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Digital Radio Mondiale in the 26 MHz band (25 670-26 100 kHz)

BS Series

Broadcasting service (sound)

International Telecommunication Union

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REPORT ITU-R BS.2251

Digital Radio Mondiale in the 26 MHz band (25 670-26 100 kHz)

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Introduction

Countries around the world are migrating from analogue to digital broadcasting techniques for television and radio. This document looks at sound broadcasting opportunities in the 26 MHz band for local coverage using Quasi Line-of-Sight propagation.

The document is intended to:

– describe service planning in the 26 MHz band and explain why, and how, a broadcaster might use this band for local broadcasting using the Digital Radio Mondiale (DRM) system;

– address some potential interference concerns when using this band for local transmissions during high levels of solar activity;

– provide new information based on practical experience with DRM used for local coverage in the 26 MHz band.

CONTENTS

1 Purpose of the document

Radio and television broadcasting is migrating to digital modulation schemes which better exploit the possibilities offered by existing and new delivery platforms. Digital modulation offers significant advantages in being able to give:

– consistent quality which is less dependent on variations in the propagation channel;
– more effective use of channel capacity through resilient coding and advanced compression techniques;
– easier access through automatic or assisted tuning;
– versatility, by including audio visual and data information in the same channel.

Recognising that analogue broadcasting technologies still find significant use and will continue to do so for some time to come, this document will restrict itself to consideration of digital systems.

While the internet and associated systems are playing an increasingly important role in the delivery of sound broadcasting services, conventional terrestrial radio still plays a very important part in delivering radio to wide audiences around the world. Demand for services outstrips the channel capacity and so there is pressure to increase that capacity. More efficient digital formats play a major part in this quest.

This document examines the possibility of using digital formats in the 26 MHz HF broadcasting band 25 670 kHz to 26 100 kHz. This part of the spectrum has limited use at the moment.

2 Why consider the use of this band for digital sound broadcasting?

Traditionally sound broadcasting has been carried out in the LF, MF, HF and VHF (II) bands. More recently, digital (DAB) sound services have been deployed in the VHF (III) band in certain parts of the world. With the exception of the HF bands, where the unique propagation characteristics are vital to long distance international sound services, VHF Band II has become predominant; so much so that in many parts of the world the 88 to 108 MHz band has become crowded and there is little or no opportunity for new services to be introduced.

For various reasons – not least, better use of spectrum – some countries are considering, or are in the process of introducing, digital sound broadcasting systems. At the present time the majority of such services are located in VHF Band III using the DAB system. It has not been easy (or even possible) to introduce DAB services into Band II because it is already heavily used and the introduction of a single DAB multiplex would require 8 existing services to be switched off to make space.

Past experience has shown that it can take a long time for a new broadcasting format to establish itself. FM in Band II was around for a very long time before it became the predominant sound broadcasting system (replacing AM in the MF band). It is therefore to be expected that any radio service will have to be simultaneously broadcast in both the old, analogue, and new, digital formats until the bulk of the audience has migrated. Obviously, this will create an increase on the demand of spectrum (albeit potentially temporary) and further inhibit any possibility to introduce new services.

The quality of analogue sound broadcasting in the LF and MF bands is currently perceived as poor. This is one of the causes of the decline in its use by its traditional users; both broadcasters and audiences. Despite this there is still a large residual use. In certain parts of the world, including parts of Europe, the LF and MF bands are crowded. For various reasons – not least the cost – they have traditionally been unattractive to local and community broadcasters.

There remains, an increasing demand for radio services covering small areas: local and even community audiences. Service areas are often less than a few kilometres radius, covering just a small part of a town or city. Where there is heavy congestion in the MF and VHF bands, this need could be satisfied by using the 26 MHz band. The cost of setting up a local station, the on-going running costs and quality of coverage are important issues to be considered. Use of digital modulation techniques would certainly provide the quality of coverage, while requiring lower transmitter power and hence lower ongoing cost.

The DAB system is suitable for covering large areas. This is particularly true where a number of broadcasters have the same geographical coverage aspiration and where several high power transmitters can be synchronised into a large single frequency network. DAB is thus suitable for national and regional coverage. Its cost to benefit balance is less pronounced where the coverage aspirations of the participating broadcasters in a given multiplex are not the same; this is frequently the case with small, local or community, broadcasters. Conventional DAB only becomes efficient in its use of spectrum when multiple transmitters can use the same channel to cover a large area. It can therefore be unattractive to local broadcasters who wish neither to reach, nor pay the transmission fees, to cover larger audiences. The DAB+ system partly addresses this by having more stations in the multiplex, thereby offering better spectral efficiency without the need for single frequency networks. However, this implies that an even greater number of stations will have to be found which are seeking identical coverage. This again limits its attractiveness to small broadcasters who might be better served by a transmitter designed to match their unique coverage requirements.

The 26 MHz broadcasting band (the highest HF Band, from 25.670 kHz to 26.100 kHz) is currently allocated to HF broadcasting, where analogue, amplitude modulation is used to cover large (international) areas (possibly several thousands of square kilometres).

This band is little used, because it is only of value to international broadcasters for a small part of the 11 year cycle when sunspot activity is high. When sunspot activity is lower it is not used at all. When sunspot activity is high, use is still limited as many international broadcasters are unwilling to invest in antennas that are only of use for a small proportion of the time. Its use for local broadcasting has therefore been considered.

3 What digital broadcasting systems might be considered?

The most appropriate digital modulation scheme currently available for the 26 MHz broadcasting band appears to be DRM30[1]. The HD Radio specification does not include modes which allow it to work in the HF band. While HD Radio operation in this band is a technical possibility, no tests appear to have been carried out. DRM was originally conceived as a digital medium for use in all of the LF, MF and HF bands below 30 MHz. Propagation conditions in the HF band can be hostile; much development effort was expended in making DRM work in these hostile conditions and so it is ideally suited to the 26 MHz HF band.

Apart from a few experimental transmissions, the 26 MHz band, like all the HF broadcast bands, is currently the preserve of analogue AM (see § 4). Compared with FM and DAB, AM is very frugal in its use of spectrum, but suffers from poor subjective audio quality. The DRM system has been specifically developed to work in (among others) the HF bands. Considerable R+D effort was expended in developing the DRM system to get the best audio quality available from a given HF channel. Existing transmissions in the lower HF bands show that while not up to the standard of (analogue) FM, remarkably high audio quality can be obtained. Further to this, the DRM

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[1] DRM30 is the DRM system initially designed for use in the frequency bands below 30 MHz.

specification incorporates various operational modes which trade audio quality against robustness in difficult propagation conditions and allow the use of channel bandwidths wider than the 9 or 10 kHz usually associated with AM broadcasting.

4 The 26 MHz band

The 26 MHz broadcasting band (often referred to as "the 11 metre band"):

– comprises the frequencies between 25 670 and 26 100 kHz;

– has found little use for international broadcasting during the previous few years (as reported by HFCC);

– provides a total of 43 channels on the basis of a 10 kHz channel raster;

– offers the opportunity for local broadcasting, the service would rely on "Quasi Line-of-Sight" propagation, similar to current VHF Band II FM transmissions.

Local broadcasting has the potential to attract wider audiences and higher commercial interest than international broadcasting.

A number of tests of DRM30 at 26 MHz have shown the feasibility of using this band for local services (see Annex 5).

4.1 The existing use of the 26 MHz band

The band 25 670 kHz-26 100 kHz is allocated to the broadcasting service under Article 5 of the Radio Regulations (RR), as shown in Table 1.

TABLE 1

Allocation of the 26 MHz band in the ITU RR

Allocation to services		
Region 1	**Region 2**	**Region 3**
25 550-25 670 kHz	Radio astronomy 5.149	
25 670-26 100 kHz	Broadcasting	
26 100-26 175 kHz	Maritime mobile 5.132	

Appendix 11 of the RR, "System specifications for double-sideband (DSB), single-sideband (SSB) and digitally modulated emissions in the HF broadcasting service", provides details of the analogue and digital modulation systems that may be used (RR 23.6).

At the moment, the 26 MHz band is used for very long distance international services and so its use has to be coordinated internationally. Planning of broadcasting services in the 26 MHz band is described in the ITU RR in Article 12, "Seasonal planning of the HF bands allocated to the broadcasting service between 5 900 kHz and 26 100 kHz". This gives the procedures to be used in the planning of the HF broadcasting service and supports the concept of informal coordination to resolve incompatibilities. Currently this is carried out in three International Coordination Groups:

– The High Frequency Coordination Conference (HFCC);

– Arab States Broadcasting Union (ASBU);

– The Asia-Pacific Broadcasting Union High Frequency Conference (ABU-HFC).

These groups meet twice a year to resolve incompatibility problems in the relevant broadcasting season. Details can be found at:

http://www.itu.int/ITU-R/terrestrial/broadcast/hf/coord/index.html.

In a few countries, the 26 MHz band is used for other local applications, including:

– Inductive applications;
– SAB/SAP;
– Defence systems.

4.2 Technical considerations related to the 26 MHz band

Transmissions at 26 MHz can propagate in three different ways:

Ground wave – This is sometimes referred to as a surface wave as the energy propagates near the surface of the earth. At 26 MHz, the distance travelled is limited to a few kilometres and depends on the conductivity of the earth's surface (see Recommendation ITU-R P.368 and the ground wave handbook now in draft in Study Group 3).

Space wave – Sometimes referred to as line-of-sight as the energy travels in a straight line from the transmitting antenna to the receiver (and at these frequencies will also include significant energy diffracted over hills and around buildings, etc.). The range depends on transmitter power and the height above ground of the transmitting antenna (the distance to the radio horizon) and can be measured in tens of kilometres.

Sky wave – In this propagation mode the transmitted wave is reflected by the ionosphere and returns to the earth's surface. It can then be reflected (again) back to the ionosphere for further reflection. The distance travelled can be measured in many thousands of kilometres.

International transmissions in the 26 MHz band use sky wave propagation. Transmissions for local services would use either ground wave or space wave or a combination of the two, depending on the type of antenna used.

Sky wave, or ionospheric, propagation of radio signals in the 26 MHz band is subject to large variations. Propagation changes from day to night, from season to season and from year to year (the latter following the 11 year solar cycle). At the maximum of the solar cycle, (high sunspot numbers) when sky wave propagation conditions are favourable, low power transmissions could cover remarkably long distances at certain times of the day and the season. When sunspot numbers are lower, propagation is restricted to the less predictable "sporadic E" mode.

Local services in the 26 MHz band using "space wave" propagation, which is not subject to the vagaries of the sunspot cycle or ionospheric variability, would be able to use the less robust/highest quality DRM modes. As the 26 MHz band is relatively large and little used, it would be quite feasible to utilize 20 kHz bandwidth transmissions, further improving quality and allowing stereo services.

A receiver, that is located close to a transmitter used for space wave local transmissions, will better protect itself against unwanted sky wave interference from other stations, at times of high sunspot activity. Larger areas might be covered, using single frequency networks of low power transmitters, exploiting the constructive nature of wave-interference from synchronised digital stations using OFDM modulation.

International sky wave transmissions usually employ far higher transmitter powers and higher gain transmitting antennas, than those used for local services. For receivers located toward the edge of the coverage area it is therefore possible that these long-distance transmissions will arrive with similar field strengths (see § 9). Even though local services can be planned to use low power, it is possible for some energy to be refracted by the ionosphere causing interference to other services some distance away. This can happen at different times of day, even at periods of low sunspot activity. For these reasons the technical parameters for planning local services and the design of the antennas for 26 MHz local services need to be set to minimise the possibility of such interference.

5 Service scenarios

Considering the use of the 26 MHz band for local broadcasting, the potential coverage area is up to around 30 km from each transmitter. Only local reception conditions need to be taken into account, notably:

Topography – Irregular terrain profiles can produce NLOS areas with significant terrain diffraction attenuation, while regular profiles present more favourable reception conditions.

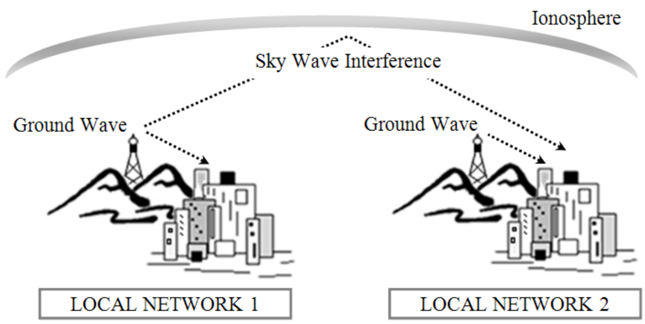
Reception environment – Rural areas offer better reception using lower transmission ERPs. Urban environments imply higher man-made noise levels, shadowing effects and multipath propagation.

This is analyzed qualitatively in Annex 2 and Annex 4.

Nevertheless, long range propagation should not be ignored in order to avoid co-channel interference from local transmissions on the same channel that are intended only to be received in another location, see Fig. 1.

FIGURE 1

Local DRM intra-system interference [1]



Ionospheric or sky wave propagation probability depends on two factors:

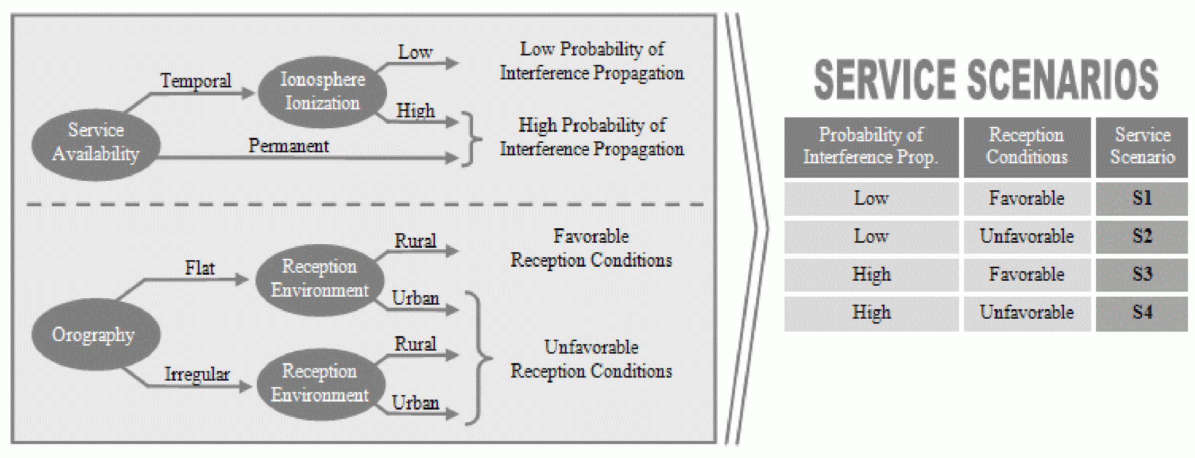
Ionosphere ionization – Sky-wave propagation will be more probable during periods of high ionosphere ionization. Under such conditions, interference is a problem that must be dealt with (further information about sky-wave interference can be found in § 9.1).

Service availability – International broadcasts will typically exist on a given frequency for a broadcast season or less. Given that even these services will not necessarily produce interference at all times, the resulting interference environment is subject to continuous change.

Four different service scenarios arise from a combination of these factors. Each gives a low or high probability of interference and favourable or unfavourable local reception conditions. This is shown in Fig. 2. The disparities between the scenarios are shown in the table on the right and lead to different network architectures, also shown in Table 2.

FIGURE 2

Service scenarios for local broadcasting in the 26 MHz band [1]



A more thorough analysis, based on Recommendation ITU-R P.1546, is given in § 10.

6 Network topologies

In order to obtain a given coverage area with a broadcasting service, three different network topologies can be considered: a single transmitter, multiple frequency networks or single frequency networks.

6.1 Single transmitter

This is the simplest way to provide coverage to a local area. However, it presents two disadvantages:

– high transmission power is needed in order to obtain large coverage areas – increasing the interference probability to other services (see § 9);

– Irregular environments or multipath may lead to shadows within the coverage area that cannot be covered with a power increase.

6.2 Multiple Frequency Networks

The same signal is transmitted from several transmitters using different channels (frequencies).

A transmission period without audio (silence) provides a short interval, during which a receiver might re-tune to an alternative frequency carrying the same programme, in order to assess its signal quality. If the quality on the alternative frequency is better, the receiver can stay on that frequency; if not, it can return to the original frequency. This operation will only work seamlessly if the audio signals on the alternative frequencies are accurately synchronised at the receiver. Where a receiver is equipped with dual signal decoding chains, it may compare two or more signals on a continuous basis or even combine the signals to provide a significant improvement through frequency and propagation path diversity.

As well as being able to operate with lower individual transmitter powers, the benefit of a Multiple Frequency Network (MFN) is that a second transmitter can give coverage in the shadow areas of the first without interfering with its reception. The disadvantages are that:

– receivers have to be able to switch from one frequency to another;

– more than one channel is used for a single service.

The first disadvantage is not an issue with DRM, as the information needed can be sent within the SDC. However, the second reduces the spectrum availability, which might not be acceptable in the 26 MHz band (see Annex 1).

An advantage of MFNs versus SFNs (see following section) is that different signals could sometimes be transmitted by different transmitters in different service areas, enabling more localized news or commercials. This is useful if the reason for using the network architecture is covering larger areas. It does not imply an improvement, however, if the goal is to deal with shadowing in a local area.

6.3 Single Frequency Networks

Single Frequency Network (SFN) operation uses a number of transmitters each with an identical signal on the same frequency. Generally, the arrangement of these transmitters leads to overlapping coverage areas. Within areas of overlapping coverage a receiver will receive signals from more than one transmitter. With careful design, and using several transmitters, a region or country may be completely covered using a single frequency, rather than a number of different frequencies (as with an MFN). Thus, spectrum efficiency is improved.

The benefit of adding a second transmitter is to increase the coverage area. The area where only the signal from one or other transmitter can be received can be considered as covered by a single transmitter. The areas where the contributions from the both transmitters have the same power are more problematic, as they can cancel each other. But, as it is stated in Annex 4, reception in the overlapping area is likely also to be possible. The OFDM modulation scheme used in DRM is specifically designed to maximise the constructive interference. This means that a network could be engineered to provide continuous and seamless coverage as the listener moves from the service area of one transmitter to that of another using only a single RF channel.

This network architecture might cause lower ionospheric interference levels if the transmitting sites and antennas are carefully chosen [1].

6.4 Network topology versus service scenario

The first step in determining the most suitable network architecture is to define the application environment in terms of ionospheric interfering signals propagation and local reception conditions. The possible scenarios have been defined in § 5, and a summary can be seen in Fig. 2.

Elevated transmitting sites, directive antennas and SFNs are the best ways to maximize local coverage area and minimize sky wave interference. These conditions might not be essential when the probability of interference is low, or the local reception conditions are favourable. In these cases, the cost of the network could be reduced. As a general result, Table 2 includes some “architecture” suggestions for local networks, depending on the service scenario.

TABLE 2

Suggested network architecture depending on the service scenario [1]

Service scenario*	Transmitter site	Transmitting antenna	Network architecture
S1	Low	Omni	Single Tx
S2	High	Omni	Single Tx
	Low	Omni	SFN
S3	High	Directive	Single Tx
	Low	Directive	SFN
S4	High	Directive	SFN

* Codes corresponding to services in Fig. 2.

7 Radiating systems

The intrinsic bandwidth of HF antennas is more than adequate for the 26 MHz band and HF antenna systems can normally be used without alteration [3]. Recommendation ITU-R BS.705 [2] explains the basic principles of the antennas used for both transmission and reception in the HF band. It also gives some guidelines for the choice of an optimum antenna. However, this recommendation does not consider local coverage, and should therefore be modified.

Studies on the use of the 26 MHz band for local services have led to two main conclusions, concerning the height, position and radiation pattern.

If a single transmitter is used, elevated locations are recommended, especially when the reception conditions are not favourable (irregular topography or high-density urban areas) [1]. Antennas may be placed in a lower location, under conditions of plain topography and in rural areas. Also, if a SFN is used network planning can be more flexible, as any shadowing due to lower antenna locations may be compensated with the coverage from other transmitters. Table 2 shows this relationship, based on the scenarios in Fig. 2.

The radiation pattern of the transmitting antenna influences the tropospheric to ionospheric propagation component ratio. Omni-directional antennas may be an adequate solution for services during periods of low ionospheric ionisation with transmitters placed inside the service area. Directional antennas are recommended, to reduce harmful interfering signals as much as possible. This is a challenging design problem, due to the electrical length of a 26 MHz antenna [1]. Further information about antenna radiation patterns dealing with ionospheric propagation is presented in § 9.1.1.

