units. Parallel and cross-polar patterns are measured for both horizontal and vertical polarizations and typical production units are guaranteed not to have any peaks exceeding the manufacturers published envelopes by more 3 dB.

In addition to catalogued specifications, major antenna manufacturers typically provide the above characteristics, including RPEs, in digitized format – including a widely used standard electronic format for use in spectrum sharing and coordination studies [4], facilitating detailed coordination and the statistical simulations outlined in this document. Antenna performance parameters are measured using appropriate test methods, such as those described in references [5] and [6].

1.4 Interference management

In choosing an antenna for a particular point-to-point link, the designer may consider:

- the necessary system gain;
- capital cost;
- any relevant council regulations;
- tower structure and wind loading;
- whether the antenna is to be used as an interference reducing aid.

The choice of an antenna as an interference reducing aid will occur only if motivated by a specific planning situation. Furthermore, the individual operator has no control over the types of antennas already deployed. Accordingly, the onus falls on administrations to consider the wider issues of interference management and spectrum utilization efficiency. In the absence of internationally agreed standards, a number of administrations specify their own certification processes and criteria for minimum acceptable antenna performance for FWS. Typically, the approaches adopted in various countries all share common elements even though each criterion is given a different emphasis. Whilst these certification approaches facilitate opportunities for overall RF spectrum reuse, it can be shown that they can be difficult to administer consistently.

It is also difficult to make quantitative decisions about the critical antenna radiation parameters and what their preferred and minimum acceptable values should be. Approaches based on quasi-deterministic measurements of averaged co-polar side-lobe levels tend to be unsatisfactory, given the large range of different models available and the confounded nature of the relationship between spectrum efficiency and antenna gain, co-polar and cross-polar RPE parameters.

As detailed in the following sections, probabilistic methods can be applied to simplify the problem.

2 Simulation

Many complex real world problems are too difficult to solve using analytic methods. With the availability of increasingly powerful desktop computers, simulation and statistical methods can be applied to solve many such problems. The simulation model and parameters detailed in Annex 1 emulate a homogeneous terrestrial point-to-point FWS interference environment, with the commercial antenna RPE as the device under test. The objective is to simplify the comparison of different RPEs through the derivation of a single figure point statistic for each antenna model. For each RPE, the simulation attempts to coordinate 10 000 randomly placed, oriented and polarized digital point-to-point links, within an area of 100 km radius and uniform link density. The statistics are then consolidated, with a view to considering the simulation derived distributions and their correlation to other antenna parameters.

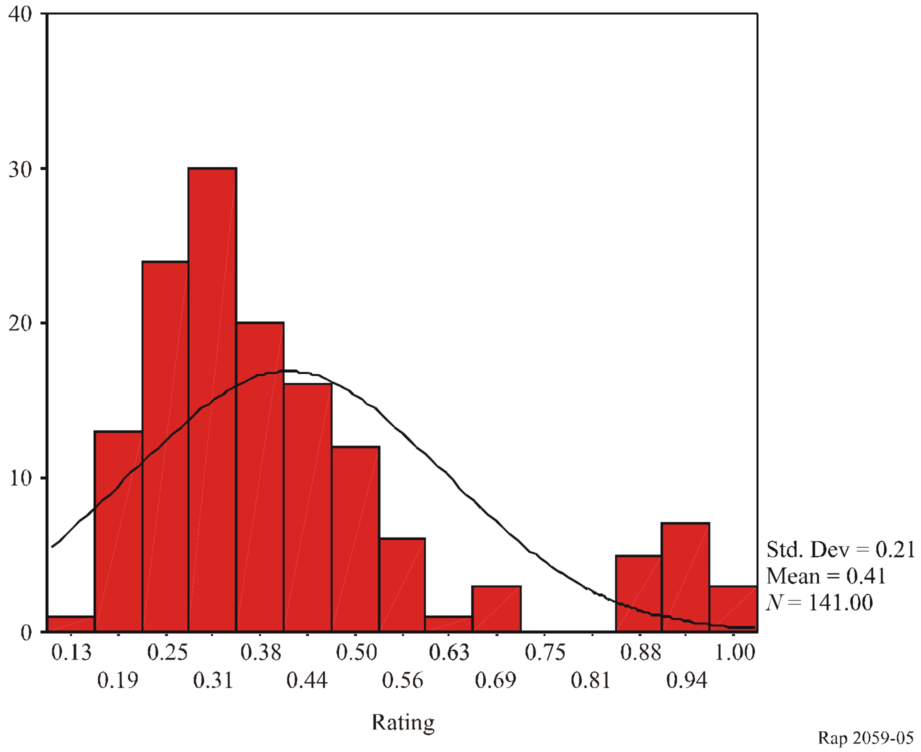
The 7.5 GHz band was selected on the basis that it is in high demand for cellular backhaul and other urban area small-to-medium capacity point-to-point services. Antennas in the 11 GHz (high capacity) and 13 GHz (medium capacity) bands were also tested under corresponding conditions.

