# ETSI TR 101 938 V1.2.1 (2002-06)

*Technical Report*

## Fixed Radio Systems;
## Electronically steerable antennas;
## Multipoint (MP) antennas;
## Fixed Wireless Access (FWA) radio systems

Reference

RTR/TM-04115A

Keywords

radio, antenna, multipoint

***ETSI***

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

# Contents

# Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (http://webapp.etsi.org/IPR/home.asp).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

# Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Transmission and Multiplexing (TM).

# Introduction

The present document discusses general properties of electronically steerable antennas and attempts to identify properties that must be regarded in standardization work. Its purpose is to facilitate the creation of standards related to electronically steerable antennas for use in fixed wireless multipoint applications.

# 1 Scope

The present document identifies the issues of electronically steerable antennas. An electronically steerable antenna is used in Point-to-Multipoint (P-MP) or Multipoint-to-Multipoint (MP-MP) systems to cover different directions with narrow beams and high gain.

# 2 References

For the purposes of this Technical Report (TR) the following references apply:


[1] EN 60950: "Safety of information technology equipment".

[2] Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity (R&TTE Directive).

[3] ETSI ETS 300 456: "Satellite Earth Stations and Systems (SES); Test methods for Very Small Aperture Terminals (VSATs) operating in the 11/12/14 GHz frequency bands".

[4] ETSI EN 302 085: "Fixed radio systems; Point-to-multipoint antennas; Antennas for point-to-multipoint fixed radio systems in the 3 GHz to 11 GHz band".


# 3 Definitions, symbols and abbreviations

## 3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

**antenna:** part of the transmitting or receiving system that is designed to transmit or receive electromagnetic radiation

**antenna directivity:** ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by $4\pi$. If the direction is not specified, the direction of maximum radiation intensity is implied.

**antenna gain:** ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. The radiation intensity corresponding to the isotropically radiated power is equal to the power accepted (input) by the antenna divided by $4\pi$.

**antenna efficiency:** ratio of antenna gain to antenna directivity. It corresponds to the amount of losses in the antenna

**boresight:** axis of the main beam in a directional antenna

**Central Station (CS):** base station which communicates each way with many terminal stations and, in many cases, repeater stations

**co-polar pattern:** diagram representing the radiation pattern of a test antenna when the reference antenna is similarly polarized, scaled in dBi or dB relative to the measured antenna gain

**cross-polar pattern:** diagram representing the radiation pattern of a test antenna when the reference antenna is orthogonally polarized, scaled in dBi, or dB relative to the measured antenna gain

**fixed beam:** radiation pattern in use is fixed relative to a defined mechanical reference plane

**gain:** ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically

**isotropic radiator:** hypothetical, lossless antenna having equal radiation intensity in all directions

**input port(s):** flange(s) or connector(s) through which access to the antenna is provided

**main beam axis:** direction for which the radiation intensity is a maximum

**main beam:** radiation lobe containing the direction of maximum radiation

**Radiation Pattern Envelope (RPE):** envelope within which the radiation pattern shall fit

**radiation pattern:** diagram relating power flux density at a constant distance from the antenna to the direction relative to the notional antenna main beam axis. Specifically referenced in the present document to the zero degree reference direction.

**Repeater Station (RS):** radio station providing the connection via the air to both the central station and the terminal station(s). The remote station may also provide the interfaces to the subscriber equipment, if applicable.

**sector angle:** declared angle of coverage in azimuth of a sectored antenna, and is related to the range of pointing angles

**Terminal Station (TS):** remote (out) station which communicates with a central station

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

| | |
|---|---|
| dBi | Decibels relative to an isotropic source |
| GHz | GigaHertz |

## 3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

| | |
|---|---|
| CS | Central Station |
| MTBF | Mean Time Between Failures |
| P-MP | Point-to-MultiPoint |
| RPE | Radiation Pattern Envelope |
| RS | Repeater Station |
| TS | Terminal Station |

# 4 Overview of electronically steerable antennas

## 4.1 General properties

An antenna is the part of the radio equipment that is designed to radiate or receive electromagnetic waves. There are a number of ways to affect the performance of an antenna with electronics. In the present document only a certain type of electronically steerable antennas are discussed. These are antennas that can point a narrow beam inside a sector angle. Switching between directions is done electronically without mechanical motion. The antenna contains no frequency translation devices such as mixers and can essentially be treated as a linear device as far as RF is concerned.