No particular antenna family has yet been found which minimizes radiation to the ionosphere. During tests in Brasilia, an unbalanced dipole was used (the vertical radiation pattern can be seen in Fig. 15). In Mexico, India and Rome, three element Yagi-Uda antennas were used; this was not intended to suppress ionospheric propagation and so vertical orientation was not optimum for this purpose. Another solution may be found in HF curtain antennas constructed of horizontal dipole elements, although these antennas would not be used for local area coverage [4].

In order to avoid F layer interference, radiation at elevation angles below 40º should be avoided; this is discussed in § 9.1.2. Additionally, the "Sporadic E" layer might also generate interference at low elevation angles – down to 0º – and so radiation at elevation angles above 0º should be avoided and antennas should direct the signal below the horizon (see Fig. 15).

8 Field strength predictions

Propagation conditions vary in both time and space. Received field strength must therefore be expressed in terms of statistics and not with determined values. Models which predict field strength values derived from tropospheric signal propagation, and refraction and diffraction around obstacles are traditionally considered for planning services in higher frequencies. The 26 MHz broadcasting band has traditionally been considered only for ionospheric propagation.

Recommendation ITU-R P.1546 [5] contains one of the models for higher frequencies. It provides some curves (field strength versus distance, depending on the frequency, ground type, transmitting antenna height and percentage of time above the given value) and methods to predict the field strength in a certain area in the frequency range 30 MHz to 3 000 MHz. As the 26 MHz band is close to this range, values could be extrapolated.

If Recommendation ITU-R P.1546 were to be used as a prediction method for DRM in the 26 MHz band, the remarks in [6] should be considered. This document presents the results of an accuracy check of the recommendation. It must be stated that Recommendation ITU-R P.1546-2 was used for this study, but currently Recommendation ITU-R P.1546-4 is in force.

Predicted values were compared with the measurements obtained in Brasilia, Mexico and New Delhi. While alignment was quite acceptable for Brasilia and New Delhi, there were significant differences in the results from Mexico DF.

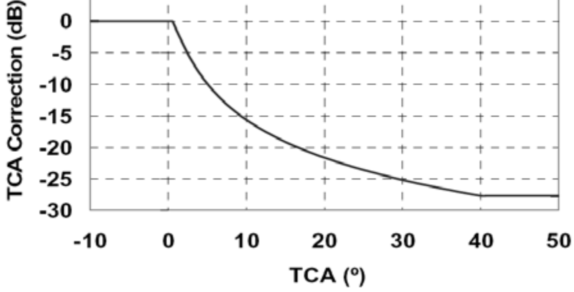
Several critical factors for field strength predictions of the 26 MHz signal were apparent:

Correction for receiving antenna height: the curves in the recommendation give field-strength values for a receiving antenna height above ground, h2 (m), equal to the representative height of ground cover around the receiving antenna location, R (m). Values of h2 which are different from the heights represented by the curve need correction according to the environment in which the receiving antenna is located. This is critical for short transmitter-receiver paths; the most likely case for 26 MHz local networks, where the coverage radius will be several kilometres around the transmitter (typically 10 to 40 km).

Terrain clearance angle (TCA): predicted field strength values are particularly influenced by this parameter. The reason is that a small variation in the value of the TCA implies a significant variation in the corresponding correction factor; an incorrect estimate of the TCA can lead to significant inaccuracies when planning the digital broadcast service. Fig. 3 shows this effect for 25.885 MHz.

FIGURE 3

TCA correction VS TCA (f = 25.885MHz) [6]

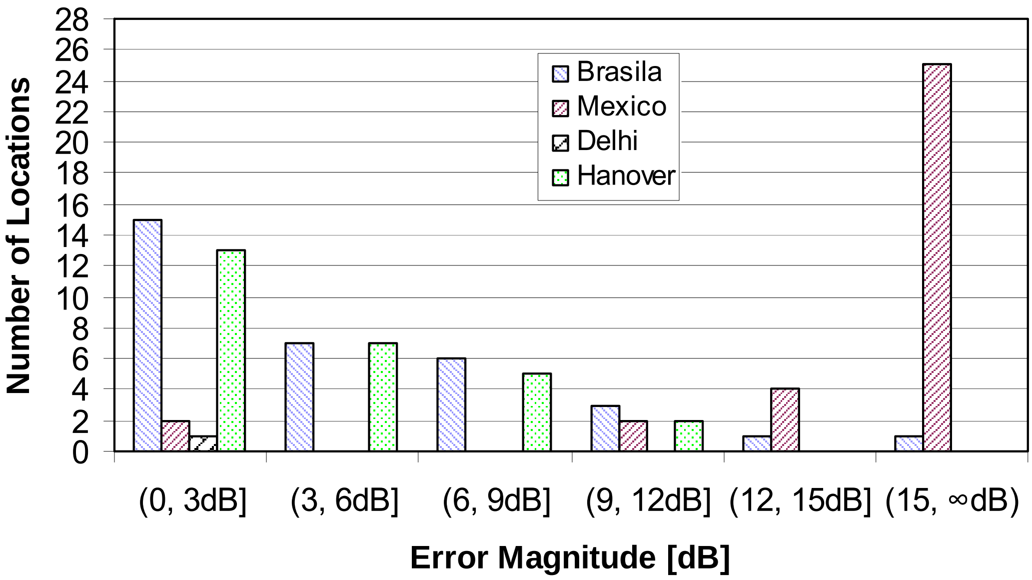


Correction for urban/suburban short paths: this correction is only considered for flat land profiles of length less than 15 km with buildings of uniform height. Therefore, this correction is too specific, and can reduce the accuracy of the method in cities located in “rough” areas and/or covering distances longer than 15 km with buildings of different heights.

In order to know when the recommendation can be applied, it is concluded that local topography must be considered in each case. Inaccuracies are obtained when it is too “sharp”, as in Mexico DF. In this case, the correction factors applied for the diffraction, TCA (Terrain Clearance Angle) and urban areas are not optimal. Figure 4 shows the error distribution. While the prediction is quite good for environments similar to Brasilia, the method does not fit environments similar to the ones in Mexico. While the terrain in Mexico is mountainous, in Brasilia it is formed by hills or rolling plains. Delhi is classified as a smooth plain. The predictions tend to be optimistic for mountainous profiles, where the influence of diffraction is considerable. In addition, the application of the TCA correction factor is harder in areas like this. Therefore, the slopes of the terrain profiles of the paths can influence the prediction error by means of the effective transmitting antenna height and TCA.

FIGURE 4

Recommendation ITU-R P.1546 prediction method error distribution



The method in Recommendation ITU-R P.1546 was tested in Hanover [7], which is located in a fairly flat area. It has recently been applied to a measurement campaign in the same area [8]. The method provided quite good results. No clear error trend was found that depended on the urbanization of the area (rural/dense urban).

This recommendation also predicts a loss depending on the receiver antenna height. The study concluded that measured and predicted height loss were very similar.

Predictions and measurements in quasi-radial routes show the major differences close to the transmitter which might influence the ground wave component. For this reason a prediction method is proposed [9] which considers ground-wave components in the vicinity of the transmitter (applying Recommendation ITU-R P.368 [10]) and space-wave at more distant points.

The prediction method suggested for the space-wave component is that in Recommendation ITU-R P.1546. However, the accuracy of this algorithm for the 26 MHz band depends on the topographical conditions of the transmission path because the Fresnel ellipsoid in this frequency range is wider than in the VHF and UHF bands. This means that the model can be optimistic for irregular terrain profiles. The diffraction attenuation has to be matched in order to reduce the prediction error which in turn means that it is necessary to introduce an attenuation factor that takes into account this effect. The accuracy of this model for estimating the received field strength in the

26 MHz band due to the space-wave contribution is therefore increased. This correction factor is defined as [9]:

$$C_{\Delta h} = \frac{h_1 - h_{Tx}}{10^{h_1 / \Delta h}} \qquad (1)$$

where:

h_1 or *Effective transmitting antenna height:* a parameter defined in Recommendation ITU-R P.1546. This is the combination of the transmitting antenna height and the terrain elevation at its location.

h_{Tx} or *Transmitting antenna height above ground level:* the height of the antenna above the local ground level including the height of the support structure.

Δh or *Terrain irregularity:* this parameter is defined in [11] which characterises the coverage area according to 6 different types of topography.

Equation (1) incorporates the effective transmitting antenna height and terrain irregularity. However, further work from the author of [9] has revealed that this correction may be unnecessary.

Only under certain restricted conditions (hilly terrain with a high peak close to the receiver) should the correction factor in equation (1) be used along with the TCA correction factor (defined in Recommendation ITU-R P.1546), as the underlying concept, terrain irregularity, is the same. As a general rule, only one of them should be used. The TCA correction factor may be better for point-to-point predictions and the correction factor in equation (1) better suits point-to-area predictions.

To validate the method, it was applied to some available data sets, and the prediction error obtained was considerably lower than the one obtained with the predictions using only the model from Recommendation ITU-R P.1546. Table 3 shows a summary of the errors (difference between predicted and measured signals) considering both ground-wave and the correction factor.

TABLE 3

Prediction errors with Recommendation ITU-R P.1546 combined with Recommendation ITU-R P.368 [9]

Applied method			**Mean error (dB)**	**Deviation (dB)**
Recommendation ITU-R P.368	**Recommendation ITU-R P.1546**	**Correction factor**		
No	All distances	No	11.62	5.81
No	From 5 km	No	11.33	6.47
Up to 5 km	From 5 km	No	6.57	8.79
Up to 5 km	From 5 km	Yes	–0.12	6.4

According to the handbook of terrestrial land mobile services in the VHF/UHF bands [12], if a detailed terrain profile is available, a much more accurate method, which is explained in [13], could be applied. Several other propagation prediction methods exist. The measurement campaign in Brasilia (from March to June 2006) led to an analysis to determine which one among five of the most popular models gives a prediction closest to the field strength obtained [14] by measurement.

Five prediction techniques were analyzed in this study; Deygout, Giovaneli, Longley & Rice, Okumura-Hata and COST-Walfisch-Ikegami. Each analysis was carried out using a common set of input data that defined the field trial and experimental network conditions: working frequency, transmission power, transmitter loss, maximum gain of the transmission antenna and transmission and reception antenna heights. Longley & Rice, Okumura-Hata and COST-Walfisch-Ikegami models required some specific parameters.

The prediction error was computed as the difference between the predicted field strength value given by each method and the measured values in the field (E_p-E_m). Figure 5 shows the behaviour of each prediction method.

FIGURE 5

Error prediction distribution for several models [14]

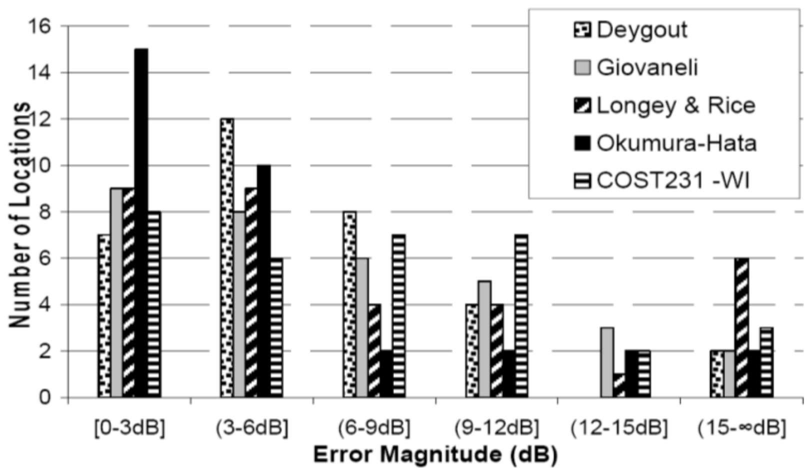


Figure 5 shows that the Okumura-Hata model gives the beat correlation with the measured results. This gives 25 out of 33 locations with an absolute value of the error lower than or equal to 6 dB and, significantly, a value not higher than 3 dB at 15 of the 25 locations. The Deygout method gave 7 locations in the 0 to 3 dB range and 12 locations between 3 and 6 dB. Finally, flatter distributions were obtained using the other methods, suggesting that they are unsuitable for network planning under conditions similar to those found in the experimental network coverage area.

Further analysis led to the following conclusions:

Due to low terrain irregularity, the Deygout and Giovaneli algorithms were found inappropriate for field strength predictions. These algorithms only consider the diffraction attenuation of isolated knife edge obstacles which is higher than the real situation. Further, in some cases, reflections from urban terrain can compensate for losses; a fact which is not considered by these two methods.

The Longley & Rice model provided a reasonably flat absolute error distribution. However, it has been found that this method could be useful for planning purposes because it provides optimistic predictions in the absence of a reception environment definition. In order to make this method useful, attenuation factors related to urban environment elements in the vicinity of the receiver location are necessary.

A similar situation is considered for the Okumura-Hata model when the Davidson modification is applied. The algorithm proved to be an optimum method to predict 26 MHz band signals over terrain with low irregularity. Nevertheless, parameters that better define the reception environment and the transmitter-receiver visual horizon obstruction are required to improve its overall results.

Once the results of the COST-Walfisch-Ikegami model were obtained, the method was discarded because it was developed for frequencies and transmitter-receiver distances very different to the ones considered in this study.

The most suitable prediction model is the one described in Recommendation ITU-R P.1546, when modified as explained above. Recommendation ITU-R P.1812 is also relevant.

9 Interference

As well as naturally occurring noise and channel phenomena, a received signal will be affected by other unwanted sources of electromagnetic energy in the same part of the spectrum. The phenomenon of interference from other radio sources is well known.

The 26 MHz band is allocated to the broadcasting service and any inter-system interference from other sources must be avoided. Those responsible for the interference must take the necessary actions to eliminate it. Recommendation ITU-R BS.1895 provides the protection criteria for terrestrial broadcasting systems. According to this Recommendation the total interference to systems operating in the broadcasting service, from all sources of interference, should at no time exceed one per cent of the total receiving system noise power [15].

In the following subsections interference from other broadcasting sources (intra-system interference) will be discussed. The protection ratios between the desired signal and the interference are presented. The ionospheric propagation characteristics of the 26 MHz band are analyzed and it can be shown that sources of radio emissions which are distant from the receiver can be a source of interference. Some intra-system interference sources are also highlighted.

9.1 Sky wave interference

The 26 MHz broadcasting band is currently allocated by the RR for broadcasting. As already stated, however, its use is limited because reliable transmission is not always possible due to low sunspot activity or variable conditions in the ionosphere. Broadcasters prefer to use other frequency bands, where propagation is more reliable. However, sky-wave propagation can still occur, and this is the main potential source of harmful interference in the 26 MHz broadcasting band.

In contrast to the VHF bands, where the same prediction curves may be used for planning the service area and assessing the field strength caused by potential co-channel interferers, long distance propagation issues related to ionospheric F layer and sporadic E layer scattering must also be considered for planning in the 26 MHz band in order to prevent mutual interference of such services [16].

Sky wave propagation can be due to two different mechanisms: through E or F layers (regular ionospheric propagation) or through sporadic E (E_S) layer (sporadic ionospheric propagation). The following subsections analyze them separately, and present a way to facilitate international frequency planning to avoid co-channel interference.

9.1.1 F layer Interference

Under normal ionospheric propagation conditions, signals refract in the E or F layers in the ionosphere. The normal E layer is not relevant for the 26 MHz band, as the maximum frequency it can refract is significantly less than this [17].

The potential for interference will depend on the probability of there being other transmitters at ranges of 3 km to 4 000 km.

More relevant for long distance propagation in the HF bands is reflection from the F layers of the ionosphere – particularly the F_2 layer, as the F_1 layer will very rarely refract at frequencies close to 26 MHz [18]. These layers are approximately 300 km above the earth's surface and have critical frequencies (f_0, – the highest frequency which is scattered back from the ionosphere at vertical incidence) of typically several megahertz. The highest frequency which is scattered back from the ionospheric layers at the flattest angle of incidence is referred to as the maximum usable frequency (MUF), and a way to predict it can be found in [19]. If the MUF is above the lower limit of the 26 MHz band (i.e. above 25.67 MHz), long distance propagation will be possible, and this could lead to co-channel interference to a local transmission. The relationship between the critical frequency and the MUF is given by [18]:

$$f_{MUF} = f_0 \sqrt{1 + \frac{r_E}{2h}} \tag{2}$$

where:

h is the height of the ionospheric layer (300-400 km in the particular case of the F layer)

r_E is the radius of the Earth.

The highest value of f_{MUF} is obtained when the wave is radiated towards the horizon. In this case the MUF will be about 3.4 times higher than the critical frequency. Hence a 26 MHz signal will be scattered back from the ionosphere when the critical frequency of the F layer is above 8 MHz.

The critical frequency of the F layer depends on the time of day, the season, solar activity and the geographical situation. Long distance propagation in the 11 m HF band will occur especially in directions where the whole path is on the "day-time" side of the Earth. During January the sun is at a low elevation compared with June, the January noon critical frequency is more than twice the summer value [18].

Solar activity increases and decreases, following an 11-year-long (sun spot) cycle. This period dependency is further analysed below.

In Europe, for example, signals coming from the centre and north-east of the continent cause less sky-wave interference to European DRM local services than those from the south-west [20].

Thus, the sunspot number is not constant, and neither is the MUF. For local radio, with many stations operating in this band worldwide, interference from co-channel stations is probable, particularly on winter days during the solar sun spot cycle maxima [16].

Periods of potential interference

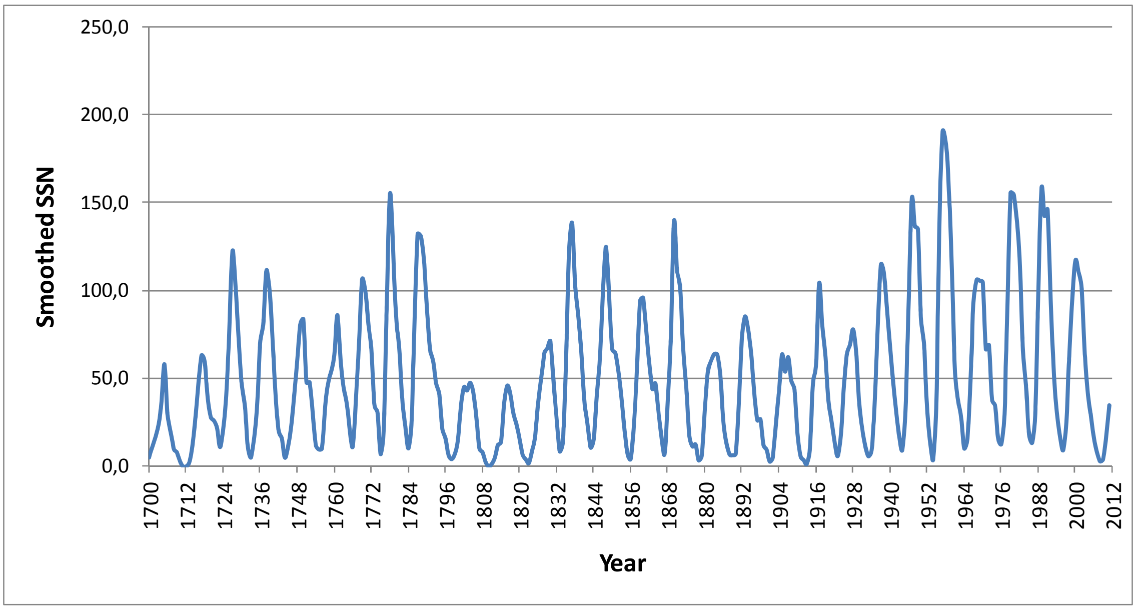
Sky wave propagation through the ionospheric F layer is not constant. As previously explained, it varies in a 3 different "timescales": solar cycle, seasonal and day-night.

Variation within a solar cycle

Solar activity is characterized according to an equivalent sun-spot number scale. This is represented by 'R', which is closely related to the ionization of the ionosphere. It is not a time parameter, but its empirical values present a periodic variation of approximately eleven years. Such a period of time is taken as the duration of a solar cycle. Most simulation methods, however, use a parameter called smoothed Sun Spot Number (SSN), R_{12}. It is the twelve-month running mean value of the monthly sunspot number, R. The value does not correspond with the actual number of sun spots, but with their area as a whole (note that sun spots can be various sizes so the influence of each is different). The higher the value of the SSN, the higher the probability of ionospheric propagation in the 26 MHz band. This is because higher solar activity increases the ionization of the ionosphere and, hence, propagation of higher frequencies is possible [21]. Figure 6 shows the values of the smoothed SSN since 1 700 [20].