2.1 Simulation results (7.5 GHz)

One hundred and forty-one 7.5 GHz manufacturer antenna RPEs applied to the simulation methodology outlined in Annex 1, representing the majority of the models currently marketed for this band, with parabolic reflector diameter in the range $0.6 \leq D \leq 4.6$ m ($15 \leq D/\lambda \leq 115$). The overall simulation derived sampling distribution is shown in the histogram (Fig. 5).

FIGURE 5

Simulation rating distribution



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Since a comparative approach is adopted, the ratings are normalized. A rating of unity corresponds to the highest achieved spectrum utilization efficiency within the simulated interference environment. The skewed distribution is multimodal. The peak mode corresponds to STD and HP antenna models and the smaller higher ratings mode with UHP types.

Table 2 summarizes the results of the simulation derived spectrum utilization ratings. As expected, on average the HP models rate consistently higher than STD models. However, the performance of the UHP models are consistently outstanding. The scatterplot in Fig. 6 compares antenna aperture (reflector diameter) against the simulation derived spectrum utilization efficiency rating.

The table of results and the scatterplot shows that, within a uniformly random distributed (location, antenna orientation) interference environment.

- The highest spectrum utilization is achieved with antennas of modest (1.8 m diameter, $D/\lambda = 45$) aperture;
- spectrum efficiency decreases quickly with the smaller (< 1.8 m) diameter antennas, consistent with falling aperture efficiency;
- on average, larger (> 1.8 m) apertures do not yield further improvements in spectrum utilization;
- the highest spectrum utilization ratings were obtained with dual polarized UHP models, of the order of five times that of STD types.

The high ratings achieved with UHP models confirm the importance of cross-polar discrimination in facilitating spectrum reuse of FWS networks. As anticipated, the HP type antennas achieved higher average spectrum utilization ratings than STD types.

TABLE 2

Simulation derived spectrum utilization ratings – 7.5 GHz ($n = 141$)

D **(m)**	**Type**	**Minimum**	**Maximum**	**Median**	**Mean**
4.6	UHP	0.940	0.990	0.965	0.965
	HP	0.236	0.520	0.345	0.361
	STD	0.236	0.555	0.294	0.363
3.8	UHP	0.930	0.935	0.933	0.933
	HP	0.251	0.583	0.440	0.447
	STD	0.196	0.359	0.284	0.279
3.0	UHP	0.847	0.847	0.847	0.847
	HP	0.362	0.515	0.459	0.449
	STD	0.239	0.470	0.339	0.343
2.4	UHP	0.872	0.932	0.914	0.908
	HP	0.314	0.548	0.392	0.410
	STD	0.239	0.392	0.317	0.321
1.8	UHP	0.407	1.000	0.894	0.788
	HP	0.181	0.565	0.362	0.359
	STD	0.191	0.518	0.302	0.315
1.2	UHP	0.616	0.681	0.672	0.660
	HP	0.193	0.535	0.314	0.315
	STD	0.193	0.462	0.239	0.268
0.6	HP	0.226	0.447	0.351	0.344
	STD	0.108	0.226	0.190	0.178

Investigation of the normalized co-variances between the simulation derived ratings and catalogue listed antenna parameters indicate a good degree of positive correlation between antenna front-to-back ratio and the spectrum utilization ratings achieved through simulation. Figure 7 confirms a function relationship between antenna size (diameter) and *F*/*B* ratio. However, as shown in Fig. 8, a high *F*/*B* ratio does not uniquely equate to high spectrum efficiency and clearly the cross-polar performance also has a major part to play in achieving a high FWS spectrum reuse.