Other categories of electronically steerable antennas are for example antennas where the beamwidth can be altered, where nulls in the radiation pattern can be introduced, the polarization can be changed or any other way in which the radiation pattern can be altered. These categories will not be treated in the present document.

The requirements of using an electronically steerable antenna with a central station or repeater station should essentially be similar to what is required of a sectored CS antenna. The focus of the present document will be on the usage of these antennas for CS and RS. The antennas could also be used with TS systems and could be of benefit to all stations in mesh topology networks. This would however require studies on intersystem interference.

Benefits of electronically steerable antennas include:

- An electronically steerable antenna can direct a narrow beam over a sector angle and give coverage like a sector antenna.
- The narrow beam corresponds to a high antenna gain and thus reduces power and amplification requirements on radios.
- The narrow beam width reduces multipath propagation problems.
- Complex and dynamically re-configurable radio networks can be created exhibiting high spectrum efficiency.
- If the steering of antennas is coordinated it potentially enables the reuse of frequencies and timeslots in different directions.

Drawbacks include:

- There is an increase of complexity in the antenna.
- There will be losses in the RF-electronics in the antenna which lowers the antenna efficiency.
- The use of non-linear devices in the antenna will demand that spectrum issues be addressed.

## 4.2 Technology overview

There are a number of techniques to achieve electronically steerable antennas. They are here divided into three groups; phased array antennas, multiple beam antennas and other types of electronically steerable antennas.

### 4.2.1 Phased array antennas

Phased array antennas consist of several radiating elements. By exciting the elements with different amplitude and phase the radiation of the elements will combine constructively in some directions and destructively in other directions. A narrow beam can be created and pointed in different directions.

### 4.2.2 Multiple beam antennas

Multiple beam antennas typically utilize Butler matrix networks, lenses, reflectors or a combination.

Essentially the antenna has several inputs and each input corresponds to the antenna pointing in a certain direction. The scanning is achieved by having a switch network that will switch between the inputs.

In a lens or reflector antenna different beam directions correspond to different focal points in the antenna geometry. A beam can be scanned by switching between feeds in the focus of the antenna.

A Butler matrix is a transmission line network that have several input ports and several output ports. An array of antenna elements are connected to the output ports of a Butler matrix. Placing a signal on one of its input ports will produce signals on the output ports that are phase shifted to make the antenna point in a particular direction.

Since all of these types of antennas are completely linear, superposition applies the possibility to utilize several beam directions simultaneously by connecting several inputs at the same time, hence the name multiple beam antennas. In the present document only the case when one direction at a time is used is considered.

### 4.2.3 Other types of electronically steerable antennas

There are other ways of creating electronically steerable antennas. A technique in so called adaptive antennas is to modify the baseband signal and upconvert it to high frequencies in a separate equipment chain for each antenna element. This type of steering is not considered in the present document.

Another approach to achieve steering is so called frequency scan antennas. They require a shift in frequency to scan the beam and is therefore unlikely to be useful for communications purposes. Hence they are not considered.

# 5 Radiation pattern specific issues

## 5.1 Merged Radiation Pattern Envelope

A method on how to compare electronically steerable antennas with conventional antennas is outlined.

For the purpose of standards the assumption that the electronically steerable antenna at any moment can point in any of the available pointing directions is made. If we merge the radiation pattern of all available pointing directions into one plot an envelope of radiation patterns can be identified (see figure 1).

This envelope represents the highest attainable gain in each direction. Thus it corresponds very well to the radiation pattern of a conventional antennas in terms of impact on coexistence issues. To avoid confusion with the term Radiation Pattern Envelope (RPE) the term "merged radiation pattern envelope" is suggested for this envelope.

The merged radiation pattern envelope method can be used for co-polar and cross-polar radiation pattern in both azimuth and elevation.