FIGURE 6

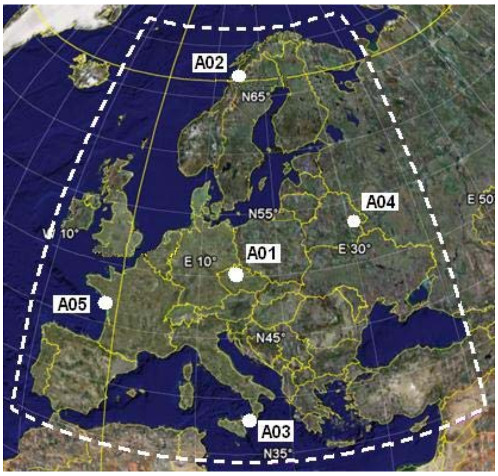
Empirical smoothed SSN values since 1700 [20]



Simulations[2] have been carried out, in the area shown in Fig. 7 [22]. In the Figure, A01 to A05 indicate transmitter locations. According to the results (shown in Fig. 8), the probability of ionospheric sky wave propagation is possible for local 26 MHz broadcasting services when the SSN is higher than $R_{12} = 50$. Over this value, the MUF is above the threshold for over 10% of the time. This value was obtained through simulation using an antenna with an elevation radiation pattern as the one shown in Fig. 15.

FIGURE 7

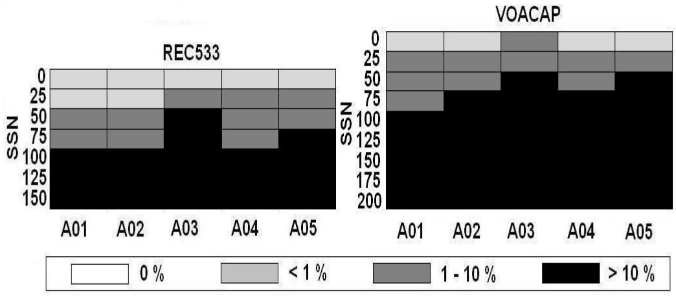
F layer propagation simulation scenario [22]



[2] Solar activity is currently low, and there is a lack of global empirical data regarding the 26 MHz band ionospheric signal propagation.

FIGURE 8

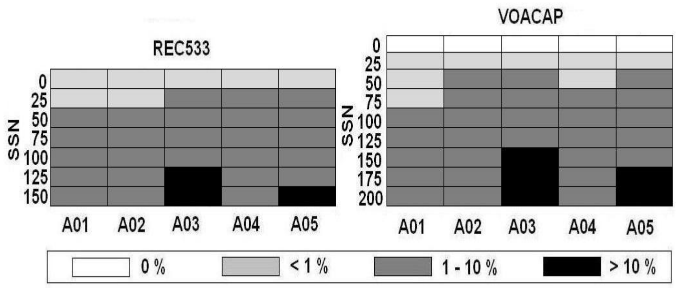
Probability of MUF > 25.67 MHz vs. SSN values [22]



Even if sky wave signal propagation occurs, there will only be harmful interferences if there is sufficient field strength at the receiver location. Assuming that the interference is not a problem when its field strength value is under 12 dB(μV/m) for 90% of the time for signals with a 10 kHz bandwidth, the value of smoothed SSN is increased to 125 (see Fig. 9). A transmission power of 200 W and an antenna with the radiation pattern shown in Fig. 15 were used for this simulation.

FIGURE 9

Probability of received field strength >12 dB(μV/m) vs. SSN values [22]

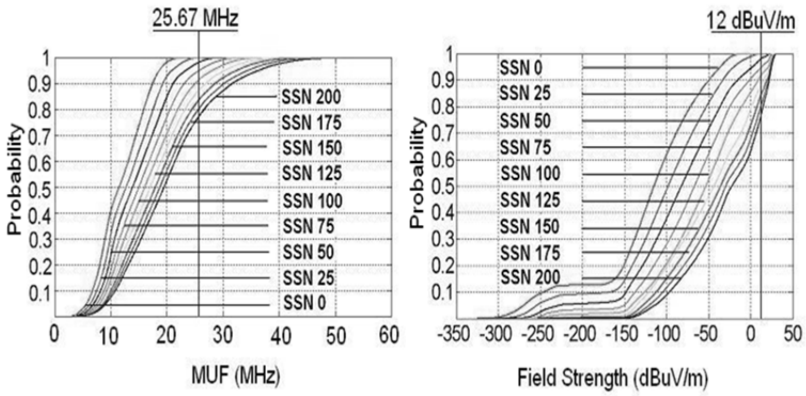


Therefore, during a whole solar cycle, interferences derived from transmissions with a DRM directive antenna are not received when the SSN is lower than R_{12} = 125.

Figure 10 shows some MUF and field strength Cumulated probability Density Functions (CDF), for several smoothed SSN values. The probability of the MUF (or field strength) being below a particular threshold can be derived for each SSN value. Thus, the probability of exceeding a certain frequency (or field strength) is one minus the value given by the curves.

FIGURE 10

MUF and field strength CDF for different smoothed SSNs [20]



Variation within a year

Ionospheric propagation is more probable during the winter [18]. However, it is possible for the MUF to exceed the lower limit of the 26 MHz band for more than 10% of the time at any time of the year – see Fig. 11.

FIGURE 11

Probability of MUF > 25.67 MHz vs. month [22]

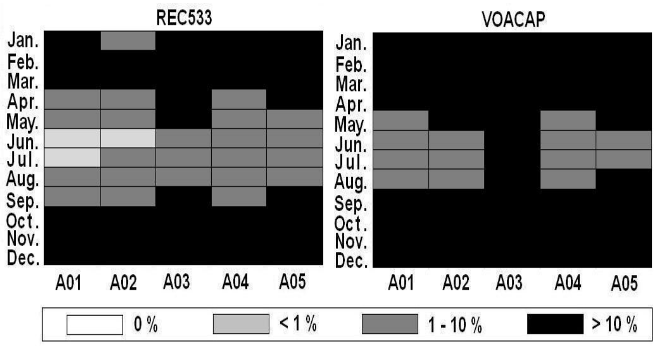
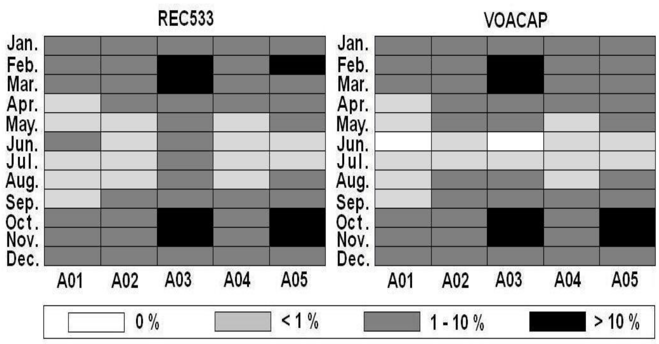


Figure 12 shows that the received field strength interference is only critical during February, March, October and November. This is due to a peak in the ionosphere electron density and is known as the “winter anomaly”. It happens mainly in Europe, North America and Australia.

FIGURE 12

Probability of received field strength > 12 dB(µV/m) vs. month [22]



It must be noted that these results are from a simulation in an area of Europe. It is not valid (the months are not applicable) in the southern hemisphere. Limiting the simulation to the northern hemisphere avoids statistical compensation, as ionization of the ionosphere and therefore the signal propagation depends on the season of the year, which is transposed in the two hemispheres [21].

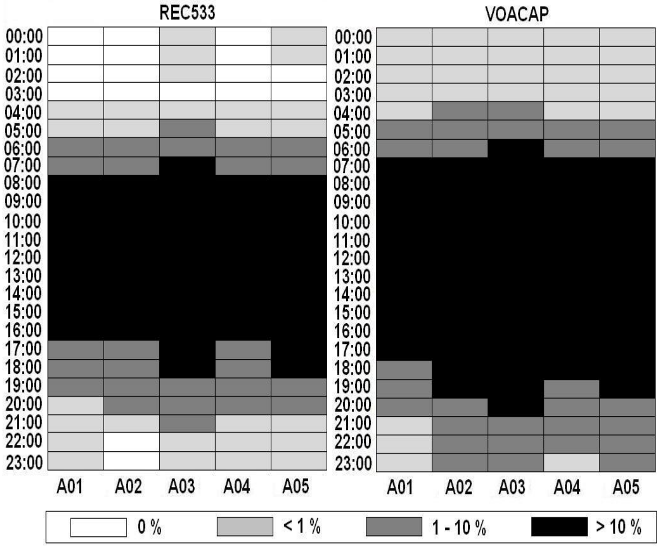
Variation within a day

Normal ionospheric propagation in the 26 MHz band is significant from 06:00 to 20:00 UTC[3], since these are the hours when the probability of MUF exceeding the considered frequency threshold is highest. This is because the electron density in the ionosphere is higher during the day time.

[3] It must be noted that these results are from a simulation in an area within Europe. For other time zones, a corresponding time shift must be expected.

FIGURE 13

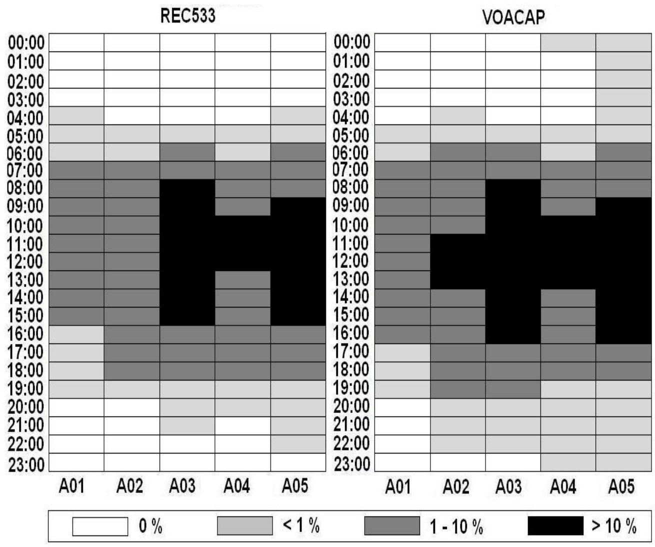
Probability of MUF > 25.67 MHz vs. UTC hour [22]



The period in which the received field strength level of interference is critical is reduced to 9 hours, from 08:00 to 15:00 UTC, if a DRM directional antenna is used (Fig. 14).

FIGURE 14

Probability of received field strength >12 dB(μV/m) vs. UTC hour



Use of directional antennas

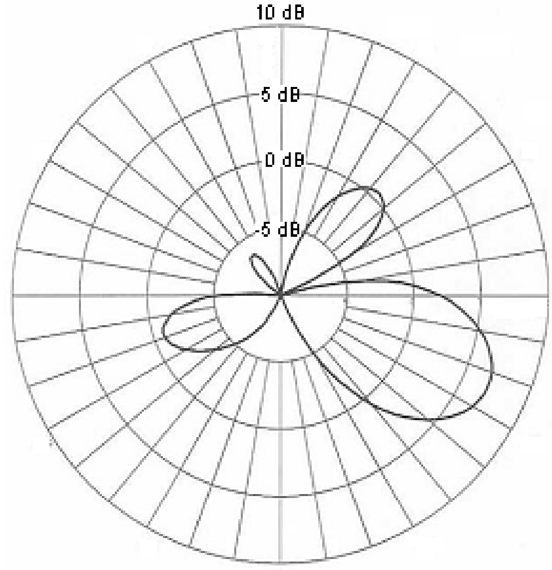
Directional transmitting antennas might be used to minimize the propagation of sky wave signals through the ionospheric F layer.

A set of simulations were carried out with hypothetical directional antennas radiating only within a vertical aperture of 10º and changing the lobe position from 0º to 90º. The conclusion was that the highest interference levels are due to signal transmission at elevation angles below 40º [22].

Therefore, antennas specifically designed to reduce the unwanted sky wave emissions should have an elevation radiation pattern which reduces the gain at angles causing the most harmful interference. An example is shown in Fig. 15.

FIGURE 15

Elevation radiation pattern which reduces unwanted sky-wave emissions [22]



Another conclusion from the same study is that the use of such an antenna can reduce the interference by as much as 15 dB when compared with a theoretical isotropic antenna.

The probability of the MUF being above the 26 MHz band is the same for isotropic and directional antennas. However, field strength level thresholds in § 9.1.1 are derived from the upper deciles of the field strength levels when a directional DRM antenna is used. Table 4 summarizes the results of that section and shows the effect of using a non-directional antenna. The effect of considering interference during 10% (upper decile of field strength) or 50% (median value) of time to determine the thresholds can also be seen.

TABLE 4

Ranges for critical interference levels [22]

Case	Isotropic 50%	Isotropic 90%	Directive 90%
Smoothed SSN	>100	>25	>125
Month	From Oct. to Apr.	From Jan. to Dec.	Feb., Mar., Oct. & Nov.
UTC Hour	From 7:00 h to 17:00 h	From 6:00 h to 21:00 h	From 8:00 h to 15:00 h

These results must be used with caution. Even if the radiating system is located at a high elevation and oriented towards the ground in the target area, it might still create signals which could propagate through ionospheric reflection. The reflectivity of the ground is quite high in this frequency range and multi-hop propagation is possible [23]. Nevertheless, signals reflected from the ground will be attenuated due to the absorption of the ground and the longer propagation path.

The difficulties associated with the design of a directional antenna in the 26 MHz band cannot be ignored. It is very unlikely that directional antennas alone would be the solution to the ionospheric sky wave interference problem.

9.1.2 Sporadic E layer interference

At frequencies higher than 10 MHz, especially during summer, highly ionised areas in the E layer, called sporadic E layers, occur. These create conditions that might favour sky wave propagation and provoke interference from transmitters located thousands of kilometres away. In contrast to the F layer, sporadic E layer propagation can also occur during periods of low solar activity [16].

Field strength prediction

Statistical data concerning the frequency of occurrence of sporadic E layers in different zones of the world, along with a method for calculating the associated field strength, are given by Recommendation ITU-R P.534 [24]. This field strength is highly dependent on the signal frequency and the distance between the transmitter and the receiver.

It must be noted that the sporadic E layer has strong temporal and spatial fluctuations [25]. This topic is covered in "Ionospheric interference to television in Great Britain" by LW Barclay, Marconi Review, v31, 254-264, 1968.

The influence of the sporadic E layer can be analyzed by comparing signal reception parameters (field strength and SNR) with data from the ionosphere obtained by an ionosonde close to the midway point between the transmitter and the receiver. The results of such a study can be found in [25]. The validity for the 26 MHz band of this prediction method was confirmed and found to be accurate predicting the time when the SNR > 5 dB and the number of measurements with

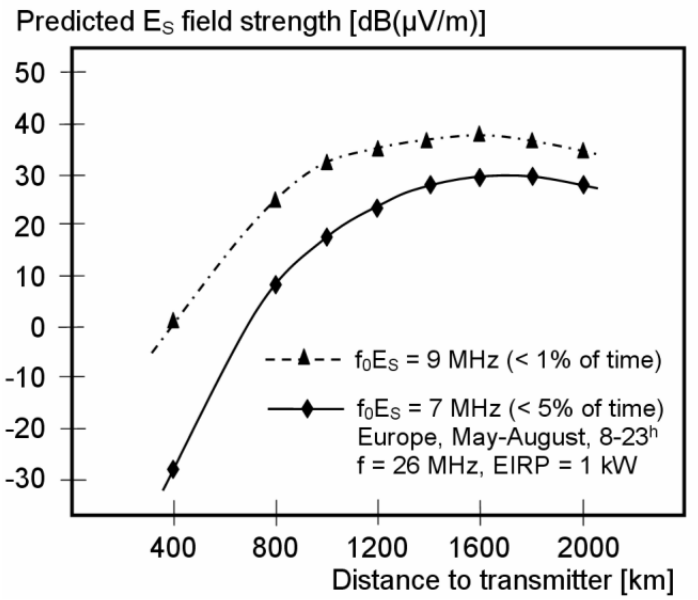
$$f_{0E_s} > 6 \text{ MHz.}$$

Some discrepancy was observed, however, concerning the total time of reception. Recommendation ITU-R P.534 states that an estimate of the probability of f_{0E_s} being greater than 6 MHz is about 5.5% in Europe for the period May to August. During the whole period of the study, this situation arose for only 2.5% of all the measurements (less than half the estimate from the Recommendation).

Figure 16 shows the predicted field strength received through sporadic E layer refraction for a set of distances. If this type of interference is to be avoided, co-channel transmitters should not be placed between 400 km and 2 000 km of each other. This will avoid interference occurring for more than 1% of the time during the summer (May to August in the northern temperate zones). It should be noted that this prediction is for a single pair of transmitters. If there are several transmitters at comparable distances, but at different directions from that being studied, the occurrence of sporadic E layers will not be correlated and the probabilities for their occurrence have to be added and interference will be more frequent [16].

FIGURE 16

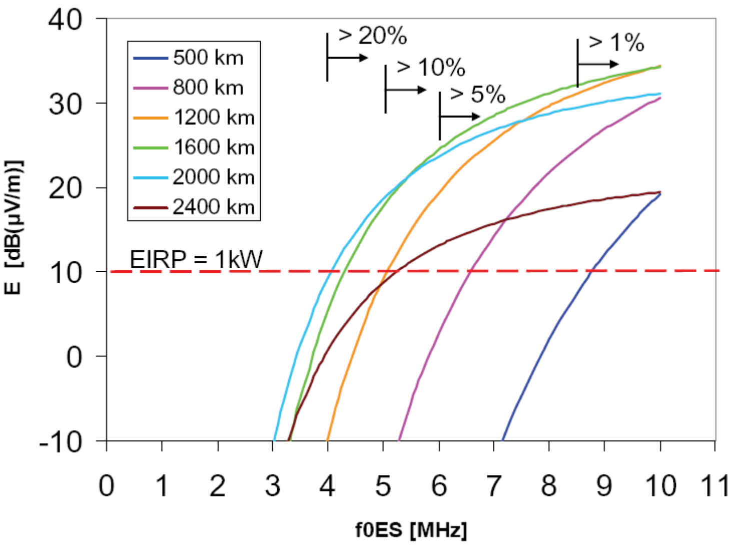
Predicted field strength refracted from sporadic E layer [16]



Overall, Recommendation ITU-R P.534 can be used to predict potential mutual co-channel interference among transmitters. Figure 17 shows the predicted field strength for different distances between transmitter and receiver, for a transmitter e.i.r.p. of 1 kW. The arrows indicate time percentages for which the values of f_{0E_s} are equalled or exceeded in Europe and North Africa between May and August [25]. Since there is no large-area correlation among f_{0E_s} values, time probabilities add if there are several co-channel transmitters at different directions and distances from a given location.

FIGURE 17

Predicted Es field strength for different distances between transmitter and receiver [25]



The curves in Fig. 17 show that frequent and strong co-channel interference has to be expected, especially from transmitters between 1 200 and 2 000 km distant. This is because field strengths, even at relatively low values of f_{0E_s} , are frequently higher in summer. It should also be recognised that the angle of incidence of the signals will be low (less than 10 degrees), and in some places attenuation of the sporadic E layer signals may occur due to topography or buildings. The use of transmission antennas which suppress these low elevation angles is very difficult: an antenna which radiates effectively towards the horizon will also radiate up to 10º elevation angle, because at a wavelength of around 11 m, forming narrower beams would require antennas which were potentially too big to be economic [25].

From these results, Lauterbach and Hofmann conclude that the transmitter e.i.r.p. should be below 10 W in order to avoid sporadic E layer interference. This power was used in a local DRM30 measurement campaign in Nuremberg by the same authors, and no long distant reception was reported.

Sporadic E interference variation

E layer ionospheric propagation occurs particularly between April and July, in northern temperate latitudes. This phenomenon may last for several hours and occurs sporadically. Propagation to distances up to 2 000 km is observed [23].