FIGURE 6

Aperture vs. rating, 7.5 GHz

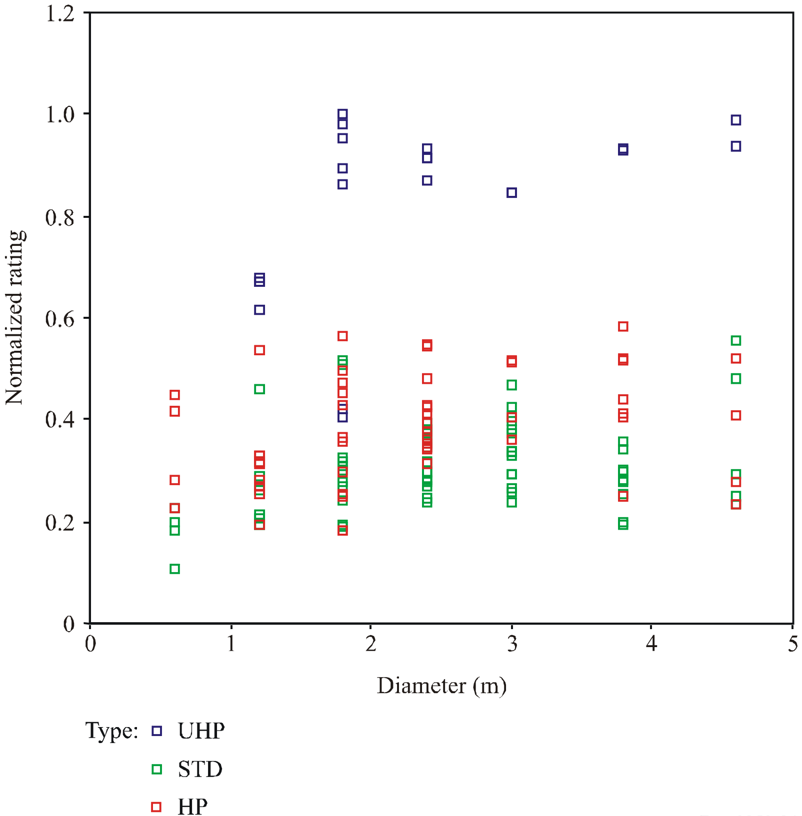

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FIGURE 7

Diameter (m) vs. *F*/*B* (dB)

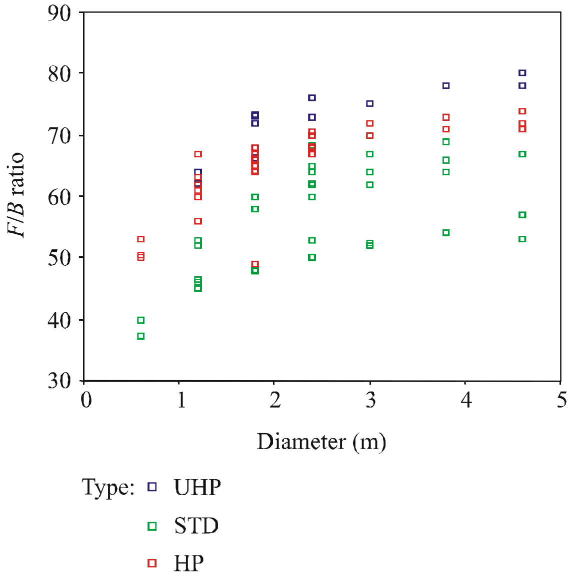
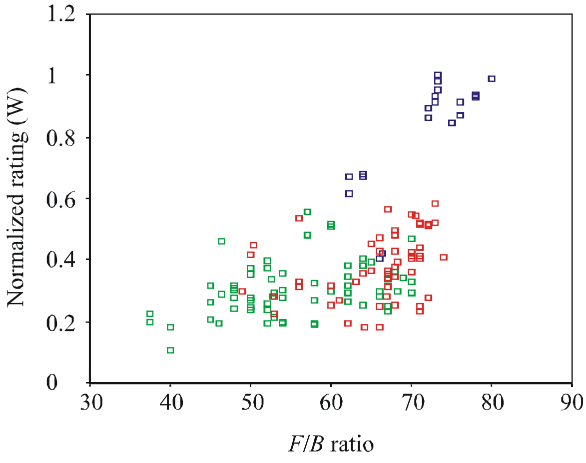


FIGURE 8

***F*/*B* (dB) ratio vs. rating**



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2.2 Other frequency bands

The conclusions derived in the previous section are based on the results of simulation for a range of 7.5 GHz antenna types. However, similar results and conclusions can be demonstrated for the antenna populations in other microwave frequency bands.

