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.

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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 $T = 1$:

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

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,

[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.

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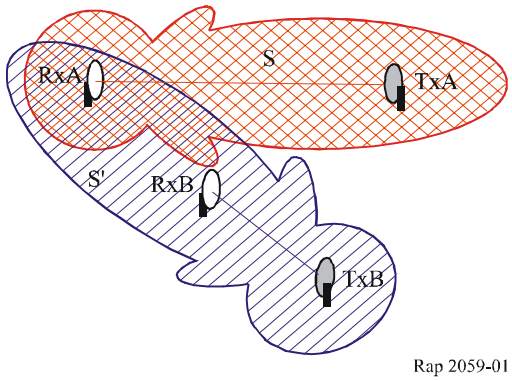
inter alia[2], by the susceptibility of the victim receiving system to interfering emissions (i.e. receiver sensitivity and the required grade of service). In principle this is somewhat analogous to the establishment of a coordination area.

FIGURE 1

Spectrum denial area "S"



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.

[2] In addition to the system gain parameters.

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FIGURE 2

Diameter (m) vs. gain (dBi)

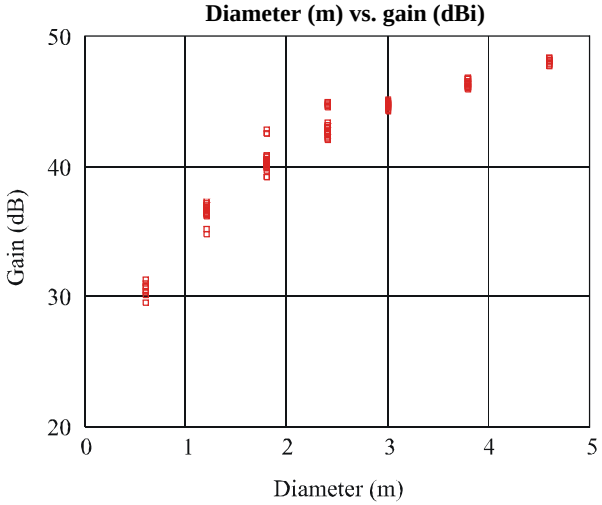
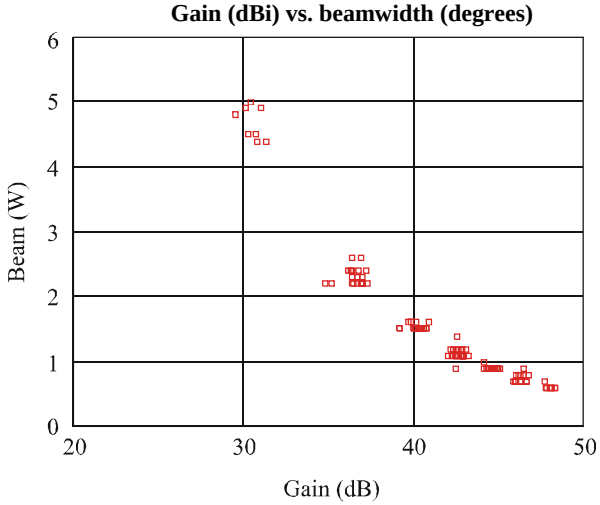


FIGURE 3

Gain (dBi) vs. beamwidth (degrees)



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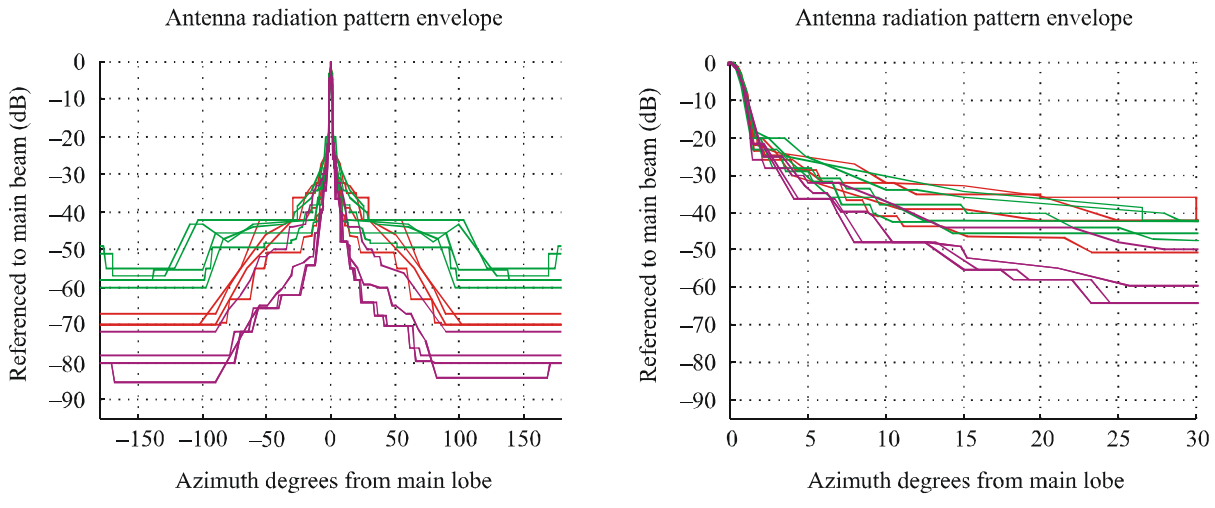
Similarly, the behaviour of on-axis gain vs. half power beamwidth is relatively well conditioned (Fig. 3), with the statistical variation including some deliberate antenna design tradeoffs. Accordingly, the behaviour of these parameters is easily approximated using established mathematical models. However, 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.

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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.

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– *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.

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