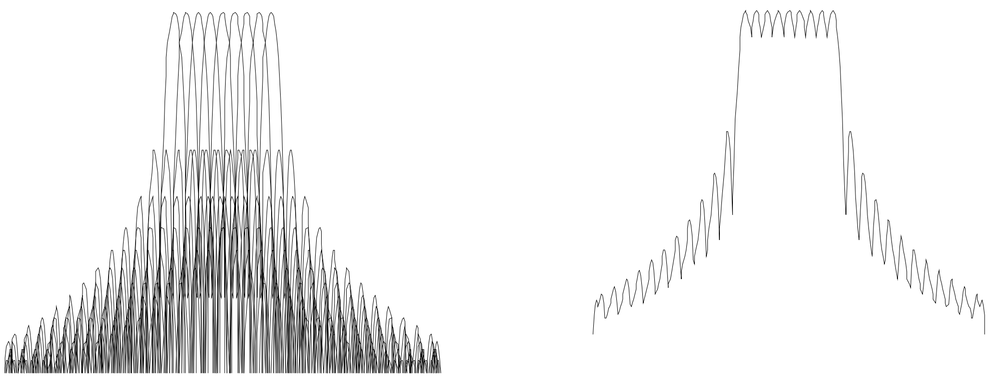

**Figure 1: Illustration of merged radiation patterns (left) and their envelope (right) for a multiple beam antenna**

## 5.2 Boresight gain

The boresight directivity of an electronically steerable antenna can approach that of a same size fixed beam antenna. Antenna efficiency may however be significantly lower than for a conventional antenna due to losses in electronics.

For a sector antenna the boresight gain is defined as the gain of the direction with the highest radiated intensity. This direction does not have to be in the middle of the sector angle. When it is of interest to compare an electronically steerable antenna with a sector antenna the relevant boresight gain is the top gain of the merged radiation pattern.

## 5.3 Scan sector

The scan sector refers to the angle sector which is declared to be covered by the antenna. A main beam can be pointed in different directions inside the scan sector. Some types of antennas (primarily multiple beam antennas) cannot be pointed continuously over the scan sector. In this coverage is achieved by having a discrete number of beams that overlap each other. The scan sector corresponds well to the sector angle covered by a sector antenna.

Properties that are important when planning coverage:

- The minimum attainable gain over the scan sector. (The attainable gain will be lower at overlap points on a multiple beam antenna for example.)
- The number of available pointing directions.

- The angle positions of pointing directions.
- The angle and amplitude of the sidelobes.

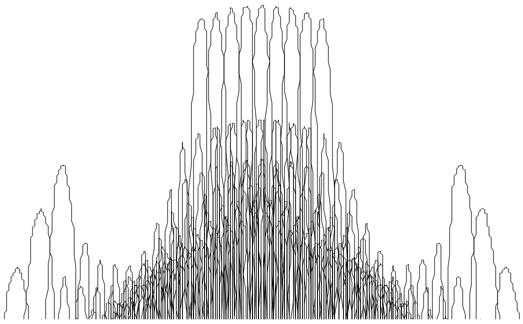

**Figure 2: Example of lobe patterns of an electronically steerable antenna**

## 5.4 Sidelobes

Sidelobes of an electronically steerable antenna will depend on which pointing direction is active. We distinguish between sidelobes inside and outside the scan angle sector. Sidelobes outside the scan sector may interfere with other systems working outside the declared scan angle, and the requirements on levels of these should be considered from an intersystem and interservice perspective.

Sidelobes inside the scan sector will be important if the system intends to reuse spectrum or timeslots in different directions inside the scan angle. For interference on other systems the sidelobes inside the scan sector will be of less importance than the main lobes.

## 5.5 Cross-polarization

Cross-polarization issues are similar to those encountered with other antennas. When designing an antenna it is often possible to employ symmetry features to reduce cross polarization. That is not possible for a steerable antenna which beams are not pointing along a line of symmetry in the antenna. Cross-polarization levels may also vary depending on which direction the antenna is pointing.

## 5.6 Elevation radiation pattern

Elevation radiation pattern may vary depending on pointing angle (see figure 3). The attainable gain will be lower at mainlobe overlap points for example.