Table 3 shows the simulation derived spectrum efficiency ratings of 58 commercial parabolic antennas in the 10.7-11.7 GHz (40 MHz channels, in accordance with Recommendation ITU-R F.397-6) high capacity point-to-point FWS band.

TABLE 3

Simulation derived spectrum utilization ratings – 11 GHz (n = 58)

D **(m)**	**Type**	**Minimum**	**Maximum**	**Median**	**Mean**
3.8	UHP	0.496	0.967	0.518	0.570
	HP	0.146	0.183	0.165	0.165
	STD	0.128	0.221	0.167	0.172
3.0	UHP	0.369	0.758	0.721	0.641
	HP	0.159	0.362	0.167	0.229
	STD	0.131	0.224	0.177	0.177
2.4	UHP	0.324	0.854	0.806	0.682
	HP	0.175	0.376	0.254	0.268
	STD	0.162	0.235	0.205	0.202
1.8	UHP	0.365	1.000	0.947	0.798
	HP	0.172	0.355	0.233	0.248
	STD	0.102	0.250	0.157	0.172
1.2	UHP	0.355	0.472	0.461	0.429
	HP	0.203	0.303	0.215	0.234
	STD	0.136	0.209	0.145	0.163
0.6	HP	0.281	0.281	0.281	.281
	STD	0.144	0.144	0.144	0.213

Table 4 shows the simulation derived spectrum efficiency ratings of 94 commercial parabolic antennas in the 12.75-13.25 GHz (28 MHz channels, in accordance with Recommendation ITU-R F.497) point-to-point FWS band.

TABLE 4

Simulation derived spectrum utilization ratings – 13 GHz ($n = 94$)

D **(m)**	**Type**	**Minimum**	**Maximum**	**Median**	**Mean**
3.8	HP	0.170	0.296	0.231	0.230
	STD	0.166	0.214	0.210	0.198
3.0	UHP	0.664	1.000	0.832	0.832
	HP	0.228	0.334	0.272	0.280
	STD	0.148	0.240	0.153	0.177
2.4	UHP	0.533	0.938	0.736	0.736
	HP	0.251	0.373	0.315	0.302
	STD	0.146	0.201	0.178	0.175
1.8	UHP	0.578	0.578	0.578	0.578
	HP	0.186	0.488	0.291	0.298
	STD	0.183	0.272	0.200	0.207
1.2	UHP	0.401	0.612	0.556	0.555
	HP	0.236	0.401	0.357	0.374
	STD	0.125	0.218	0.200	0.190
0.6	HP	0.243	0.494	0.366	0.351
	STD	0.101	0.247	0.228	0.205

Thus the conclusions concerning the simulated spectrum utilization efficiency of 7.5 GHz antennas are also relevant to the 11 GHz and 13 GHz antenna population.