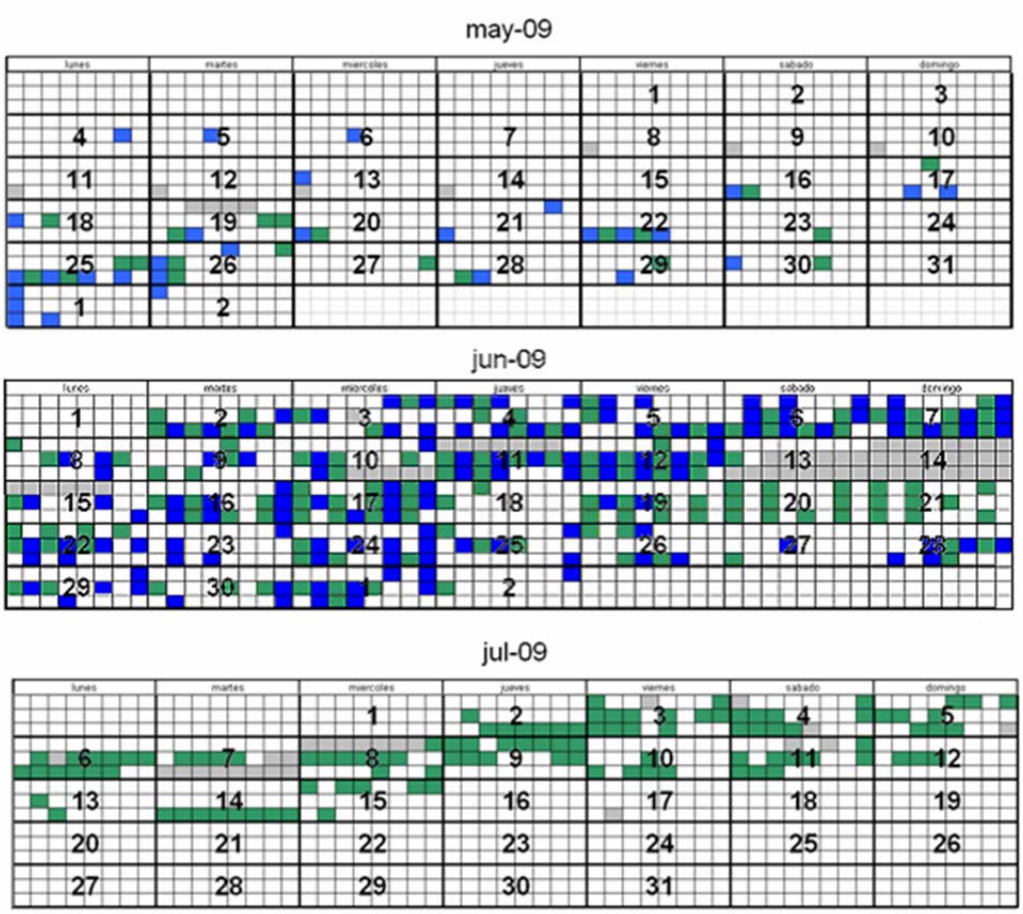
A medium-term study of sporadic E layer propagation can be found in [26]. Yearly, daily and spatial variation is considered.

Yearly variation

The study lasted only two and a half months (May, June and the first half of July), so a whole year pattern was not obtained. However, as can be seen in Fig. 18, it was confirmed that propagation in June and July (Summer) was much more probable than in May (Spring). This matches the predictions of the ITU-R Recommendation.

FIGURE 18

DRM reception through E_s layer (blue and green: received; grey: problems with receiver) [26]



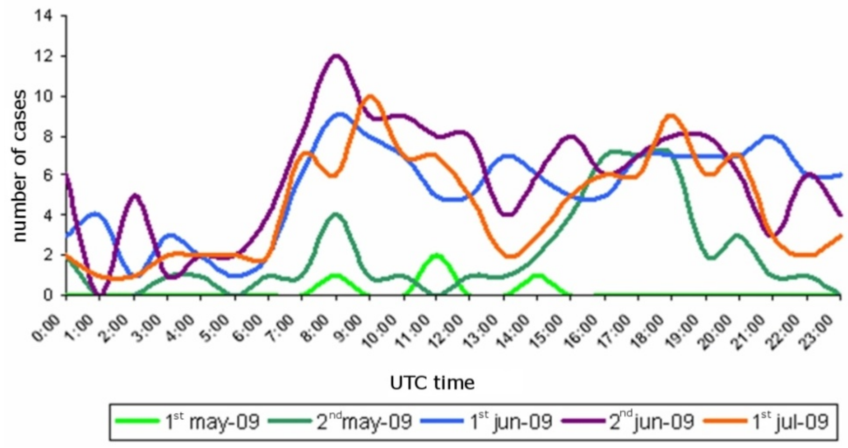
DRM reception, however, was frequently possible only during isolated time slots. Longer reception, while unusual, was more frequent in June and July than in May. During these months, a higher ratio of synchronization was also achieved.

Daily variation

Figure 19 shows the number of DRM interference cases plotted against time of day. Each line corresponds to half a month. It can be concluded that sporadic E layer interference is more probable between 6:00 UT and 22:00 UT, which again aligns with the Recommendation.

FIGURE 19

Number of measured Es interferences in a daily basis [26]



The period during which interference is apparent is very variable. Sometimes signal refraction can last for several hours and sometimes no refraction is observed for several days.

Spatial variation

Two different ionospheric circuits (signals from transmitters located in different places) were studied simultaneously. It was found that their behaviour was independent. Considering that the transmitters were in Germany and Italy and that the receiver was in Spain (not large distances on a global scale), this means that sporadic E layers are characterized by a high spatial variability, unlike F layer propagation. Total interference power is far from being the sum of several single interference sources as they are not correlated in time (they do not happen simultaneously). This lack of correlation means that while the interference power is less likely to be increased, the occurrence probability is increased.

Field strength and SNR statistics

The study also suggested that both received field strength and SNR of a signal refracted from a sporadic E layer have a normal probability distribution [26].

The measurements lead to the field strength statistics shown in Table 6 and the SNR statistics in Table 7. The main characteristics of the transmitters are presented in Table 5. High values of field strength and SNR are useful for international services, but not for local services, as higher values lead to more severe potential interference.

TABLE 5

Transmitter characteristics in sporadic E layer measurement campaign [26]

Location	Freq [MHz]	Power [W]	Gain [dBi]
Hanover	26.045	80	1.27
Dillberg	26.000	30/75	2
Andrate	26.010	250	3.5

TABLE 6

Received sporadic E field strength statistical parameters [26]

Transmitter	Received field strength (dB(µV/m))					
	Median		Maximum		90-percentile	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Dillberg	26	2.9	29.3	5.9	27.6	4.2
Hanover	21	2	28.5	6	24.6	3.2
Andrate	24.2	4	36	8	29.5	5.5

The received field strength values associated with the three transmissions were over 12 dB(µV/m). This value is considered critical, and interference above this level is considered harmful (see § 9.1.1). Transmitter power would need to be decreased to reduce this interference. The lack of power could be compensated with the use of SFN networks to meet local coverage requirements.

TABLE 7

Received sporadic E SNR statistical parameters [26]

Transmitter	Month (2009)	Received SNR [dB]					
		Median		Maximum		90-percentile	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Dillberg	May	–1.63*	2.53*	2.09*	2.88*	–0.16*	2.58*
Hanover	May	8.64	4.27	15.94	4.05	13.36	3.06
	June	9.50	10.39	17.05	2.90	14.54	2.34
Andrate	June	10.94	3.62	20.09	6.37	15.51	4.48
	July	10.64	3.36	20.85	5.48	15.50	4.55

* In this location and month, small values were received and therefore the parameter is affected by synchronisation issues.

It may be seen that the results from the transmitter in Andrate are more or less the same in June and July. Results from the transmitter in Hanover, however, are different in May and June. This is because June and July both have similar, summertime, sporadic E layer conditions, while in May (Spring) the situation is different. The characteristics of the ionosphere do not change drastically from one month to the other, but the effect in the results can clearly be seen.

9.2 Other sources of interference

The 26 MHz band (25 670-26 100 kHz) is reserved for broadcasting purposes, so any harmful interference originating outside this band must be avoided, and the necessary steps must be taken by those responsible to eliminate it.

In the local broadcasting measurement campaign carried out in Dillberg, reception problems were found due to local interference, mainly when the receiver was placed in an industrial zone. The impairments occurred every day at the same time and were probably caused by some electrical appliance which was always operated at the same time of the day [16].

New noise sources causing harmful interference into the shortwave bands have been found by radio amateurs. Among them are plasma television displays and photovoltaic solar power plants [27]. The influence on the HF broadcasting bands of oceanographic radars [28] and PLT systems [29] has also been studied.

Interference from machinery is frequently narrow band. A method to detect narrow band interference using tags is suggested in [30]. Recommendation ITU-R BS.1895 [15] provides the protection criteria for terrestrial broadcasting systems. According to this recommendation, the total interference to systems operating in the broadcasting service, from all sources of interference should at no time exceed one per cent of the total receiving system noise power. The presence of these sources of interference has been noted because, although manufacturers should ensure EMC compliance, this can’t always be assumed.

10 Frequency planning scenarios of local coverage services

Previous sections have leaded to the conclusion that if high transmission power is used for local coverage, ionospheric propagation phenomena may cause harmful co-channel interference.

To achieve sufficient coverage in large areas, such as big cities, two different approaches may be applied:

– to use a single frequency network with several low power transmitters;

– to use a single transmitter with several kilowatts of power for local radio, carefully planning the re-use of the frequency, taking account of ionospheric refraction.

These approaches need not be taken separately. A combination of appropriate antenna design (itself a challenging problem), elevated transmitting antennas and SFN networks is the best choice to maximize the local coverage area and minimize sky wave interference. Also, SFNs might cause lower ionospheric interference levels if the transmitting sites and antennas are specifically chosen to avoid radiation in the same ionospheric regions, so that only the signals that find high ionization levels are refracted towards the Earth [1].

The complexity of designing directive antennas comes from the electrical length at 26 MHz. An antenna with a radiation pattern suppressing ionospheric propagation would be very big, and would not prevent very long distance modes. This makes it more difficult to develop SFN networks with several transmitters, as appropriate locations have to be found. This will encourage lower transmitter numbers and consequently increased power for each one, increasing the interference probability. A compromise must be made between antenna radiation pattern and power in order to minimize interference.

Even if transmission power is minimised, ionospheric interference may occur occasionally (albeit much less frequently). In addition, therefore, its use has to be coordinated. The 26 MHz band is currently allocated to broadcasting by Article 5 of the RR [31]. Frequency allotments are decided twice a year subject to seasonal planning procedures that involve administrations, broadcasters, FMOs (Frequency Management Organizations) and the 3 regional HF coordination groups. The planning of current international services in the 26 MHz band is described in [32].

As with the other HF broadcasting bands, the planning process requires multilateral coordination between FMOs. These organizations are free to select the frequencies that satisfy their broadcasting requirements, and therefore interference problems could exist in the band. The ITU encourages the regional coordination groups to manage informal face-to-face meetings between FMOs in order to solve or minimize potential incompatibilities. After these meetings, and once the compatibility among services has been analyzed the corresponding results, as well as the seasonal HF broadcasting schedule, are published by ITU BR [32].

Local use of this band requires a different regulatory scenario. Two approaches are currently envisaged: cellular planning and band deregulation. A third proposal is to take advantage of the different responses of the ionosphere depending on the frequency.

HFCC, one of the bodies charged with the informal co-ordination of the HF bands has already proposed that the 26 MHz band be split such that local services can be (locally) administered in one part while international broadcasting continues to use the other part under existing arrangements. Little use of the band is made by international broadcasting and so the reduction in the number of available frequencies would not be a major problem.

10.1 International regulatory approach

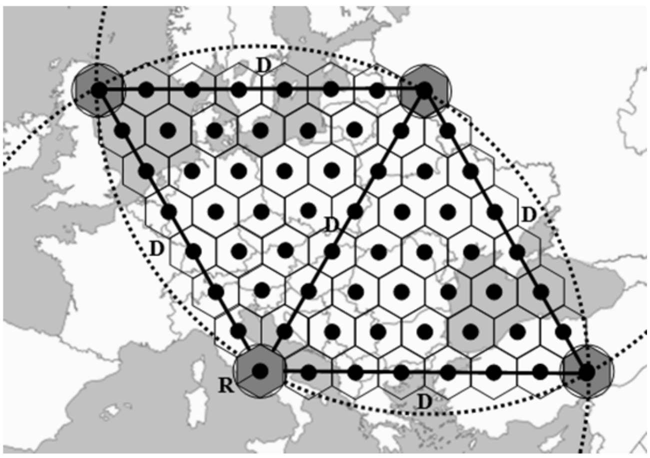
From the properties of ionospheric propagation reviewed above, it must be concluded that if the 26 MHz short wave band were widely used for local broadcasting, without international channel assignment, a situation would arise where, during daytime in the period around the sunspot maximum, a number of co-channel stations at distances of up to several thousand kilometres could generate a significant level of interfering field strength. The coverage area of the desired transmitter would then shrink dramatically. During summer-time, due to sporadic E propagation, there will be additional interference from nearby stations, even in the years around the sun-spot minimum [16].

Figure 20 shows a simplified frequency allocation example based on coverage cells. Consider the cells highlighted grey. If a frequency is assigned within the cell, it can be used in the whole cell, which is a hexagonal area within a circle of radius *R*. No ionospheric propagation can occur in this area because the elevation angle would be high. In order to avoid (or minimize) co-channel interference, this frequency should not be assigned to a nearby cell. A co-channel separation distance must be left between cells on the same frequency. Ionospheric co-channel interference can exist if local network transmitting centres are placed at distances between 400 km (greater in mid-latitude regions) and 4 000 km from each other [1].

Repeating this process with the rest of the cells, the diamond shaped pattern in Fig. 20 is produced. This pattern can then be repeated.

FIGURE 20

Generic cellular system over Europe. R=Cell Radius; D=Co-channel distance [1]



The number of channels *N* that is needed to avoid interference can be obtained from equation (3), where S_D and S_H are the areas of the diamond and the hexagon respectively [33].

$$N = \frac{S_D}{S_H} = \frac{\frac{\sqrt{3}D^2}{2}}{\frac{3\sqrt{3}R^2}{2}} = \frac{D^2}{3R^2} \qquad (3)$$

For the case under study, R and D are 200 km and 4 000 km respectively, so that at least 134 different channels are needed to establish an international regulatory approach free of interference. The 26 MHz band offers, at most, only 43 channels for DRM signals of 10 kHz bandwidth. For this reason, the problem can only be solved by restricting local broadcasting within single frequency specific areas of 200 km radius that are not affected by mutual interference. This solution would prevent the band from being used on a global basis, failing to stimulate the digital broadcasting market for this part of the short wave spectrum.

10.2 Local regulatory approach

The results from the previous section show that effective cellular planning is difficult to achieve. A local regulation approach, which is associated with an international de-regulated service, has been suggested. It consists of frequency planning carried out on a national basis (and regional/bilateral agreements among neighbouring countries). The procedures to be followed would be similar to the ones applied to services in the VHF band:

– each country will apply its own planning procedures;
– frequency coordination will be required in neighbouring regions;
– a maximum ERP limit will be set for every station in every region;
– the service areas will depend on the available channel to interference ratios (C/I);
– the number of stations within an area (country) will be limited.

This approach would work well during the minimum sunspot period. The potential interference would be restricted to sporadic E propagation; it should be noted that television broadcasting services in Band I and Band II suffer from this phenomenon [34]. This approach has also been applied for MF band channels around 1 500 kHz, where signals can cause and suffer the same interference problems [65].

If the 26 MHz band were regulated in this way, broadcasters would have to assume and accept the existence of statistical sky wave interference (in certain periods and under specific conditions), limiting the local coverage. Nevertheless, there would still be areas where good digital quality could be obtained. The size of the area would depend on factors such as: reception environment, transmitting antenna height, radiation pattern, season, region of the world, maximum ERP limits and number of stations per country.

10.3 Dual broadcast band

It should be noted that the problems caused by mutual interference from distant stations are complementary in the MF and 26 MHz HF bands. At night time, no long distance propagation occurs at the 26 MHz band, while in the MF band long distance propagation only occurs at night time [23].

A solution for local broadcasting in the bands below 30 MHz could therefore be to switch frequencies twice a day: using a 26 MHz band frequency during the night, and an MF frequency during the day. Many more channels would be available [16]. This would, however, require the assignment of 2 channels for a single service.

When classifying F layer propagation by month, contradictory results were found [20]: frequency CDF curves present opposite tendencies in two frequency ranges. The percentage of MUF values above frequencies up to approximately 16 MHz is higher during spring and summer months and lower in autumn and winter. However, the probability of MUF values exceeding a specific frequency above 16 MHz is higher in autumn-winter than in spring-summer (it must be noted that sporadic E layer propagation is more significant in summer time in the 26 MHz band).

Future DRM receivers are expected to be able to follow changes in the transmission frequency seamlessly with no interruption to the audio output; changes can be signalled in advance. This facility could be used to switch between an HF frequency and an MF frequency. The correct switching time can either be derived from propagation predictions or using monitoring receivers at the fringe of the desired coverage area. The cost of operating such a dual transmitter site will be significantly higher than that of a single station [16].

11 DRM deployment for local coverage and regulatory conditions of the 26 MHz band

DRM is described in ETSI standard ES 201 980. A downloadable version of the system specification (ETSI ES 201 980 V3.1.1) is available on the ETSI website, http://www.etsi.org. It covers DRM30 for use in the frequency bands below 30 MHz and DRM+ for use between 30 and 174 MHz.

DRM30 is one of the systems recommended for use in the bands below 30 MHz in Recommendation ITU-R BS.1514 – System for digital sound broadcasting in the broadcasting bands below 30 MHz. The planning parameters can be found in Recommendation ITU-R BS.1615 – "Planning parameters" for digital sound broadcasting at frequencies below 30 MHz. ITU-R Resolution 543 (WRC-03) – *Provisional RF protection ratio values for analogue and digitally modulated emissions in the HF broadcasting service* – gives the RF protection ratios, extracted from Recommendation ITU-R BS.1615, to be used on a provisional basis. However, the use of DRM30 for local services, in the presence of sky-wave interference has not been studied.

The 26 MHz band continues to be used by international broadcasters wishing to exploit the long distance propagation characteristics during periods of high sunspot activity. If the band is to be used for local services, due account must be taken of this. A means must be found to allow these services to co-exist, a means which, ideally, does not require local broadcasters to participate in the international coordination process.

As already stated, one solution would be to sub-divide the 26 MHz band. International services could continue in one part and be co-ordinated under Article 12 as at present. In the other part, local services could be planned by administrations taking the necessary care to avoid internal and cross border conflicts. This approach has already been implemented in the coordination groups on an informal basis. Currently the lower part of the band (25 670-25 850 kHz) is recommended for long-distance international services, while the upper part (25 850-26 100 kHz) is recommended for local services. The actual frequency boundary could be adjusted in light of the needs for each type of service. If this approach is used – and acknowledging that the band's effectiveness for long distance coverage is governed by sunspot activity – it would be prudent to look at the historic use of the 26 MHz band for international broadcasting over previous 11-year sunspot cycles, to determine a more appropriate sub-division. For example, if only a couple of frequencies had been used for international broadcasting over the last few sunspot maxima *and* the usage is unlikely to change in the future, then the majority of the band could be allocated to local broadcasting. However, some caution with this approach would be needed as, once local broadcasting is licensed, it would be practically impossible to review the sub-division in favour of international broadcasting should this increase above anticipated demand.

High power international and low power local services could share the same spectrum, relying on the informal coordination procedures of Article 12 to resolve any interference problems. This would require either the individual local broadcasters or a representative from the national licensing authority to attend the coordination meetings. This could well be cumbersome and difficult to achieve in practice.

Consequently, band partitioning is likely to be the best option, but this would need global recognition. If global recognition were accepted, it would not require a change to Article 5 of the RR as the band 25 670-26 100 kHz is already allocated to the broadcasting service.

Irrespective of the possible international coordination, there needs to be a national regulatory or licensing framework. This could specify the technical parameters for each station in order to reduce the potential of interference to other stations using the same frequency in another area.

12 Conclusions and proposals

The 26 MHz band is a valuable resource for broadcasting. Its value is enhanced with the robustness and quality of the DRM standard, which provides a way of using these frequencies for local broadcasting. Several trials in different parts of the world have demonstrated that local services would be possible using "Quasi Line-of-sight" coverage, with antennas placed at dominant sites with limited ERP. The coverage expected for a typical station would be limited to tens of kilometres.

Bearing in mind the potential impact of statistical ionospheric interference at the peak of the solar cycle (every 11 years), frequency planning could be achieved by two methodologies:

– international regulation;

– local regulation.

The technical data available concluded that any regulation will probably prevent the band from being used globally. The possibility of ionospheric propagation means that there will be times where a certain degree of statistical interference will be present. Therefore, the regulated approach will not be feasible.