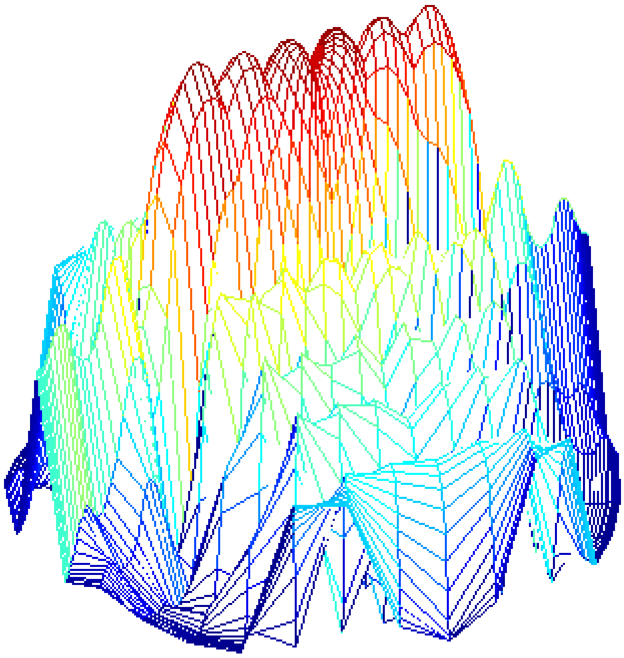

**Figure 3: Illustration of merged radiation pattern envelope in both azimuth and elevation for a steerable antenna with 6 discrete pointing directions**

# 6 Electronics related issues

## 6.1 Switching

The time to switch between different beam positions needs to be specified. Switch times are completely dependent of the technology used. Semiconductor switches and phase shifters can have switch times in the order of nanoseconds. Ferrite phase shifters can have switch times in the order of microseconds.

It is important that the antenna does not radiate above stipulated RPE during switching. If it is a feature of the design that this will be violated during switching then the RF power should be turned off during switching. This could be solved in the antenna or at the system level.

It is also important that the switching process does not cause the antenna to radiate outside the spectrum mask. If the cause is intermodulation, the problem can be solved by turning off RF power in the same manner as for the RPE. If the switching process itself introduce spurious emissions it can be handled with filters.

## 6.2 Gain stability

Depending on what electronics the antenna contains, the gain stability of the antenna can be an issue. For example if the antenna contain amplifiers the amplification may be dependent on temperature. It may therefore be necessary to set up requirements on gain stability.

## 6.3 Interfaces

There would typically be three interfaces when an electronically steerable antenna is connected to a system. They may all be on different connectors or two or all three may share the same connector. This should be agreed on between antenna manufacturer and user. When testing an electronically steerable antenna a manufacturer shall provide means to connect to the antenna and control it.

- RF input. The input connector for the RF would be similar to that for other antennas.
- Steering Control. An interface is needed to control the beam of the antenna.
- Power Supply. Electric power is necessary for the electronics.

## 6.4 Spectrum issues

Since electronically steerable antennas most often contain non-linear components, they may cause spectrum pollution. Hence requirements on spectrum must be addressed. The approach will be that systems employing steerable antennas should meet the same requirements as systems with conventional antennas.

Two paths are identified:

- The electronically steerable antenna should always be tested together with the rest of the system equipment. The complete system should meet the spectrum mask requirements.
- The electronically steerable antenna should give a small enough amount of intermodulation so that a system will meet the spectrum mask even if the antenna is connected to a system that lie on the limits of the spectrum mask.

Two factors will determine the intermodulation in the antenna:

- The amount of nonlinearity of the antenna.
- The RF power level applied to the antenna.

The impacts of intermodulation will be of two kinds:

- Spurious emissions inside the channel band will affect the performance of the system.
- Spurious emissions outside the channel band will primarily affect intersystem interference.

## 6.5 Noise

The noise performance needs to be considered for an electronically steerable antenna. If the antenna is passive it can be regarded as a similar conventional antenna with the same gain. If the antenna contains amplifiers, the noise figure of the antenna needs to be determined.

## 6.6 Input level range

The noise performance of the antenna will set a lower limit on the acceptable level of input signal on receive. On transmit the linearity of the antenna will set an upper limit.

## 6.7 Reciprocity

Some types of electronically steerable antennas are not reciprocal. That is they have different properties when transmitting and receiving. This can be due to what type of components are used in the switching or phase shifting devices. If an antenna is not reciprocal it should be declared and there should be two specifications on how the antenna perform on both receive and transmit. It is necessary to place requirements on receive mode because it will affect the output power of the stations it is communicating with.