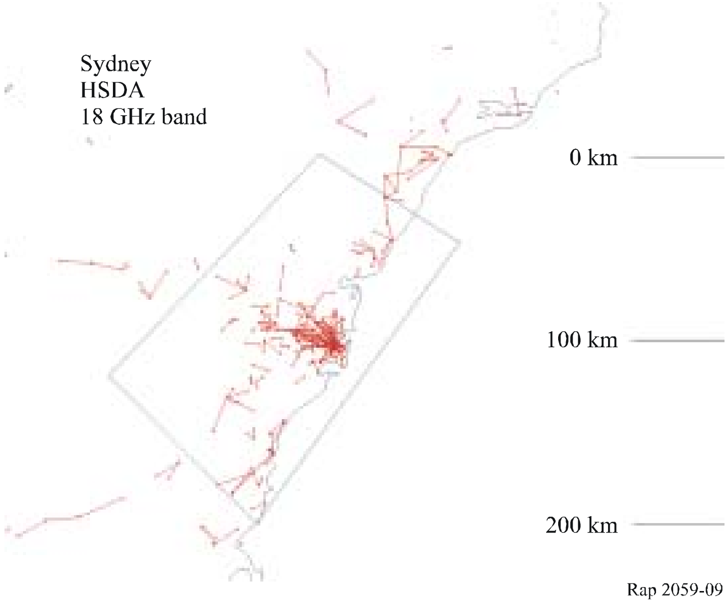
3 Further work

The simulation derived spectrum reuse ratings were developed on the assumption of a uniformly distributed (location and antenna orientation) basis. Whilst this was considered necessary in order to derive a simple Monte Carlo limit function for consistently comparing antenna patterns with widely varying characteristics, the actual geographic distribution and orientation of FWS growth does not necessarily follow a uniform distribution. This is particularly the case for long-haul FWS, which follow distinct trend lines. As we move closer to urban centres, trend lines do become more random, e.g. Fig. 9. Accordingly, further study may be required to analyse the behaviour of the radio-relay trunk route in respect of preferred antennas for such application.

Finally, the simulation employed a homogeneous interference environment with all antennas being the type currently under test. Recognizing that a major contributor to spectrum denial would be the interaction between the main lobe of the antenna at one end of the interference path, and the back, side or cross-polar gain of the antenna at the other end of the path, it would be desirable, although more complex, to devise a simulation using a non-homogeneous antenna type environment. In analysing the results of such a simulation it would be useful to test the correlation with rating of absolute back, side and cross-polar gain parameters, as well as their ratios (e.g. F/B) to forward gain.

FIGURE 9

18 GHz FWS trend lines around Sydney, Australia



4 Summary

In an increasingly congested interference limited microwave spectrum environment, it is important to establish antenna technical criteria that are consistent and facilitate the efficient use of the radio-frequency spectrum. Antenna radiation parameters are a dominant spectrum reuse limiting factor and to develop effective certification criteria it is necessary to develop a quantitative methodology that takes account of several statistically confounded (antenna RPE) variables.

The simulation results confirm that no single antenna radiation parameter in isolation provides a consistently reliable estimate of antenna spectrum efficiency. However, the antenna *F*/*B* ratio parameter is a potentially useful estimator for the co-polar case and at least one administration is considering using it for antenna certification purposes [7]. We have also considered evidence to show that comparisons based on simple aperture/gain/beamwidth criteria and/or an arbitrary co-polar envelope can lead to ineffective outcomes, with the potential for adverse impact on spectrum utilization efficiency. A reliable, quantitative estimate of the spectrum efficiency of an antenna requires the concurrent evaluation of on-axis gain, co-polar and cross-polar radiation pattern envelope behaviour over the full (0°-360°) azimuth range. Such an estimate may be established using a constraint based Monte Carlo model, such as described in Annex 1. The studies presented in this document consider homogenous point-to-point FWS link populations with a uniform random distribution. However, for real FWS systems, especially radio-relay systems with interference paths concentrated along directional “trend lines”, the behaviour around the axis of the main beam may be more important and further studies on this aspect are anticipated.

5 Conclusions

a) The use of UHP antennas, with optimum co-polar and cross-polar patterns lead to potential spectrum utilization up to five time higher than STD models.

b) The use of HP models also leads to significantly higher FWS spectrum reuse and should be preferred over STD models in high spectrum usage areas.

c) Notwithstanding (a0 and b)) above, UHP and HP antenna models are more expensive than STD types and economic efficiencies also need to be taken into account.

d) The use of HP antenna types should be preferred over STD types in urban and other high density use areas, including any such areas subject to coordination with neighbouring administrations.

e) Administrations should encourage operators to use of HP and UHP antenna types in high spectrum use areas.

f) In developing antenna certification arrangements, administrations may consider the application of Monte Carlo techniques, such as detailed in this Annex, to samples of real antenna radiation characteristics as a means to consolidating consistent outcomes.

g) Further studies are needed on preferred antenna characteristics and it is suggested that this study be brought to the attention of Radiocommunication Study Group 1 (Spectrum Management).