The only realistic approach would rely on an internationally deregulated scenario with the following restrictions:

– a maximum ERP should be established for any station in the 26 MHz band;

– the number of stations within an area should be limited;

– frequency assignments/allotments should be made on a national basis;

– bilateral/multilateral agreements would be needed for bordering countries, where local broadcasting at 26 MHz is implemented.

If the 26 MHz band is partitioned as it is currently, on an informal basis, in the HF Coordination Groups, the total spectrum available for local transmissions would be 250 kHz. This provides 25 DRM channels, using DRM30 in the 10 kHz mode, and 12 DRM channels using the 20 kHz mode. If the whole 26 MHz broadcasting band were to be made available for local broadcasting, the numbers increase to 43 and 21 DRM channels respectively. This does not include any guard band and assumes adjacent channel conflict can be resolved in the planning process.

The geographical separation needed between channels (carrying different programmes) on the same frequency will depend on transmitter power, antenna gain and directivity characteristics. Clearly, the total number of separate channels that could be found in, for example, a country will be established through normal frequency planning techniques, given knowledge of the relevant planning parameters. If the 26 MHz band is to be used for relatively small area coverage it is likely that any one frequency might be used several times.

Finally, given that there is a demand for services to cover different geographical areas, it must be concluded that DRM30 in the 26 MHz band could work in tandem with other systems, such as DRM+, and provide services that were complementary.

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14 Acronyms and abbreviations

AAC	Advanced Audio Coding
ABU	Asia-Pacific Broadcasting Union
AGC	Automatic Gain Control
AM	Amplitude Modulation
AMSS	AM Signalling System
BER	Bit Error Ratio

CA	Conditional Access
CDF	Cumulative Density Function
CELP	Code Excited Linear Prediction
CIR	Channel Impulse Response
CR	Code Rate
CRC	Cyclic Redundancy Check
DAB	Digital Audio Broadcasting
DRM	Digital Radio Mondiale
DSB	Dual Side Band
EEP	Equal Error Protection
EMC	Electro-Magnetic Compatibility
ERP	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
FAC	Fast Access Channel
FhG	Fraunhofer-Gesselschaft
FMO	Frequency Management Organization
HF	High Frequency band
HMmix	mixed Hierarchical Mapping
HMsym	symmetrical Hierarchical Mapping
HVXC	Harmonic Vector eXcitation Coding
I	In-phase signal component
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication sector
LF	Low Frequency band
LOS	Line-Of-Sight
MER	Modulation Error Rate
MF	Medium Frequency band
MFN	Multi-Frequency Network
MMI	Man-Machine Interface
MSC	Main Service Channel
MUF	Maximum Usable Frequency
MW	Medium Wave
NLOS	Non-Line-Of-Sight
NVIS	Near Vertical Incidence Skywave

OFDM	Orthogonal Frequency-Division Multiplexing
OoB	Out of Band
PL	Protection Level
PLT	Power Line Telecommunications
Q	Quadrature signal component
QAM	Quadrature Amplitude Modulation
RDS	Radio Data System
RF	Radio Frequency
r.m.s.	root mean square
SBR	Spectral Band Replication
SDC	Service Description Channel
SFN	Single Frequency Network
SM	Standard Mapping
SNR	Signal to Noise Ratio
SPP	Standard Protected Part
SSB	Single Side Band
SSN	Sun Spot Number
TCA	Terrain Clearance Angle
TDD	Transmit Delay Diversity
TEM-cell	Transverse ElectroMagnetic cell
UEP	Unequal Error Protection
UHF	Ultra High Frequency band
UPV/EHU	Universidad del País Vasco/Euskal Herriko Unibertsitatea
UTF-8	8-bit Unicode Transformation Format
VHF	Very High Frequency band
VSPP	Very Strongly Protected Part

Annex 1

Transmit delay diversity techniques

The properties of the radio channel in local broadcasting are quite different from those of the ionospheric channel for which the DRM system has been designed. In particular, the delay spread is only in the order of a few microseconds for local broadcasting, in contrast to (up to) several milliseconds for the ionospheric channel. Therefore, the bandwidth of the DRM signal (4.5-20 kHz) is significantly smaller than the coherence bandwidth of the channel, which is in the order of several hundred kHz. In the case of multipath propagation, the DRM signal will therefore suffer from flat fading [25]. This phenomenon is further analyzed in Annex 2.

To overcome this problem, diversity techniques are common practice. Due to the wavelength (of around 11 m), antenna diversity at the receiver seems impractical, because, typically, antennas would have to be separated by a quarter wavelength; almost 3 m. However, the simple scheme whereby the original signal is transmitted several times from different antennas with a specified time delay (known as Transmit Delay Diversity – TDD), can be implemented without any change to the system or to the receivers and, therefore, may be implemented even at a later stage of network development [25].

In the case of DRM, the OFDM guard interval is designed for ionospheric channels and large area single frequency networks, which have greater associated delay spreads. Therefore, the different signals in a local scenario (with shorter inherent delay spreads) can be delayed by several hundred microseconds without violation of the guard interval.

This technique has been added to the most recent iteration of the DRM standard [35], in order to avoid flat fading in a DRM+ service. However, no mention is made of this for the 26 MHz band. This document points out that two requirements have to be considered when choosing the value of the delay:

– the delay should be large enough to increase the frequency selectivity of the composed channel, formed by the superposition of the channels for the transmitting antennas;

– it should be much less than the DRM guard interval duration, in order to avoid inter-symbol-interference.

In the following paragraphs, some simulation and field test results are presented. They were obtained from the measurement campaign in Nuremberg [25]. The characteristics of the signal used are (for both the simulation and field tests): 10 kHz bandwidth, mode A, CR 0.62, long interleaving and MSC with 16-QAM. The delay between signals is 0.266 ms.

When diversity is used, an error floor occurs due to the frequency selective fading that is introduced (errors before decoding), but the high BER peaks are no longer present. This gives the possibility for the channel coding to correct erroneous bits. With a single antenna, the channel decoding mechanism is not able to deal with the errors properly; resulting in many frames with high remaining BER. In contrast, with a ‘diversity’ system, the channel decoder works well with the resulting error structure. There are few erroneous frames and low BER.

The results of several simulations are combined to plot values of mean BER against SNR in Fig. 21. These curves show the improvement obtained when a diversity technique such as TDD is used. From this plot it can be seen that the target BER of 10^{-4} can be reached with 21 dB of SNR when using TDD. In contrast, the BER with the single antenna system is much higher at 6×10^{-3}.

FIGURE 21

Net BER vs. SNR with transmit delay diversity (simulation during 2 000 s) [25]

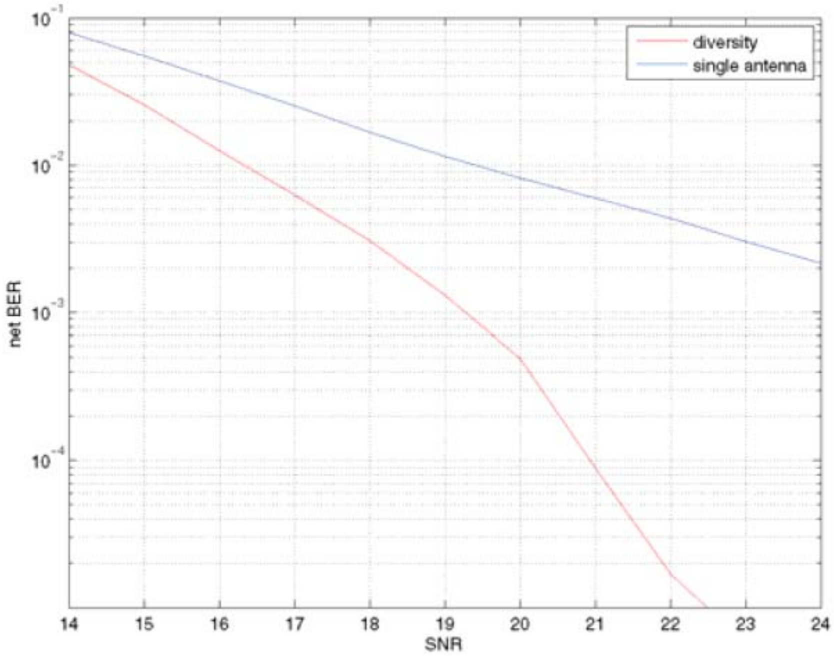


Figure 22 presents the block diagram of the signal generation system used in the field trial. The two output signals were fed to different antennas at different positions, about 35 m above ground level on the Fachhochschule building. The receiver was located 2 km away from the transmitter, in a narrow street in a residential area.

FIGURE 22

Block diagram of signal generation for TDD [25]

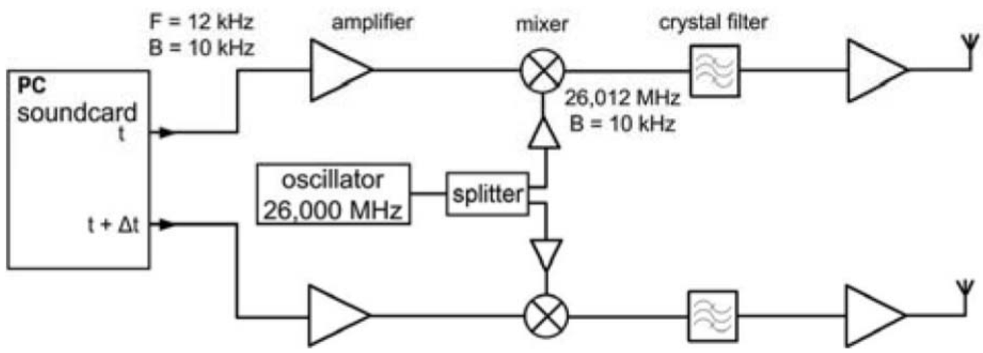
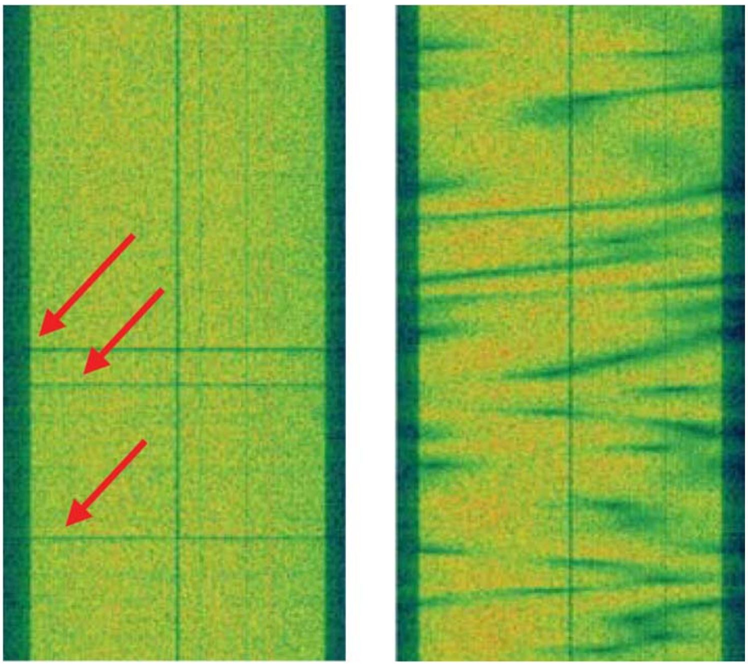


Figure 23 allows a comparison of the ‘waterfall’ diagrams without and with the use of the TDD technique. Flat fades no longer exist. There is frequency selective fading instead; the DRM system is designed to cope with this and can correct the resulting errors. When the mobile unit stopped at a spot where previously flat fading caused an audio dropout, reception was possible with no problem.

FIGURE 23

Comparison of waterfall diagrams without (left) and with (right) TDD [25]



These results show that for improving portable and low speed mobile reception, TDD is an interesting alternative to single frequency networks, especially for low power local stations which do not operate more than one transmitter site.

TDD can also be applied in a SFN network (see § 6.3), where the selective fading resulting from the delay is far less damaging than the flat fading without it, so that the increased signal strength can outweigh the more difficult channel [36].

Annex 2

Propagation phenomena

The Friis transmission formula implies a simple model of propagation loss based on the assumption of a spherical wave spreading out from its source without obstruction. But this model cannot apply to propagation paths with obstructions such as buildings and the Earth itself. In these cases, a number of physical phenomena which influence the propagation loss will come into play, including reflection, refraction, absorption, multipath phase interference, and diffraction [37].

The characteristics of these phenomena will depend on the type of propagation mode which is being used. As this study concerns local coverage, interest is focused on space wave propagation. In this section, this type of propagation is presented. The suitability of different channel models is analysed and the influence of noise is shown.

Tropospheric propagation and path loss

Short-range coverage may be provided by tropospheric propagation. In the case of local services, the sky wave component through the ionosphere may exist, but it is not desired, because it is only useful for long distances. One of the greatest challenges for local coverage using the 26 MHz band is to deal with the interference from distant transmitters propagating via this mechanism. This is analyzed in § 9.1. NVIS (Near Vertical Incidence Sky wave) propagation is not suitable either, because its coverage area is not local, but it extends up to several hundreds of kilometres from the transmitter. In addition, this type of propagation is rarely possible in the 26 MHz band.

In the literature, different definitions for "tropospheric wave", "ground wave" and "space wave" can be found. In this document, the following nomenclature is used:

Tropospheric propagation: Propagation within the troposphere and by extension, propagation beneath the ionosphere, when not influenced by the ionosphere [38].

Ground wave: A radio wave basically determined by the properties of the ground, which propagates in the troposphere and which is mainly due to diffraction around the Earth [38].

Space wave: refers to all the tropospheric propagation mechanisms (LOS and NLOS) except the ground wave.

The following paragraphs contain a description and verification of the propagation methods involved in local 26 MHz broadcasting. When planning a DRM transmission network, however, the reception coverage area for each transmitter must be predicted. The algorithms which can be used to achieve this goal are discussed in § 8.

Ground wave propagation

The materials which form the surface of the Earth are not perfect conductors. Thus, the energy transmitted to the Earth generates some ground currents. It propagates near the ground by the mechanism of diffraction following the surface of the Earth. Ground-wave propagation is the usual mechanism utilized by LF and MF broadcasters desiring to provide continuous service throughout the day. This is because the quality of signal delivery in this mode is not so much affected by time-of-day or other time variations. [39].

This type of propagation also appears when transmitting within the HF band, including the 26 MHz sub-band. This is stated in Recommendation ITU-R P.368-9 [10], where vertical electric field strength curves are plotted for different ground conductivities, for frequencies up to 30 MHz.

These curves have been plotted assuming the transmitting antenna to be a short vertical monopole and that both transmission and reception antennas are at ground level. Local area coverage in cities should be obtained from an antenna well above the ground (see § 7) so the electric field amplitude due to ground-wave propagation may be significantly lower. Nevertheless, its contribution cannot be neglected, especially for receiving antennas immediately above the surface of the Earth (e.g. receivers in cars).

In order to verify the utility of these curves and the presence of a ground-wave component, data from a measurement campaign in Mexico DF [40] may be used. In some locations, where the line of sight was obstructed due to the topography (12 km from the transmitter), a field strength of 39-41 dB(μV) was measured.

This value should be compared with the one obtained theoretically in Recommendation ITU-R P.368: a ground conductivity of 25 mS/m is derived from [41] for Mexico DF. This allows the correct curve from Recommendation ITU-R P.368.9 to be chosen giving an electric field amplitude[4] of 38 dB(μV).

It should be noted that the transmitting antenna in the measurement campaign in Mexico DF was 40 m above the ground level while, according to the expression provided by the Recommendation, these curves should only be used when the antennas are located up to 6.9 m ($h = 1.2\ \sigma^{1/2}\ \lambda^{3/2}$, with $\lambda = 11$ m and $\sigma = 25$ mS/m).

But even if this is only an approximation and the space wave propagation contribution must also be considered, the similarity between both values leads to the conclusion that ground wave propagation must be considered when using the 26 MHz band for local broadcasting.

With the data currently available, it is not possible to determine the ground wave to space-wave electric field ratio accurately. However, as shown in this section, there is ground wave propagation, and it must be considered for system planning. Work is being carried out in this field by the UPV/EHU.

This conclusion is validated by a measurement campaign carried out in Geneva [42], which led, among others, to the following two conclusions:

– propagation can generally be treated as quasi-line of sight;

– in the range of 8-9 km around the transmitter, the additional ground wave propagation component can be considered for the 11 m broadcast band.

The presence of a ground wave component is also suggested in [8], as an explanation of the larger differences between measured and predicted levels (with Recommendation ITU-R P.1546 [5]) in the vicinity of the transmitter. This suggestion is corroborated in [9], where a prediction method considering both ground wave and space wave is presented.

Space wave propagation

As the antenna should be installed high above the coverage area, the main expected propagation mechanism is the space wave. Theoretical and simplified free space power loss is then proportional to the inverse of the squared distance to the transmitter. But this law may change substantially due to the various channel effects (reflection, refraction, surface conductivity and irregularity, multipath, interferences, shadowing, etc.). A compendium of these effects and the associated parameters can be found in [43].

Figure 24 shows the electric field strength values plotted against the distance to the transmitter, measured during the field trials in Brasilia [44]. These values are depicted and classified by different fixed reception environments. It can be seen that the field strength level received in open locations is higher than the level received in dense urban locations, even when the distance to the transmitter is the same. The points marked with dashed circles were in open locations, where the received field strength level was very low. These points were located in the direction of the transmission antenna back lobe.

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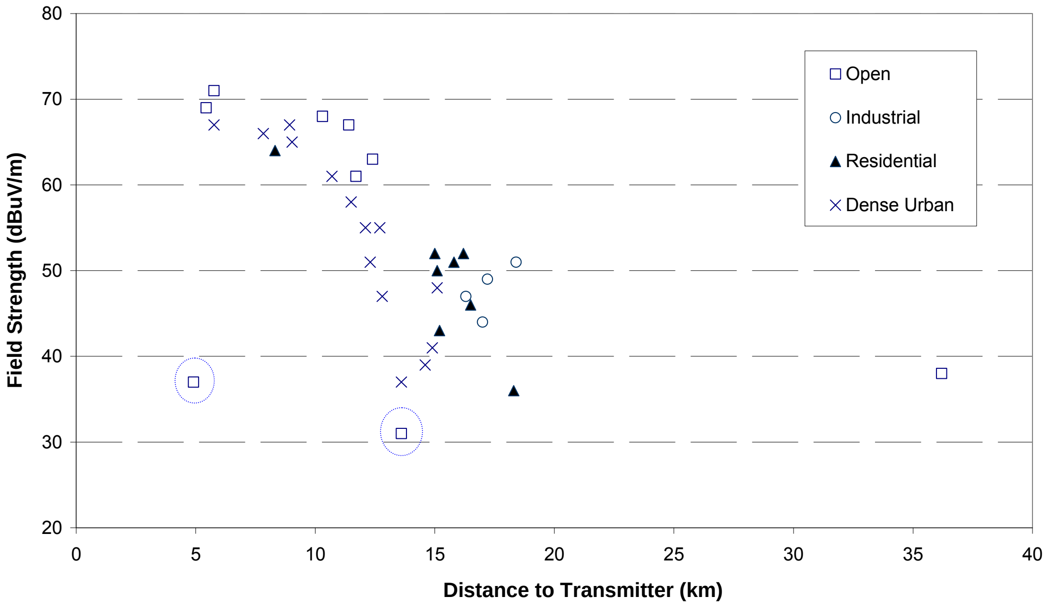
4 As the location under consideration is a city, a conductivity much lower than that obtained from the atlas may be considered for the theoretical calculation. Nevertheless, if there is a conductivity of 0.1 mS/m and $\varepsilon = 3$ (very dry ground conditions), a 20 dB(μV) field strength is still expected.