It is possible to build an artificially reciprocal antenna by separating the rx signal path from the tx signal path and process them in non-reciprocal devices. This should however not be regarded as a reciprocal antenna.

## 6.8 Equipment failure issues

Multiple beam antennas have a predictable behaviour if the electronics fail. The pointing direction is governed by which input that is active. That may correspond to a certain input port of a Butler matrix or a certain feedpoint in a lens/reflector system. The antenna will not point in any direction that it cannot point under normal circumstances.

It is more difficult to assess phased array antennas behaviour if electronics fail. An outmost limit of error in pointing is given by the element factor of the array. The antenna will not radiate in a direction where the individual elements are not radiating. With more knowledge of the specific phase shifting technique used it may be possible to make a more precise prediction. To overcome this difficulty with a failure condition four alternatives are identified.

- Use radiating elements with an element factor that restricts radiation to be confined inside the RPE for the antenna. The drawback is that this would require the antenna to have sector antennas as its radiating elements. It may make the physical size of the antenna much larger than it otherwise would have to be.
- Include failure reporting mechanisms in the antenna (e.g. a return loss monitoring mechanism) so that the antenna can report to the connected system the need for some maintenance action (e.g. shut down RF-power to the antenna). The drawback of this is that it will increase the complexity and cost of the antenna.
- The terminal station systems with which the antenna communicates can report on if the antenna is working properly. If the reports stop coming in the CS or RS station that the antenna is connected to must shut down RF power. The drawback of this is that it will not work if the antenna starts to radiate where there is no terminal stations and the other terminal stations still detect a signal in the valid range.
- Do nothing. Given the disadvantages of the above approaches it may be a reasonable alternative if the failure condition can be appreciated to be very unlikely or the impact of it is not too severe. A manufacturer could provide documentation to show the probability and impact of failures.

Some sources of failures could be:

- Electronics fail. MTBF of antenna can be computed from MTBF of components.
- External factors such as lightning, animals, etc.

# 7 Other issues

## 7.1 Mechanical issues

An electronically steerable antenna has a narrower beam and typically presents a greater wind load, because of greater size, than a commensurate sector antenna. These two features require the antenna to be more mechanically stable than a sector antenna. In other regards the mounting issues of an electronically steerable antenna are similar to those encountered with sector antennas.

## 7.2 Esthetical issues

An electronically steerable antenna is typically larger than the commensurate sector antenna. Some local authorities may impose restrictions on antenna installations with regard to the esthetical impact. For example it may be required that antennas below the roofline have a diameter of less than one meter.

Electronically steerable antennas can have many appearances depending on the technology employed. The number of available designs is almost as diverse as for conventional antennas.

## 7.3 Safety, EMC, overvoltage protection and microinterruptions on power supply

It is expected that the antenna must meet the same requirements as radio equipment in these respects, due to the need of power supply. The issues regarding safety are dealt with in the low voltage directive described in EN 60950 [1] and in the R&TTE Directive [2]. Lightning protection issues are described in ETS 300 456 [3] and similar requirements hold for electronically steerable antennas.

# 8 Conformance tests

There are some new challenges when testing electronically steerable antennas.

## 8.1 Radiation pattern

For a multiple beam antenna each pointing direction can be measured in both azimuth and elevation and for both co- and cross-polarization. Essentially the measurements of each pointing direction are done in the same way as for a fixed beam antenna. If an antenna is declared not to be reciprocal it should be tested in both receive and transmit mode.

Suggested test procedure for a antenna that is steerable in azimuth (see figure 4):

The antenna is first measured in azimuth for each pointing direction, in the case of an antenna with a discrete number of beams. In the case of a continuously variable scanning antenna, measurements should be made at the two extremes and the centre of the scan sector as a minimum. The measurements of all pointing directions are superimposed on the same graph. All radiation should fit below the prescribed RPE for the relevant antenna class (see clause 5.1).

The antenna is then mounted so that the elevation plane of the pointing direction under measurement lie in the horizontal plane. The measurement of all elevation patterns are superimposed on the same graph. All radiation should fit below the prescribed RPE for the relevant antenna class.