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Annex 1

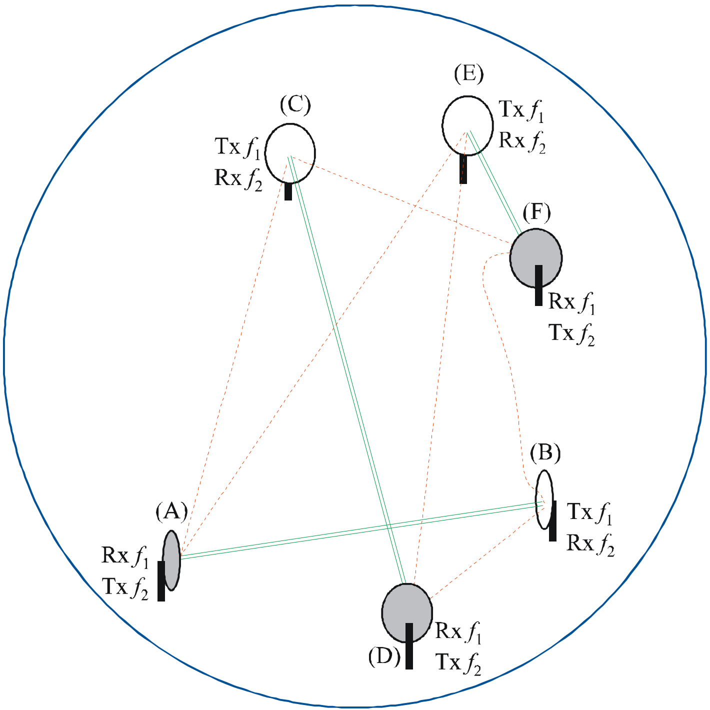
Simulation methodology

In the real terrestrial service FWS environment new point-to-point links may be introduced as long as they do not cause interference to, or suffer interference from other existing FWS operating on the same frequency channels. As the density of use increases, antenna orientation and side-lobe performance play an increasing role in determining the success or failure of coordinating a new link. Narrow-beam antennas with minimal side lobes minimize the overall interference levels in the direction of the population of potential victim receivers, thus maximizing the potential number of services that can theoretically be accommodated within a given coordination area.

A Monte Carlo computer simulation can be applied to emulate a homogeneous point-to-point FWS environment, with the FWS antenna as the device under test[4]. The model parallels a real world interference environment with the growth of digital fixed networks in an urban area of defined radius and with uniform FWS distribution (location, orientation). Figure 10 demonstrates the concept, with a circle representing a coordination area of radius R, centered on an arbitrary location. In this example, three co-channel point-to-point FWS operate within the defined coordination zone, the double lines representing the wanted signal paths and interference paths shown as dotted lines.

FIGURE 10

Signal and interference (dotted line) paths, *N* = 3



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From Fig. 10 we can establish that the number of coordination calculations needed is:

$$c(k) = 0, 2, 6, 12, 20 \qquad \text{or}$$

$$c_k = c_{k-1} + 2(k-1) \qquad \{\ \forall\ k \in \aleph\ \} \tag{2}$$

which simplifies to:

$$C(n) = \sum_{n=1}^{N} 2(n-1) = N^2 - N \qquad \approx (O)\, N^2 \tag{3}$$

Thus the computational order of the coordination model algorithm is *N* squared, where *N* represents the total (maximum) number of attempted coordinations in any given run of simulation.

The simulation algorithm is outlined Fig. 11. The coordination parameters are given in the next section.