FIGURE 24

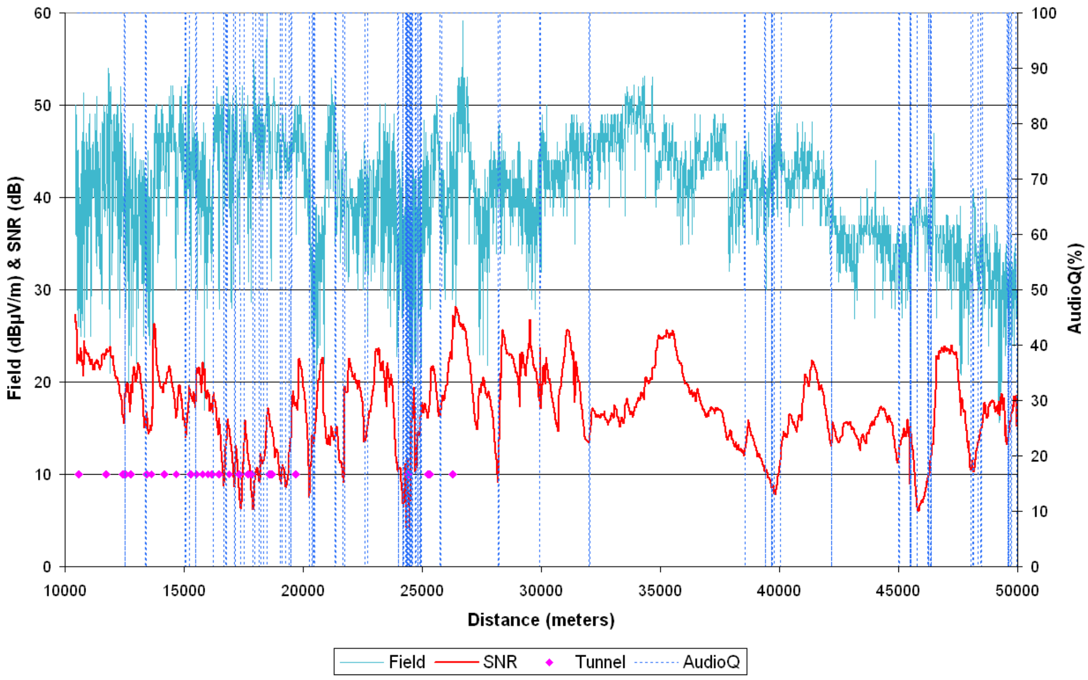
Electric field strength VS reception environment in Brasilia [44]



The effect of multipath and, thus, the differences between city and rural areas are shown in Fig. 25. These values were obtained in a mobile reception scenario in Mexico DF, with a mean speed of 50 km/h and a maximum of 80 km/h. The route was radial from the transmitter (with the city closest to it) and open areas became more frequent as the receiver moved further away. In an open environment, the multipath is lower than in the city, so the variability is also smaller. It can be seen that in the first half of the route, the field strength did not follow a clear pattern. Nevertheless, for distances further than 34 km away from the transmitter, a negative slope pattern is clearly shown. This reinforces the fact that in the city, the received levels were more influenced by topology than by the distance to the transmitter [45].

FIGURE 25

Influence of the environment on the electric field strength in Mexico DF [45]

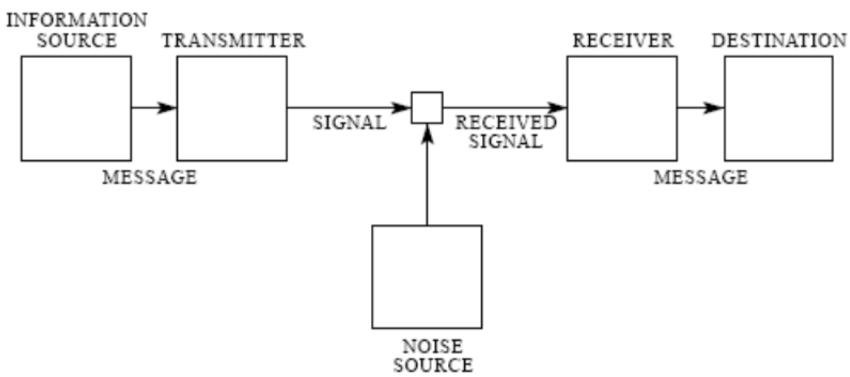


Channel model

The architecture of a generic communication system was defined by Claude Shannon in 1948. Its representation can be found in Fig. 26 [46].

FIGURE 26

Schematic diagram of a general communication system [46]



An information source attempts to send information to a destination. The data is converted into a signal suitable for sending by the transmitter and is then sent via a frequency channel. The channel itself modifies the signal in ways which may be more or less unpredictable to the receiver, so the receiver must be designed to overcome these modifications and hence to deliver the information to its final destination with as few errors or distortions as possible [47].

In order to be able to build efficient receivers, the modifications introduced by the channel must be known and so an accurate channel model is crucial.

A set of 6 channel profiles are presented in Annex B of the DRM standard [35] for frequencies below 30 MHz. Each of these channels is expressed as a combination of paths which are defined separately. For each path the following data is given: the delay and path gain referred to the main one, the Doppler shift and the Doppler spread.

As stated in Annex B of the DRM standard [35], the channels to be considered are in the LF, MF and HF broadcast bands (HF includes the 26 MHz band). It continues: "In principle all three are multipath channels because the surface of the earth and the ionosphere are involved in the mechanism of electromagnetic wave propagation". For local reception there is no signal path through the ionosphere. There is a ground wave component (see Annex 2), and several space wave reflections (mainly in urban areas) which must also be considered – these are the main components Thus, multipath characteristics are completely different, and the channel models considered in the DRM standard are unsuitable for local reception.

This is explained [40] as follows:

– Channel 1 is a Gaussian channel, which is associated with ground wave propagation.
– Channel 2 corresponds to night time propagation, formed by a ground wave component and an ionospheric component.
– Channel 3 is a variation of Channel 2, where ionospheric components predominate.
– The other 3 channels contain multipath, but from reflections in the ionosphere and from the ground.

This is quite different from the multipath found in local transmissions, because of the distance and the number of reflected waves. None of the six channels defined in Annex B of the standard is suitable for 26 MHz local propagation.

The latest version of the DRM standard (August 2009) adds a second part to Annex B, defining channel models for DRM+. These channel types better correspond to the characteristics of 26 MHz local propagation (urban, rural, terrain obstructed, hilly terrain and SFN), but as the working frequency is different (DRM+ is designed to work between 30 and 174 MHz) actual values may differ and their suitability for the 26 MHz band has not yet been validated. In addition, these models do not take into account the ground wave component in the areas closest to the transmitter.

In order to obtain a more specific channel model, the data collected in different measurement campaigns can be analyzed. Such an analysis can be found in [40]. The conclusions obtained relating to time and space variability are introduced in the following subsections.

The prediction of the received radio signal strength is a two stage process involving an estimation of both the median received signal level within a relatively small area, and the signal variability about that median level. First, there is the variation in the median signal itself, as the receiver moves from place to place. This is caused by large-scale variations in the terrain profile along the path to the transmitter and by changes in the nature of the local topography, producing slow or log-normal fading. Superimposed on this slow fading is the rapid and severe variation in the received signal strength (fast or Rayleigh fading) caused by multipath propagation in the immediate vicinity of the receiver. A quantitative measure of the signal variability is essential for several reasons. An estimate of the variability is as important as a prediction of the median value itself [48].

The characteristics of the received signal, when using a fixed receiver, are usually different from those obtained with a mobile receiver. Separate studies must therefore be carried out. In order to analyze the variability of the signal in static receivers, changes in the time domain must be considered. If the receiver is moving, variations due to its location (spatial variability) are also relevant.

Time variability

For analogue broadcasting, a coverage availability of 50% can be considered a reasonable quality target. However, a much higher percentage availability is sought for digital systems, due to the ‘brick-wall’ effect. In order to satisfy this constraint, signal variations in the time domain must be analyzed. Once the corresponding field-strength probability distribution function is known, proper planning is possible.

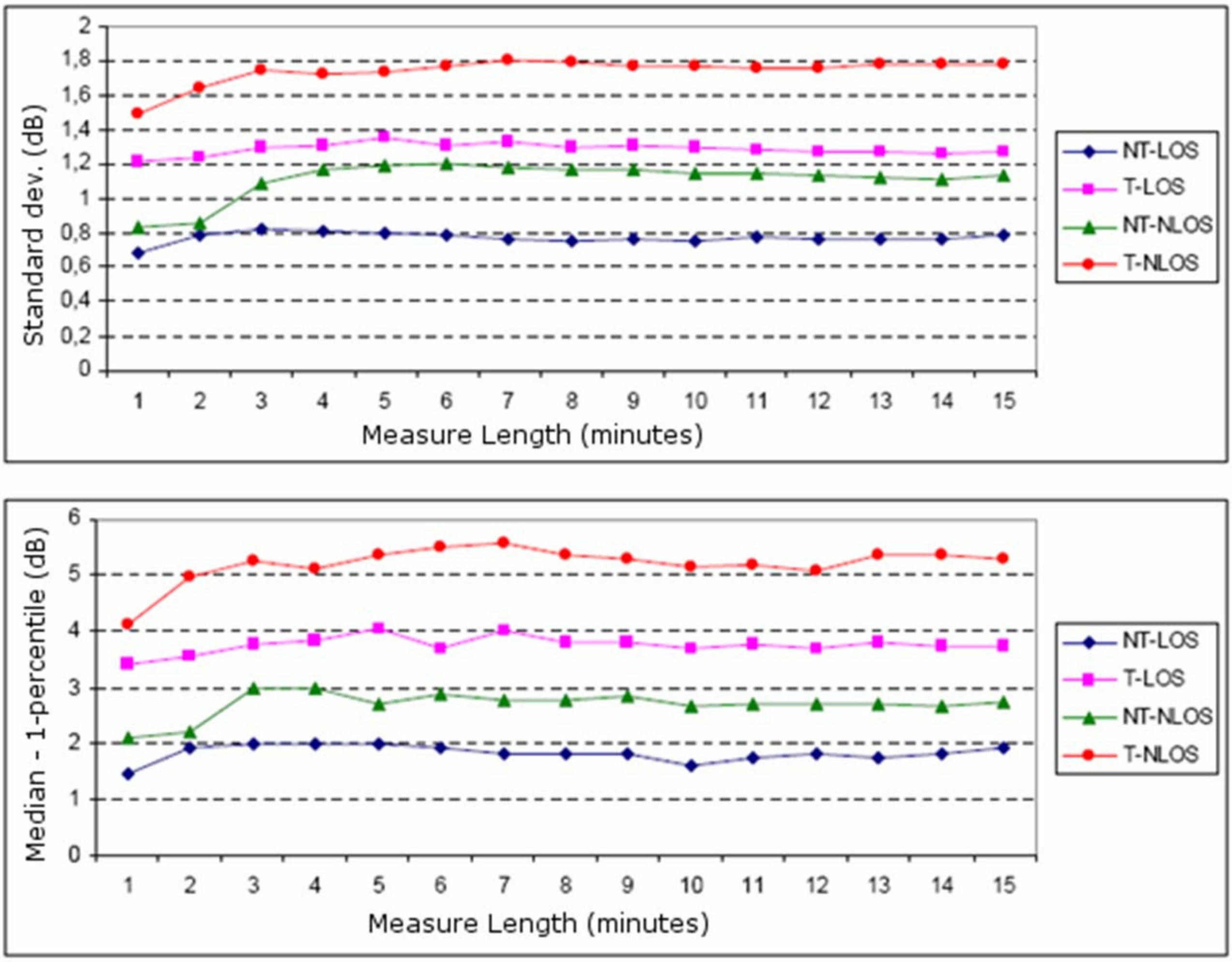
Characterization

When studying time variability, only static measurements should be considered. In [40] two parameters were analyzed: the standard deviation of the electric field strength and the difference between the field strength value which is exceeded 50% of the time and the one exceeded 99% of the time.

Measurements lasting 3 minutes give results close to those lasting 15 minutes, as shown in Fig. 27 [40], so there is no need to make lengthy measurements.

FIGURE 27

Influence of the measurement duration on the considered variability parameters [40]



Recommendation ITU-R P.1057-2 [49] shows the most commonly used probability distributions for modelling field variability. Matías considered normal, log-normal, Rayleigh, Rice, Nakagami, exponential and Weibull for his study. He discarded Suzuki, which is intended for spatial variability, as it considers both fast and slow variations (and this is not applicable to time variability).

Table 8 shows the global results obtained in the Mexico and Brasilia measurement campaigns.

TABLE 8

Global time variability results [40]

	Mexico DF	Brasilia
σ (mean)	1.28 dB	0.63 dB
$P_{50} - P_1$ (mean)	3.84 dB	1.58 dB
$P_{50} - P_1$ (90 percentile)	7 dB	2.80 dB
# Measurements	68	33

In this Table, σ stands for the typical deviation of the variability and P_{50}-P_1 is the difference between the 50-percentile (median value) and the 1-percentile (this value is the correction factor to ensure coverage for 99% of the time). The second row of the table corresponds to the P_{50}-P_1 correction factor to ensure coverage for 99% of the time at 50% of locations, and the third row for 90% of locations. The particular statistic parameter calculated by the combination of the values obtained for each measurement location is expressed in brackets.

One of the most interesting values is the $P_{50} - P_1$ (90 percentile) measured in Mexico. This value means that in order to ensure the coverage for 99% of the time (in 90% of locations) power should be increased by 7 dB over the median value (which is usually provided by field strength estimation algorithms). Field strength variability in Brasilia was much lower than in Mexico, which is a larger and denser location, with difficult propagation characteristics.

Matías also found that the lower the median value of the received field (in a very small area), the higher the variability. But as few measurement points showed significant differences in the median value from one day to another, he was not able to state a general trend. He suggested however that this difference could be the result of having the same variable component (as a very small area is considered) and a different median value (due to space variability, which will be analyzed in the corresponding section).

The main conclusion is that the different characteristics of Mexico DF and Brasilia lead to a significant difference in the received field strength variability.

Analysis of several phenomena

Traffic density

During the measurement campaign in Mexico, it was observed that traffic had a large impact on the received electric field strength. Traffic density was classified in 3 different groups: isolated (places with little or no traffic), non-dense (continuous traffic, but flowing), and dense (heavy traffic or traffic jams). Applying these criteria to the measurement points, the following results were obtained:

TABLE 9

Time variability depending on the traffic intensity in Mexico [40]

Mexico	Traffic intensity		
	Isolated	Non-dense	Dense
σ (mean)	0.83 dB	1.14 dB	1.51 dB
$P_{50} - P_1$ (mean)	2.06 dB	3.43 dB	4.55 dB
$P_{50} - P_1$ (90 percentile)	2.90 dB	4.40 dB	7.20 dB
# Measurements	18	7	20

TABLE 10

Time variability depending on the traffic intensity in Brasilia [40]

Brasilia	Traffic intensity		
	Isolated	Non-dense	Dense
σ (mean)	0.49 dB	0.61 dB	0.86 dB
$P_{50} - P_1$ (mean)	1.11 dB	1.31 dB	2.63 dB
$P_{50} - P_1$ (90 percentile)	1.20 dB	2 dB	3.60 dB
# Measurements	9	16	8

Values in Mexico were considerably larger than in Brasilia, as noted previously. However, the result is the same in both cases: variability increases as traffic intensity becomes heavier. Thus, when traffic is not negligible, higher power is needed to achieve the same coverage.

Line-of-Sight

Similar processing was carried out to determine if the existence or lack of a direct line of sight affects the variability of the signal. To define whether there was direct line-of-sight, for each measurement point, the criterion followed was not the first Fresnel ellipsoid (as at these frequencies it is always obstructed), but the existence of an obstacle in the path between transmitter and receiver.

Results indicated there was no relationship between direct visibility and the time variability of the received signal.

Aircraft

Aircraft landing or taking off from the airport in Mexico City influenced the DRM signal reception. Table 11 shows their influence on time variability, presenting the differences obtained when an aircraft flew above the receiver when the measurement was being made.

TABLE 11

Time variability depending on the presence of aircraft [40]

Mexico City	No aircraft	Aircraft
σ (mean)	1.24 dB	1.42 dB
$P_{50} - P_1$ (mean)	3.57 dB	4.86 dB
$P_{50} - P_1$ (90 percentile)	7 dB	10.2 dB
# Measurements	54	14

It can be concluded that when an aircraft flies at a certain altitude it increases time variability. This effect significantly changes the P_{50}-P_1 value. This is because variability increases for a very short period of time. This is not enough to change the standard deviation by very much, but it does affect the value of the field strength which is exceeded 99% of the time (and hence the field strength which is not exceeded 1% of time) which decreases considerably.

Statistical interference

The previous study leads to correction factor values for an availability of 99% of the time. In order to estimate other probabilities, the probability distribution of the time variability must be characterized.

Normal, log-normal, Nakagami, Weibull, Rayleigh, Rice and exponential distributions were compared with the results. In order to determine the most suitable value of the parameters associated to each distribution, a maximum likelihood method was applied.

It was concluded that high K factor Rice distribution (or a normal distribution, which would lead to similar results) is best for coverage planning, while the log-normal distribution is better for interference calculations.

As time variability more closely resembles a Gaussian channel than a Rayleigh channel, there is a very stable component of the received field strength and less intense variable components.

In general, high K factor Rice, Nakagami and log-normal distributions were those that best fitted the measurement sets; Nakagami distributions led to values between those given by the other two distributions.

Table 12 shows the values of the parameters of the normal distribution (to which the Rice distribution would converge) suggested for both cities.

TABLE 12

Proposed statistics for a normal distribution [40]

	m	σ
Mexico City	1.004	0.25
Brasilia	1.002	0.11

The presented value of σ corresponds to the 90-percentile for all locations; in order to ensure that in more than 90% of locations the coverage would be better than the one specified by the probability distribution.

When considering the effect of the reception environment (differentiating the areas as: open, residential, industrial and dense urban), the probability distribution which best fits the results is Nakagami for almost every type of area. Only in dense urban locations in Mexico and open areas in Brasilia does the normal distribution give a better match. However, there is little difference, and both distributions fit similarly to measurements in all these environments.

Table 13 shows the suggested distributions (including the parameter values) for traffic and aircraft conditions. For the normal distributions, the *m* parameter has been obtained as the mean of the results, and σ as the 90-percentile, so the desired coverage in time would be attained in 90% of locations. For the same reason, in Nakagami distributions, the Ω value has been obtained as a mean, and *m* as 10-percentile.

TABLE 13

Proposed probability distributions according to traffic and aircraft conditions [40]

Traffic	**Isolated**		**Non-dense**		**Dense**	
Aircraft presence	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Mexico	Nakagami m = 13.12 Ω = 1	Nakagami m = 9.68 Ω = 1	Nakagami m = 8.91 Ω = 1	–	Normal m = 1 σ = 0.29	Normal m = 1 σ = 0.29*
Brasilia	Nakagami m = 57.93 Ω = 1	–	Nakagami m = 30.73 Ω = 1	–	Normal m = 1 σ = 0.13	–

* A value of σ = 0.27 is shown for dense traffic with aircraft in Mexico. But the author suggests, afterwards, using the same value in both cases: with and without the presence of aircraft.

It must be noted that, in general, Matías suggests the use of normal distribution in the case of heavy traffic, and Nakagami in the case of non-dense or isolated traffic.

Space variability: Slow and fast fading

Mobile DRM reception implies a radio path where the transmitter is stationary and the receiver is moving. In this case, path loss will vary continuously with location, depending on all the factors affecting it. These influences can be classified into three main categories [5]:

Multipath variations: Signal variations will occur over distances of the order of a wavelength due to phase addition of signals with differing path lengths – reflections from the ground, buildings, etc. The statistics of these variations are typically found to follow the Rayleigh distribution.

Local ground cover variations: Signal variations will occur due to nearby obstructions – buildings, trees, etc., over distances of the order of the size of the obstruction. The scale of these variations will normally be significantly larger than that for multipath variations.

Path variations: Signal variations will also occur due to changes in the topography of the entire propagation path – the presence of hills, etc. For all except very short paths, the scale of these variations will be significantly larger than that for local ground cover variations.

For a moving receiver these variations, which are classified spatially, can be expressed as a time domain characteristic. For a particular speed, multipath variations (which occur in the order of a wavelength) are much faster than other path variations. This is why they are considered as "fast fading". Slow fading would include both local ground cover and path variations. Nevertheless, a spatial variability study is usually defined for areas large enough to consider local ground cover variations, but small enough not to consider path variations [5] [43] [48] [50].

Lee proposed a method to separate the fast and the slow fading components from a signal [51] [52], so they can be analyzed separately. The principle is first to obtain all the slow fading components using a "running mean" which smoothes the signal. Then, fast fading is computed by subtracting the slow fading from the overall signal. Thus, the signal r(x) can be expressed as a product of slow fading m(x) and fast fading r_0(x):

$$r(x) = m(x) r_0(x) \tag{1}$$

The mobile local mean is obtained as:

$$\hat{m}(x) = \frac{1}{2L} \int_{x-L}^{x+L} r(y) dy \tag{2}$$

Lee demonstrated that, when the channel has a Rayleigh response, for a correct value of *2L*, $\hat{m}(x)$ has the same value of m(x) and is constant from x-L to x+L. It is more usual, however, to work with discrete space samples. The running mean is, in this case, defined as:

$$\hat{m}(x) = \frac{1}{N} \sum_{i=1}^{N} r(x_i) \tag{3}$$

The parameters to define would be the number of samples *N* in the window (whose size is equivalent to *2L*) and the distance *d* between samples. Once the value of *2L* is fixed, a suitable combination of *N* and *d* must be selected. The variance of $\hat{m}(x)$ decreases when *N* is increased, but *d* must be large enough to ensure independence between samples.