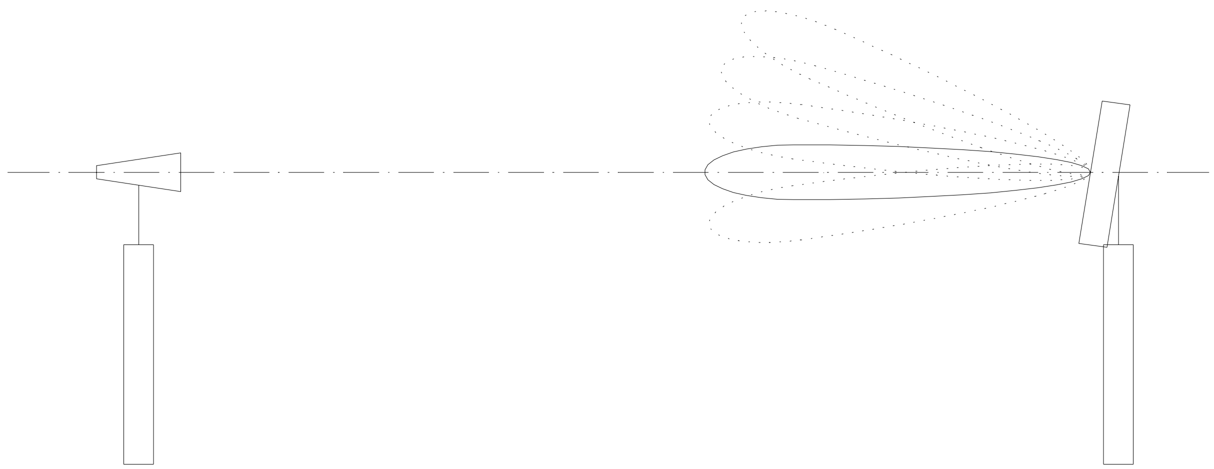

**Figure 4: Illustration of measurement of radiation pattern in elevation for an antenna that is steerable in azimuth**

## 8.2 Spectrum

The need for the emitted spectral density of the system including the antenna should be investigated. The manufacturer may be required to provide access points so that the radiated spectrum can be measured. For example in a multiple beam antenna employing reflector antennas the connector to the feed antennas can be the access points.

# 9 Relation to existing standards

## 9.1 Comparison to EN 302 085

EN 302 085 [4] is a standard for point-to-multipoint antennas in the 3 GHz to 11 GHz range. It can serve as an example for how to relate electronically steerable antennas to standards for sector antennas.

When an electronically steerable antenna is employed with a CS or RS system the antenna effectively replaces a CS sector antenna. The sector antennas requirements should be adequate for the steerable antennas with appropriate translations as discussed below.

Letting the merged radiation pattern envelope (as defined in clause 5.1) take on the role of the CS sector antennas' radiation pattern, the requirements for electronically steerable antennas can be completely aligned to the requirements of CS sector antennas of EN 302 085 [4] for both co-polar and cross-polar pattern.

The RPEs in the P-MP antenna standard EN 302 085 [4] are defined relative to boresight gain of antennas. In analogy the RPE of an electronically steerable antenna should be defined relative to the maximal attainable gain in the scan sector (the top of the merged radiation pattern).

Antenna classes could be defined as in clauses 5.2.1 and 6.2 with the only difference that the merged radiation pattern envelope rather than the radiation pattern should lie beneath the prescribed RPE.

The boresight gain requirement specified in clause 6.2.2 could be an adequate requirement for the "boresight" (top of the merged radiation pattern envelope) of an electronically steerable antenna.

The elevation RPE requirements in clause 6.4 should be applicable in the same manner for the merged radiation pattern envelope in elevation.

# 10 Conclusions

Electronically steerable antennas applied to CS or RS have advantages compared to traditional sector antennas, among other things they can give sector coverage with a narrow beam.

There are several techniques to build electronically steerable antennas. We have identified the properties that are common to antennas of phased array and multiple beam types and that may be of interest in standardization work. The list of issues discussed is believed to be more exhaustive than is necessary to include in a standard.

Standards for electronically steerable antennas can be created in alignment to existing standards for conventional antennas. The impact of employing electronically steerable antennas on frequency co-ordination should be beneficial compared to commensurate sector antennas.

# History

| Document history | | |
|---|---|---|
| V1.1.1 | February 2002 | Publication (withdrawn) |
| V1.2.1 | June 2002 | Publication |
| | | |
| | | |
| | | |