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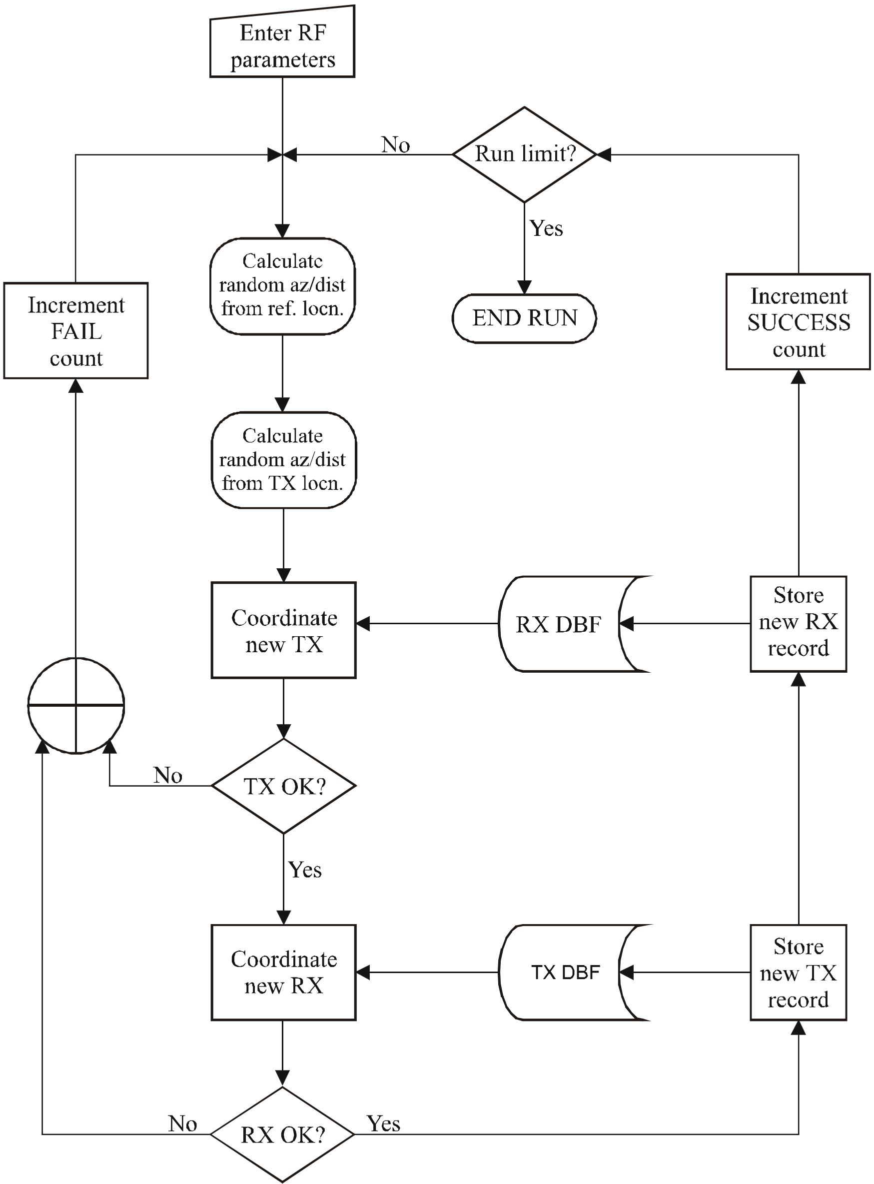
[4] Question 110-1/9 – Antenna radiation patterns of fixed wireless statios for use in sharing studies.

FIGURE 11

Simulation algorithm



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At each iteration of the simulation, a new point-to-point FWS is introduced into the simulation environment and coordinated against all previously defined FWS links. If the interference levels to/from the proposed new FWS are calculated as acceptable then it is accepted into "service" and its details included in a database of successfully coordinated FWS. If the single-entry interference levels exceed the specified (d*T*/*T*) interference threshold criteria, then the orthogonal (H or V as the case may be) polarization is attempted[5]. If this should also fail, then the attempt is abandoned, the failcount increments and, as long as the attempt count *N* is not exceeded, the simulation proceeds to the next iteration.

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[5] The simulations were carried out only for linear polarizations as that is normally used for terrestrial point-to-point FS.

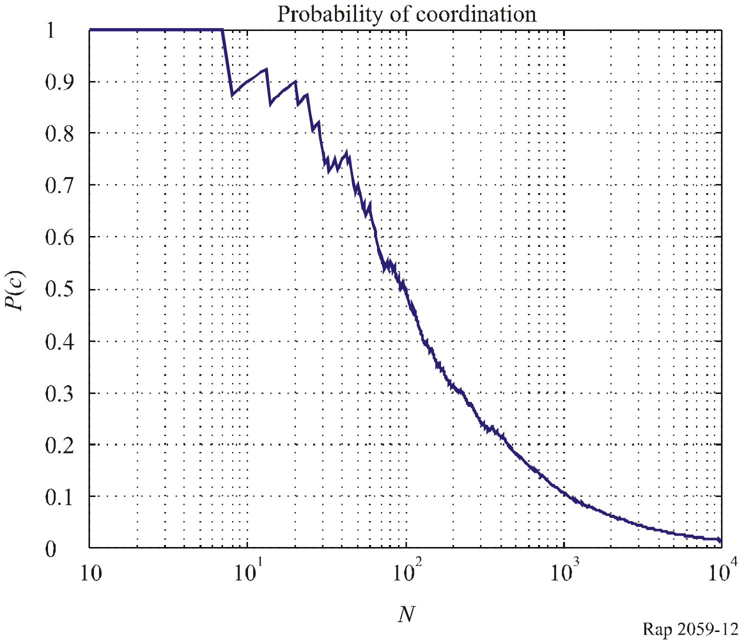
The probability of successful coordination, $P(c)$, is a form of limit function (4), inversely proportional to the probability of received interference power exceeding the threshold criteria:

$$P(c) = \frac{1}{1 - P(Interference \geq threshold)} \tag{4}$$

For the first iteration, FWS (“A ↔ B”), P(c) = 100%, since there are no interference sources and the probability of interference $P(I) = 0$. With the introduction of the second link it is now possible that interference above the threshold value may occur. Accordingly, it is now necessary to calculate and evaluate intersystem interference levels (i.e. signals propagated over the paths shown by the dotted lines of Fig. 10). In this and subsequent cases, the probability of interference power exceeding the threshold level is dependent upon the relative locations and azimuths of the interferer and victim antennas, and the off-axis discrimination performance of those antennas. The probability of interference increases as the population density inside the coordination area rises and at some point, coordination failures will begin to dominate the model with decreasing numbers of new co-channel services able to be accommodated.

FIGURE 12

Probability of success (*N* = 10 000)



At each iteration of the coordination model, a count is maintained of successful and unsuccessful coordinations. At the conclusion of the simulation, the number of successes is recorded together with other relevant details including the model of antenna under test. The results can be normalized for later comparison against runs of the simulation using one or more other antennas.

For each simulation run, we change the antenna characteristics (manufacturers RPE), but hold all other non-probabilistic parameters constant.

In this simulation model, the antenna which allows the greater number of services to be coordinated represents a “better” antenna than one with a lower score of successful coordinations, assuming that all other parameters are kept constant.

Coordination model

The simulation assumes that point to-point FWS are:

- uniformly distributed within an area of 100 km radius – i.e. a high density urban area;
- free space propagation model is used, with all links co-channel and equal bandwidth;
- individual link path lengths are normally distributed about the mean value.

Based on the input parameters and the antenna gain parameters, the interference power levels at the potential victim receiver are calculated. The calculation is based upon a single-source co-channel interference budget, i.e. although interference signal power is cumulative, for the purposes of simulation it is reasonable to assume that a single interferer will be dominant.

$$I = P_t + G\angle t - L_t - L_b + G\angle r - L_r \tag{5}$$

where:

I: interference power (dBW)
P_t: transmit power (dBW)
L_t: transmit feeder loss (dB)
$G\angle t$: transmit antenna effective gain (dB)
L_b: total propagation loss (dB)
$G\angle r$: receive antenna effective gain (dB)
L_r: receive feeder loss (dB)

and

$G\angle t = G(0) - G(\theta)$ {for co-polar signals}
$G\angle r = G(0) - G(\varphi)$
$G(0)$: On-axis gain (dBi)
$G(\theta)$, $G(\varphi)$: Antenna gain at relative azimuth (dB)

$$(G\angle t + G\angle r) = 10 \log \left[10^{\frac{G_t H + G_r V}{10}} + 10^{\frac{G_t V + G_r H}{10}} \right] \quad \text{\{for cross-polar signals}^{6}\text{\}} \tag{6}$$

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[6] For further details see Recommendation ITU-R F.699, *recommends* 7 and its Annex 2.

RF parameters

The path length and RF parameters are consistent with ACA database information for Australian medium capacity digital systems operating in the band 7 425-7 725 MHz (Rec. ITU-R F.385-6) and similar to those described in Recommendation ITU-R F.758:

Bandwidth: 14 MHz
Transmit power: +30 dBm
Transmit feeder loss: 3 dB
Mean path length: 34.6 km
Receiver feeder loss: 3 dB
Receiver noise figure: 3 dB
Receiver noise: –125 dBW
Allowable $\mathrm{d}T/T$: 1.0 dB