Typical values are: *2L* = 40λ, d = 0.8λ *and N = 50*, in order to obtain a median accurate to ±1 dB, with 90% probability (as in § 7 in [53] or § 3.2 in [43][5]).

Lee's method, however, cannot be applied directly to DRM 26 MHz signals [40]:

The method requires a Rayleigh channel, but at such a low frequency it cannot be assured that this statistical model is representative of the real channel. It is only defined for theoretical signals. There is no upper bound definition for the parameter *2L*, even if it is identified by Lee.

In order to address these problems, a "generalized Lee's method" was suggested [54] [55] [56]. In the generalized version, the value of 2L is computed from the samples, and d from those that are uncorrelated in the fast fading[6]. This sample dependency instead of theoretical signal dependency makes it more appropriate than the standard model when the channel model is not Rayleigh, or when it is not known. Using this method, with the samples from the measurement campaign in Mexico, the following parameters are suggested for a 26 MHz DRM signal in [40]:

---

5 The actual suggested value of *N* in this last document is *36* (as a minimum), following the Recommendation in [51], not the newer value proposed by the same author in [74].

6 In order to obtain the fast fading component, $r_0(x)$, a value of *d* is needed. A preliminary value *d'* is computed from the complete signal, *r(x)*.

TABLE 14

Lee's method parameters applicable to 26 MHz DRM signals [40]

Parameter	Value
2L	16.92λ
d	0.38λ
N	45

These values lead to a ±1.04 confidence interval with a 90% confidence level. Once these values are fixed, the slow fading component can be computed from the samples using equation (3). Then, the fast fading component can be derived from equation (1).

Slow fading

The probability distribution of slow fading values follows a log-normal distribution for DRM on 26 MHz [40], as it does for higher frequencies (such as 450 MHz [57] or 900 MHz [58]). Normalizing the slow fading signals to their mean value, the measurement campaign in Mexico lead to the following parameters for the log-normal distribution:

TABLE 15

Log-normal distribution parameters for slow fading [40]

	m	σ
Mean	–0.03	0.22
90-percentile (σ)	–0.06	0.35

Parameters m and σ, as defined in [49], are the mean and standard deviation of the logarithm of the variable, and not the variable itself (field-strength). The actual mean value of the variable can be computed as:

$$mean = e^{m+\frac{\sigma^2}{2}} \tag{4}$$

As the distribution has been normalized, the mean value would always be equal to unity. Therefore, these parameters are not independent. Using the 90-percentile of σ ensures that the slow fading variability will be within bounds for 90% of occasions.

The same study presented the correction factors which should be added to the predicted field strength median values in order to receive higher field strength in 90% (P_{50}-P_{10}), 95% (P_{50}-P_5) and 99% (P_{50}-P_1) of locations. These results are presented in Table 16 and are very close to the ones obtained with Recommendation ITU-R P.1546 [5].

TABLE 16

Recommended space domain correction factors for 700 m distance slow fading [40]

Correction Factor	P_{50}-P_{10} (dB)	P_{50}-P_5 (dB)	P_{50}-P_1 (dB)
Value	3.90	5	7.07

Little difference is observed in space variability when analyzing the effect of the surrounding area. According to the measurement campaign in Mexico, correction parameters for non-dense and dense areas differ by no more than 1 dB. Thus, correction factors in Table 16 can be applied to any environment.

Fast fading

The probability distribution of fast fading values follows a Nakagami distribution. Good agreement is also obtained with Weibull, Rice and Rayleigh distributions. As the actual data distribution predominantly follows a Rayleigh distribution, the suitability of the other three distributions is to be understood, since for all of them Rayleigh is a particular case [40]. The suggested Nakagami distribution parameter values are shown in Table 17. The values of the second row are the ones recommended for planning purposes, as they ensure that actual variability will be smaller than predicted for 90% of occasions.

TABLE 17

Nakagami parameters for fast fading modelling [40]

	m	**Ω**
Mean	1.19	1.22
10-percentile of m 90-percentile of Ω	0.92	1.35

Table 18 shows power correction factors to minimize space variability effects. The first row of the table represents the results from the samples obtained in Mexico and the second row the ones obtained from the parameters in Table 17.

TABLE 18

Recommended space domain correction factors for fast fading [40]

Origin of results	**P_{50}-P_{10} (dB)**	**P_{50}-P_5 (dB)**	**P_{50}-P_1 (dB)**
Samples	8.8	11.9	18.9
Estimation	8.7	12.1	19.8

Fast fading is more affected by the characteristics of the environment than slow fading. Correction factors from one type of area to another can differ by as much as 4.5 dB [40]. For Nakagami distributions, the suggested m parameter values, depending on the surrounding area, are shown in Table 19. Values of m below unity imply a distribution more variable than Rayleigh. The multipath component increases with the density of population (larger and closer buildings).

TABLE 19

Recommended power correction factors for fast fading considering the environment [40]

Surrounding area	m (Mean)	m (10-percentile)
Open residential	1.28	1.07
Non-dense industrial	1.06	1.06
Wide and narrow streets, small buildings	1.17	0.97
Wide streets, large buildings	1.25	0.92
Dense urban	1.13	0.90

Flat fading

The "Coherence bandwidth" is a statistical measure of the range of frequencies over which the channel can be considered "flat"; in other words the approximate maximum bandwidth or frequency interval over which two frequencies of a signal are likely to experience comparable or correlated amplitude fading.

Depending on the temporal dispersion of the channel (Δ), an associated value for coherence bandwidth can be obtained. The precise definition of coherence bandwidth often differs from one reference to another and tends to depend on the extent of the correlation, determined subjectively, over which the two signals are correlated. A typical definition is [50] [59]:

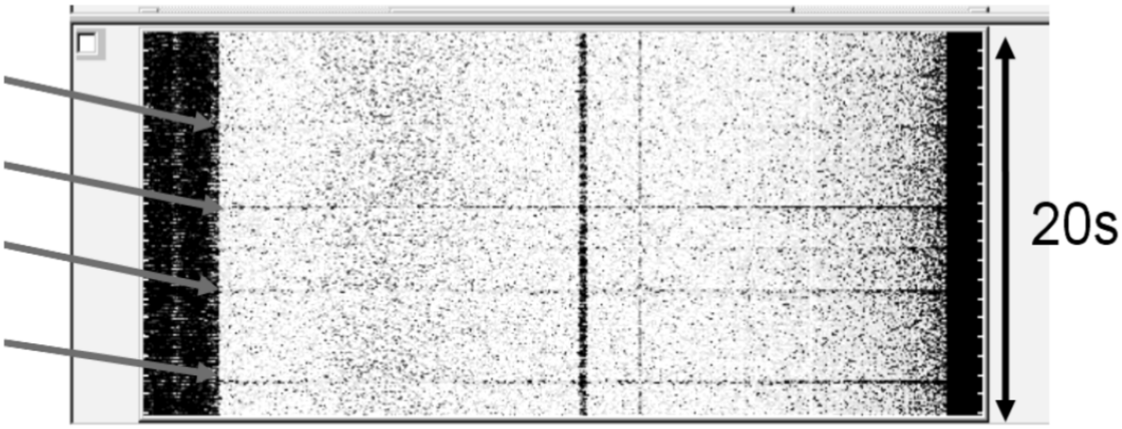
$$B_C \approx \frac{1}{8\Delta} \tag{5}$$

As shown before, multipath propagation in urban areas is going to be present in a space wave broadcast on 26 MHz. From the deep fades it may be concluded that the interfering signals have about the same power. The path differences will be small, especially since the coverage area of the transmitter is of only a few kilometres [23]. The delay between the different components is not as large as for long distance (international) propagation. Therefore, the temporal dispersion of the channel is smaller than the one for which the DRM system was designed. The related coherence bandwidth will not be as narrow. Matías suggests a coherence bandwidth of 95 kHz [40] and Hernando a value of 53 kHz for urban environments [60].

Due to the small bandwidth of the signal (compared with the coherence bandwidth), the fading is not frequency selective, but flat (Fig. 28 shows that when fading occurs, it affects the whole channel). This is because with low transmitter power, only reflected signals in the vicinity of the receiver contribute to the received signal, leading to a delay spread in the order of only few microseconds. Hence the coherence bandwidth of the channel is in the range of several hundred kilohertz. This indicates that at frequencies close to 26 MHz, reflections from buildings must be considered as leading to flat fading as a main cause of reception problems in cities [61]. This will in turn lead to the unfavourable situation with audio dropouts occurring during mobile reception of DRM signals at low vehicle speeds or at stops (e.g. at traffic lights) [36]. The same problem will occur for indoor reception without an external antenna [23]. This will happen at some locations, even within the service area, where mobile reception at higher speeds is unimpaired due to forward error correction and time interleaving [25]. At low speeds, time interleaving does not improve reception due to the slow time variance of the channel. It is important to remember that the DRM system is not designed to operate in such channels. Therefore, these dropouts cannot be avoided by increasing power [16].

FIGURE 28

Flat fading. Waterfall diagram of a signal received along a route of 20 s in Nuremberg [16]



This problem can be solved by using a transmit delay diversity technique explained in Annex 1.

Annex 3

DRM 26 MHz measured threshold values

Minimum SNR values

Theoretical SNR values [64] can be compared with the ones actually measured in Mexico and Brasilia, which are shown in Table 20. Fixed reception values in Mexico have been obtained from [45], and mobile reception values from [62]. The source of the results in Brasilia is [63].

TABLE 20

Measured SNR thresholds in Mexico and Brasilia

City	Mode	Fixed reception		Mobile reception	
		Mean AQ [%]	SNR min [dB]	Mean AQ [%]	SNR min [dB]
Brasilia	18K B 16 4 0.5 L	99,73	13	99,23	15
Mexico	18K B 16 4 0.5 L	99,1	17	90,23	18
	10K B 16 4 0.5 L	96,34	23	89,94	17
	18K B 16 4 0.5 S	N/A	N/A	89,72	20
	10K C 16 4 0.5 L	N/A	N/A	91,87	18
	18K B 64 16 0.6 L	93,79	20	79,29	20
	18K A 64 16 0.6 L	96,08	25	82,86	21

During the tests, the 18K_B16405 DRM mode was shown to be the best for the 26 MHz band. The tests were therefore focused on this mode. This mode is recommended for normal operation, but using a bandwidth of 20 kHz (instead of 18 kHz) due to the channelling arrangements in the HF band (two 10 kHz channels) [62].

The mobile measurement campaign carried out in Dorset (United Kingdom) [36] led to the SNR (MER) threshold values shown in Table 21. Different combinations of robustness mode, constellation and code rate were tested.

TABLE 21

Minimum MER values from the Dorset measurement campaign (10 kHz BW) [36]

MSC Constellation	**16**		**64**			
Code Rate	0.5	0.62	0.5	0.6	0.71	0.78
Mode A	12 dB	13 dB	14 dB	15 dB	18 dB	18 dB
Mode B	12 dB	15 dB	16 dB	16 dB	17 dB	19 dB

For each dropout detected on the test route, the minimum MER was measured within the 2 s (equivalent to the inter-leaver length) immediately before the dropout occurred. The 10% value of the resulting cumulative distribution of these MER values shows, approximately, the minimum MER above which audio was received without dropouts (the 10% MER threshold indicates that 10% of measured values were below this threshold and 90% were above).

The results for modes A and B are roughly the same. However, the robustness of these modes is apparent when high delay or Doppler spread is present. The delay in local transmissions is much lower than for the ionospheric services for which DRM was originally designed, so it does not have any effect. Doppler spread was not significant in either mode, since the speed of the receiver was not high (speeds above 100 km/h would be needed to show a difference).

In 2003, a measurement campaign was held in Hannover [8]. The parameters of the signal were: MSC of 64 QAM, 10 kHz bandwidth, long inter-leaver. UEP was used (Unequal Error Protection) with protection level 0 (PL0) for part A and PL1 for part B for mode A. For mode B, UEP with PL1 for part A and PL2 for part B; the same PL configurations as in mode A was also tested. A 16 dB SNR threshold was obtained for every combination.

Audio quality versus SNR

As seen in Table 20, mobile reception is more restrictive than fixed. A further analysis of mobile reception is given in the following paragraphs. This subsection shows how the quality of the decoded signal varies with the SNR at the receiver, and how this variation depends on the environment.

Figures 29 and 30 show the sections with correct and incorrect reception (in Mexico and Brasilia), classified according to the minimum SNR. The reception thresholds considered in Table 20 are the values that ensure correct reception for 90% of sections.

FIGURE 29

Sections with correct and incorrect reception vs. SNR in Mexico (Mode 18K_B16405) [62]

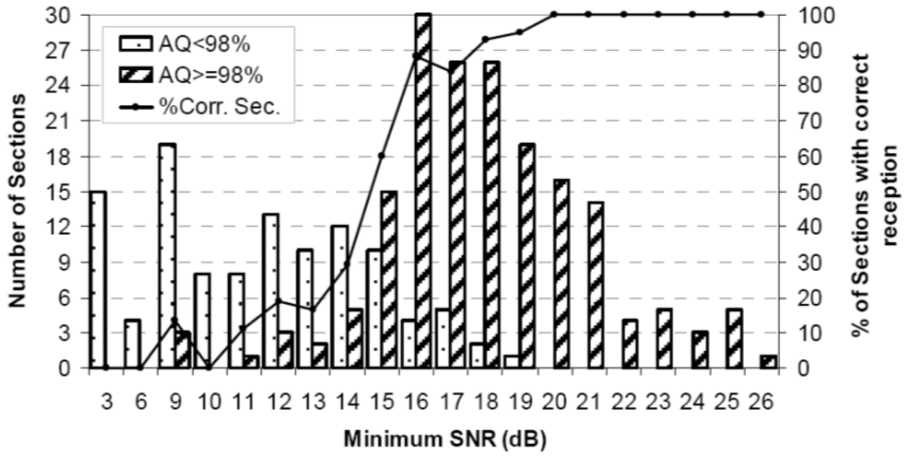
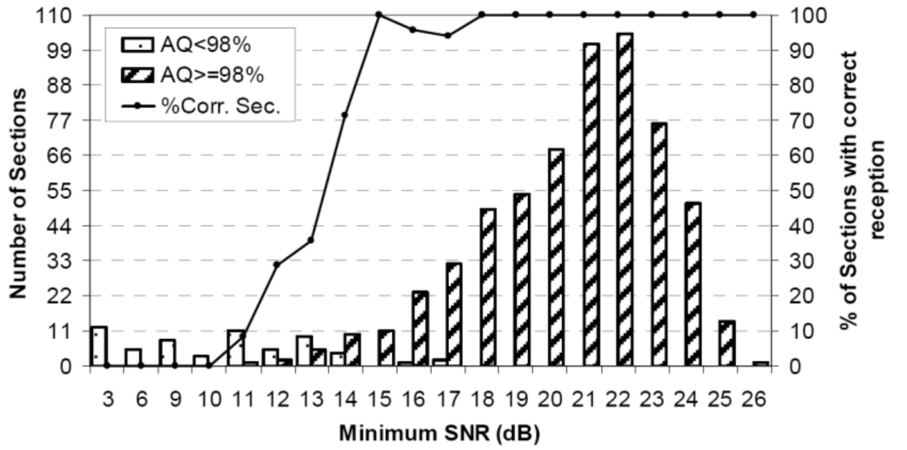


FIGURE 30

Sections with correct and incorrect reception vs. SNR in Brasilia (Mode 18K_B16405) [62]



The SNR values correspond to the minimum measured in each 200 m section. Although it is usually more convenient to calculate the thresholds as a function of median values, in this case, they do not give the thresholds as clearly as the minimum values for the section. This is because the requirement for good reception is high (98%), and any minor problem means reception is impaired. These minor problems are reflected in the minimum value for the section, but usually not the median.

Minimum usable field strength values

Theoretical electric field strength values [64] can be compared with those actually measured in Mexico and Brasilia; shown in Table 22. Fixed reception values in Mexico have been obtained from [45], and mobile reception values from [62]. The source of the results in Brasilia is [63].

TABLE 22

Measured electric field strength thresholds in Mexico and Brasilia

City	Mode	Fixed reception		Mobile reception	
		Mean AQ [%]	E min [dB(µV/m)]	Mean AQ [%]	E min [dB(µV/m)]
Brasilia	18K B 16 4 0.5 L	99,73	37	99,23	35
Mexico	18K B 16 4 0.5 L	99,1	38	90,23	35
	10K B 16 4 0.5 L	96,34	39	89,94	38
	18K B 16 4 0.5 S	N/A	N/A	89,72	38
	10K C 16 4 0.5 L	N/A	N/A	91,87	36
	18K B 64 16 0.6 L	93,79	45	79,29	40
	18K A 64 16 0.6 L	96,08	45	82,86	38

In addition to the values shown in Table 22, measurements carried out by Deutsche Welle with a 10 kHz bandwidth signal concluded that the threshold for 60% audio in a mobile scenario is 23 dB(µV/m) in Nuremberg and 26 dB(µV/m) around Dillberg [23]. These values are somewhat higher than the value of 17.6 dB(µV/m) proposed by the ITU [64] as a planning parameter for the DRM mode (10kHz/A/16/4/0.62/L). This may be due to the higher man-made noise in the city of Nuremberg and along the motorway. In addition, due to multipath fading (and its variation in time), a higher level is required for mobile reception than for stationary reception [16].

According to the results shown in this document, there is no significant difference between DRM operation in modes A and B. Nevertheless, an interleaving depth of 2 s performs better than 0.4 s for mobile reception, and a relatively short AGC time constant for the receiver seems to be useful [23].

The mobile measurement campaign carried out in Dorset (United Kingdom) [36] led to the field strength threshold values shown in Table 23. Different combinations of robustness mode, constellation and code rate were tested. The procedure to determine them is exactly the same as the one explained for the corresponding MER values from the same tests.

TABLE 23

Minimum field strength in the Dorset measurement campaign [36]

MSC Constellation	16		64			
Code Rate	0.5	0.62	0.5	0.6	0.71	0.78
Mode A	31 dB(µV/m)	34 dB(µV/m)	33 dB(µV/m)	35 dB(µV/m)	37 dB(µV/m)	37 dB(µV/m)
Mode B	32 dB(µV/m)	N/A	36 dB(µV/m)	34 dB(µV/m)	36 dB(µV/m)	39 dB(µV/m)

In 2003, a measurement campaign was held in Hannover [8]. The parameters of the signal were: MSC of 64 QAM, 10 kHz bandwidth, long inter-leaver. UEP was used (Unequal Error Protection) with protection level 0 (PL0) for part A and PL1 for part B for mode A. For mode B, UEP with PL1 for part A and PL2 for part B; the same PL configurations as in mode A was also tested. The obtained field strength threshold was about 40 dB(µV/m), but a slight decrease was observed with the mode robustness.

Audio quality variation with field strength

As can be observed in Table 20, mobile reception is more restrictive than fixed. Therefore, a further analysis of mobility will be held in the following paragraphs, applying the same methodology as for SNR in the previous section. This subsection shows how the quality of the decoded signal varies depending on the field strength at the receiver, and how this variation depends on the environment. Results are shown in Figs 31 and 32.

FIGURE 31

Sections with correct reception vs. field strength in Mexico (Mode 18K_B16405) [62]

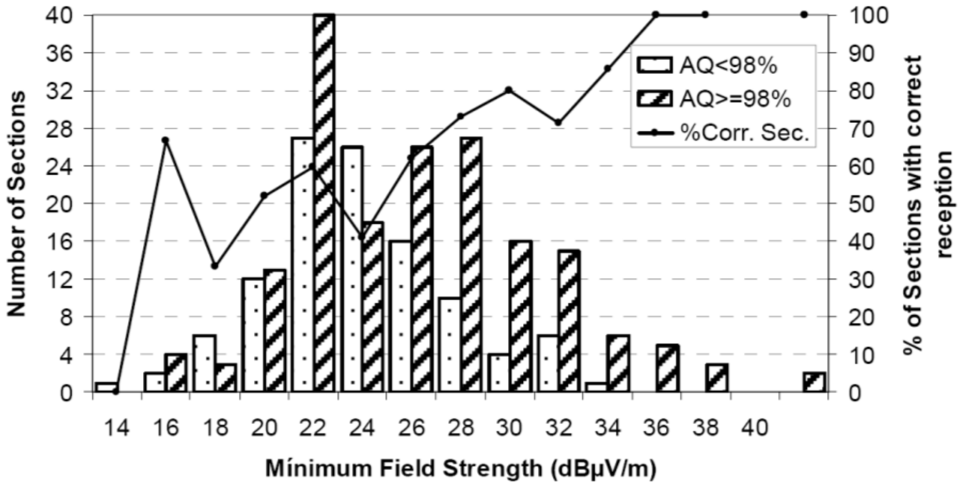
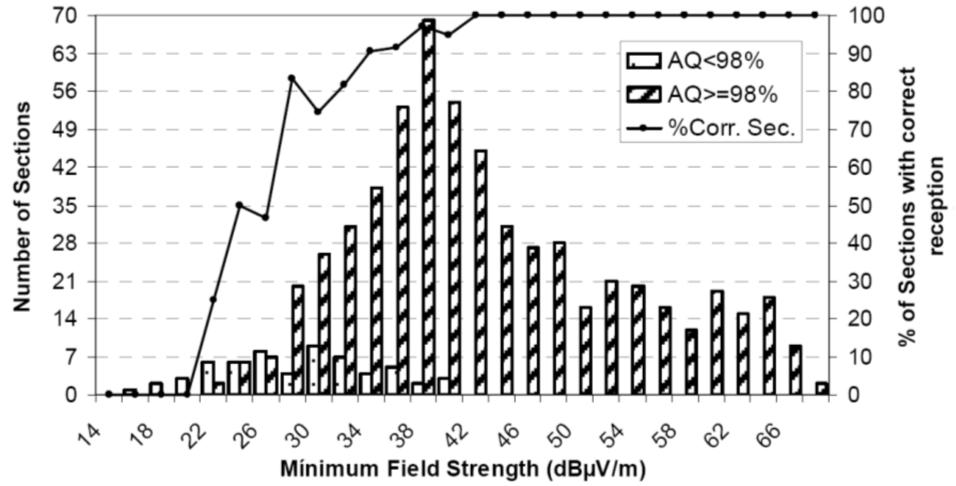


FIGURE 32

Sections with correct reception vs. field strength in Brasilia (Mode 18K_B16405) [62]



Annex 4

DRM 26 MHz coverage aspects

Coverage area

The coverage area of a radio broadcasting system is the area where the service can be properly received. When a single transmitter is used, the extent of this area depends on several factors:

e.i.r.p.: If the power of the transmitter is increased, the thresholds of field strength and SNR, which are presented in Annex 3, will be attained at a greater distance from the transmitter. The tests carried out in Delhi showed that if very high power is used, a very large area is covered [66]. However, interference and regulatory issues must be considered and the power used should not be higher than needed.

The robustness of the DRM mode used for the transmission: As shown in Annex 3, the necessary field strength and SNR depend on the parameters of the chosen mode. This is stated in [8]: "with a given transmission power, the coverage area will be wider if a more robust mode is used". Similarly, a reduction in data rate translates to a requirement for a reduced field strength and SNR; the coverage area therefore increases.

The environment of the receiver: The topography, the outdoor or indoor location of the receiver and the urbanization all have a direct influence on shadowing of the signal. Shadows are, by definition, locations within the expected coverage area where there is no actual coverage. For example, reception is generally better in areas without dense woods; at the same distance from the transmitter, shadowing from trees impairs reception [16].

Noise: The SNR in noisy areas can fall below the relevant threshold, taking these areas out of the coverage area.

Receiver mobility: Because of more demanding conditions, the coverage area is smaller for mobile reception than for fixed. Actual values are given in the following subsections.

Using a network of transmitters can extend the coverage area. As explained in § 6, two network types are relevant: Single Frequency Networks and Multi Frequency Networks. The analysis of MFN in this section is unhelpful as the resulting coverage area is simply the addition of the individual coverage areas of each single transmitter. SFNs should be examined because, as the same frequency is used for each transmitter, constructive and destructive interference occurs.

In the following subsections, the coverage areas obtained in measurement campaigns will be presented, for both fixed and mobile reception. The impact of a SFN on the coverage area will be analyzed and the suitability of some prediction methods will be discussed. Finally, the need for indoor reception measurements for a particular prediction method in this band will be examined.

Fixed reception coverage

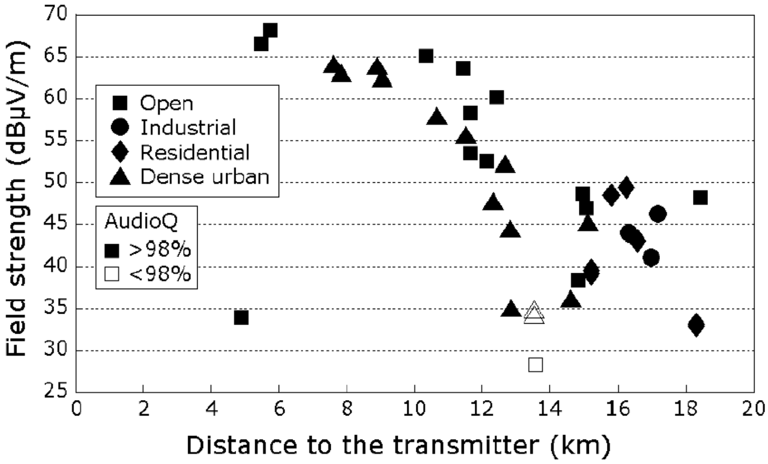
The fixed reception coverage area can be quite extensive when line of sight (LOS) propagation is available for every location. It can be reduced, however, if there are obstacles in the path or if there is a significant multipath effect.

If multiple reflections arrive at the receiver and the contribution of the different paths is destructive, the receiver might not be able to recover the signal. The effect is the same as the flat fading discussed in Annex 2. If the main (destructive) contributions are fixed (the signal is not reflected from moving surfaces) the shadow will not change with time, and the zone will be permanently out of the coverage area; permanently shadowed. The only way to alleviate this problem is by installing a gap-filler to eliminate the shadow.

Depending on the receiver location, a different number of obstacles will lie between it and the transmitter and so the multipath characteristic of the signal will be different. Figure 33 shows the electric field strength measured in Brasilia in different receiving locations where the distance from the transmitter is the same. It is clear that the field strength decays more quickly in dense urban areas than in open ones. The coverage area is larger in open environments than in dense urban ones.

FIGURE 33

Stationary measurement results in Brasilia [63]



In Brasilia, with an 18 kHz bandwidth signal (18k/B/16/4/0.5/L) and an EIRP of around 650 W, a fixed coverage area up to 15 km was obtained in dense urban areas. In non-dense urban areas the coverage area was up to 20 km [63].

Using a transmitter with 100W e.i.r.p. at an appropriate site and fixed reception with outdoor antennas, reception was found to be possible at distances of more than 40 km in Dillberg (Germany), with audio availability higher than 97%. A transmitter in Nuremberg with 10 W e.i.r.p., gave a fixed coverage area of 15 km. The signal transmitted had a 10 kHz bandwidth (10 kHz/A/16/4/0.62/L) [23].

See Annex 4 for a comparison of the coverage areas between fixed and mobile scenarios.

Mobile reception coverage

Mobile reception coverage depends on the environment of the receiver (urban versus open areas) [63]. A moving receiver is less likely to be shadowed from the transmitter for long periods of time. However, due to the varying multipath, flat fading can occur, noticeably degrading the signal (this phenomenon was studied in Annex 2).

As the receiver is moving and multiple reflections may occur, an additional effect on reception coverage is Doppler spread. Each reflection comes from a different angle, so the Doppler shift due to the motion of the receiver is different for each of them. This makes the received signal wider in bandwidth for each OFDM carrier. The spreading is velocity dependent, and at some point interference between carriers may occur. Reception becomes more difficult, and the values of the SNR thresholds are higher in comparison to those associated with fixed reception (see Annex 3). Thus, the mobile reception coverage area is smaller than that for fixed reception.

With a transmitter of 100 W e.i.r.p. at an appropriate site, mobile reception was found to be possible at distances up to 20 km from the transmitter in Dillberg. Audio availability was higher than 97% within this area. With the transmitter in Nuremberg, which was operated with 10 W e.i.r.p., the mobile coverage area was 3-5 km [16]. The transmitted signal had a 10 kHz bandwidth (10 kHz/A/16/4/0.62/L).

In Brasilia, with an 18 kHz bandwidth signal and an e.i.r.p. around 650 W, mobile reception coverage area extended up to 12 km in dense urban areas and up to 35 km in rural areas [63].

Table 24 summarizes and compares fixed and mobile reception coverage areas in the measurement campaigns mentioned.

TABLE 24

Comparison between fixed and mobile reception coverage areas

Location	e.i.r.p. [W]	Mode	Fixed area [km]	Mobile area [km]
Dillberg	100	10k/A/16/4/0.64/L	40	20
Nuremberg	10	10k/A/16/4/0.64/L	15	3-5
Brasilia (rural)	650	18k/B/16/4/0.5/L	>20	35
Brasilia (urban)	650	18k/B/16/4/0.5/L	15	12

Depending on the parameters selected for the transmission system, the coverage area may change. Table 25 shows the coverage as a function of robustness mode (A or B), MSC constellation (16 or 64) and code rate. The measurement campaign was held in Dorset, UK, and the results correspond to a mobile scenario. To determine the coverage, the route was subdivided into 50-meter-long segments. If more than 50% of the received audio frames in that segment were correct, the whole segment was marked as showing "successful reception" (which is different to the criterion of 98% used in the majority of the campaigns). The share in percent of successfully received 50-meter-segments of a complete tour was then equivalent to the coverage [36].

TABLE 25

Coverage area as a function of the transmission mode (tests in UK) [36]

MSC Constellation	16		64			
Code rate	0.5	0.62	0.5	0.6	0.71	0.78
Mode A	92%	90%	82%	70%	62%	54%
Mode B	92%	88%	79%	64%	60%	54%

The results clearly show that the chosen combination of mode constellation and code rate has a fundamental impact on the coverage area and should be carefully adjusted to balance an acceptable coverage against audio quality.

As it can be seen in Table 25, there is little difference in coverage between robustness modes A and B. Differences can be neglected. In fact, as mode B is more robust, a bigger coverage area might be expected. Mode A may have greater coverage than the comparable parameters for mode B because mode A has a smaller proportion of signal energy in the pilot cells (it has a smaller proportion of boosted pilot cells) and consequently the SNR of the data cells is higher for a given overall SNR [36]. There was also little difference in coverage between these modes, in the tests carried out in Nuremberg and Dillberg [23].

Other influences are noted in [23]: the interleaving depth of 2 s performs better than 0.4 s in mobile reception, and a relatively short AGC time constant for the receiver seems to be favourable.

Single frequency network coverage

SFN tests were carried out in Dorset, UK in November 2002. Measurements in a network with up to three different transmitters were obtained. Figure 34 is a map with the locations of the transmitters' and the route followed. The main conclusions were [36] that:

– Mode A performed better than mode B (most likely as mode A has a smaller proportion of signal energy in the pilot cells).

– Best network gain was obtained using mode A, MSC 64 QAM, 0.78 CR.

– Some sets of parameters showed little or no network gain. In certain cases there was a negative gain (SFN degradation).

– Vehicle speed (up to 110 km/h) had no observed effect.

FIGURE 34

Map of transmitter sites (red) and vehicle route (blue) for SFN tests in Dorset, UK [36]

Table 26 shows the quality of the link and the minimum MER as measured with an FhG receiver, considering a different number of active transmitters and several transmission configurations.

TABLE 26

Link quality and minimum MER in SFN tests in Dorset, UK [36]

FhG Receiver data	Transmitters: Rampisham, Febuary and March data	Transmitters: Rampisham	Transmitters: Janet's farm	Transmitters: Both	Transmitters: All 3 sites	Transmitters: Rampisham	Transmitters: Janet's farm	Transmitters: Both	Transmitters: All 3 sites
	Calc_qual (%)					Minimum MER			
Mode: A MSC: 16 QAM									
Code rate: 0.50	92	95	88	94	79	15	12	13	11
Code rate: 0.62	90	92	78	92	65	15	14	13	13
MSC: 64 QAM									
Code rate: 0.50	82	84	90	84	52	22	17	13	14
Code rate: 0.60	70	86	68		49	18	18	16	16
Code rate: 0.71	62	71	66	74	63	22	21	20	20
Code rate: 0.78	54	57	71	44	53	22	22	22	21
Mode: B MSC: 16 QAM									
Code rate: 0.50	92	70			97	14			12
Code rate: 0.62	88			91	96			15	11
MSC: 64 QAM									
Code rate: 0.50	79								
Code rate: 0.60	64	62	75	78	93	19	19	19	19
Code rate: 0.71	60				86				19

The coverage area is therefore affected when 2 or more transmitters are combined in a SFN network. The tests in Dorset led to the values in Table 27.

TABLE 27

Coverage values in a SFN network [36]

Mode	Rampisham only	Batcombe only	Rampisham and Batcombe	
			No delay	0.6 ms delay
A/64/0.5	78.9%	65.7%	58.5%	92.2%
B/64/0.5	77.6%	84.3%	81.1%	94.7%

For mode A, the coverage with both transmitters on, but no delay, is less than for each transmitter operated individually. This is because there is destructive interference between the signals from the two transmitters, causing flat fading. A variation in signal strength of more than 10 dB was seen as the interference went from constructive to destructive. So, without a delay, a network loss was incurred. Introducing a delay makes the fading become frequency selective, so that, at any given position, some carriers are cancelled out whilst others are reinforced. This appears to make the channel more benign, so that the coverage becomes much better than for a single transmitter [36]. This idea can also be applied to a single transmission station (see Annex 1). In mode B, the results are similar. Only when the delay is introduced is there a clear network gain.

The value of the delay was not adjusted in the tests. A delay of T s results in a frequency response with peaks and nulls every 1/T Hz. Any delay value that gives a few nulls across the 10 kHz channel could be valid. A shorter delay may be equally effective. In a larger scale SFN it would be sensible to keep the relative delay low, so that as much as possible of the guard interval is available to deal with natural multipath propagation.

Indoor reception

In situations involving propagation over combined outdoor to indoor paths, it is usually appropriate to concentrate on the points of entry that allow the transmission of electromagnetic radiation between the two environments. Points of entry can be apertures such as windows, skylights and doors, ventilation intake and exhaust penetrations, other structural openings and, if the electromagnetic shielding provided by the building materials is low, even the exterior skin of the building itself. If the distribution of the electromagnetic fields across the points of entry are known or, alternatively, can be inferred, then these points of entry can replace the actual sources of radiation as equivalent radiation sources. The total field at the desired observation point will then be the result of superposition of the fields at the observation point due to each of the equivalent sources taken individually. If it happens that a single point of entry is expected, it is often sufficient to concentrate on obtaining the desired electromagnetic field distribution for this single point of entry, excluding the others [12].

As DRM is a broadcasting system it is not practical to analyze each situation individually. An alternative approach is to use empirical data for building entry loss (defined in § 5 of Recommendation ITU-R P.1411) and then account for the transmission effects of interior walls and panels, ignoring diffraction and reflection.

While several studies and recommendations exist for other higher [67] and lower [68] frequencies, recent and accurate empirical values are not currently available for the 26 MHz band.

A measurement carried out in Hanover suggests a building loss of 6 dB [7]. A single measurement in Australia suggested that indoor levels in the test house were found to be approximately 12 dB below the outdoor vehicle level [69]. Further work is recommended on the effects of building loss.

Annex 5

Results of DRM 26 MHz band trials

Measurement setup

Despite the successful launch of many DRM services, there is still a need to verify network planning parameter values through field measurements, and to analyse the behaviour of the DRM system under several reception conditions and environments.

DRM tests in Mexico

Source: Document 6E/274 [70]

A test transmission and evaluation measurements were planned in 2005 in Mexico D.F. The main aim was to evaluate the field strength needed in a city for DRM transmission in the 26 MHz broadcasting band. The minimum field strength needed was calculated for different DRM transmission configurations and for different environments. The minimum SNR was analysed separately. In addition, mobile reception reliability was analysed. The system tested had the features in Table 28.

TABLE 28

Transmission centre features

Transmission centre	Radio Ibero (Santa Fe, México DF)
Broadcaster	Radio Educación
Transmission centre coordinates	99º 15.920’ W; 19º 22.071’ N
Frequency	25 620 kHz
Transmitted power	200 Wrms
Bandwidth	20 kHz
Radiating system	7 dBi 3 element Yagi-Uda antenna 40 m above ground level
Transmission site height	300 m above the average city height

Three system variants were tested, all having 18 kHz bandwidth:

– DRM mode A, 64-QAM, code-rate 0.6, offering a data rate of 48.64 kbit/s;

– DRM mode B, 64-QAM, code-rate 0.6, offering a data rate of 38.18 kbit/s;

– DRM mode B, 16-QAM, code-rate 0.5, offering a data rate of 21.20 kbit/s.

The trials showed that the third variant (Mode B, 16-QAM, CR 0.5) is the most suitable and is therefore recommended. This configuration requires a minimum SNR of 18 dB and minimum field strength of 37 dB(μV/m). This value is higher than the one given in Recommendation ITU-R BS.1615. This increase was probably required in order to overcome several sources of noise and interference that affect the reception in an urban environment (voltage transformation equipment, traffic, interference sources from other transmission facilities).

The results obtained for this mode can be easily extrapolated to the mode with 20 kHz bandwidth, which provides a slightly higher data rate and is the appropriate mode for the 10 kHz channeling used in the 26 MHz broadcasting band.

The trials also showed that to provide 100% coverage for the whole Mexico City area, an output power in the range 2-6 kW would be necessary.

DRM tests in Brazil

Source: Document 6A/106 [71]

Similar tests to those carried out in Mexico were carried out in Brasilia, using another antenna type; a TCI Unbalanced Dipole. Again, the recommended system variant was (Mode B, 16-QAM, CR 0.5).

The results in Brasilia showed a better performance from this transmission configuration with a SNR threshold of 12-13 dB; compared with 18 dB in Mexico. The estimated power required to cover the whole city of Brasilia was 800 W.

It was noted that the man-made noise values in this band were much lower than in the Medium Wave band. Moreover, the reference values of man-made noise given in the Recommendation ITU-R P.372 are valid in a “quiet” environment such as Brasilia.

DRM tests in India

Source: Document 6D/10 [72]

This contribution is based on a series of tests and measurements that were carried out in Delhi and New Delhi (India) from 9 to 12 May 2007. The trials were a part of the DRM-AIR-ABU Showcase Project on Digital Radio Mondiale (DRM) simulcast technologies that took place from the 7th to the 12th May 2007.

The 26 MHz DRM service provided very good quality local coverage with the following parameters:

– bandwidth: 20 kHz;

– mode: B/16/4/05/L;

– data rate: 21 kbps;

– RMS power: 500 W;

– Antenna: 3 element Yagi-Uda.

The cut-off point was detected at about 7 to 10 km from the transmitter and the reception quality was considered as "good" by expert listeners.

DRM tests in Italy

Source: Documents 6A/227 [73]; 6A/411

In 2008 RAI and Vatican Radio signed an agreement to develop and test new digital broadcasting technologies. DRM was mentioned in the agreement. As a consequence, a test in the 26 MHz band was carried out, to explore the possibility of using DRM in this band for local coverage. Accordingly, a low power transmitter was installed in the "Marconi" building located inside the Vatican garden and field measurements were made in the urban area of Rome. This paper gives an overview of the results.

The issue of minimum signal-to-noise ratio needed to decode DRM mode A in a 20 kHz channel bandwidth, related to the minimum field strength required to achieve it, has been taken into account.

1 Scope of the test

Measurements were designed to verify the coverage of a DRM service in the 26 MHz band in a complex urban environment such as downtown Rome, in order to assess the quality of reception that can be obtained when low-power transmitters are used as gap-fillers. The electromagnetic field was measured outside, and at the same time, mobile outdoor reception was verified using a calibrated antenna and a professional receiver.

2 Installation description

A low power transmitter was installed in the "Guglielmo Marconi" transmitter building (41° 54' 7"N; 12° 26' 55"E) located in Vatican City. The position has been identified as CVA-Marconi in all the maps shown below.

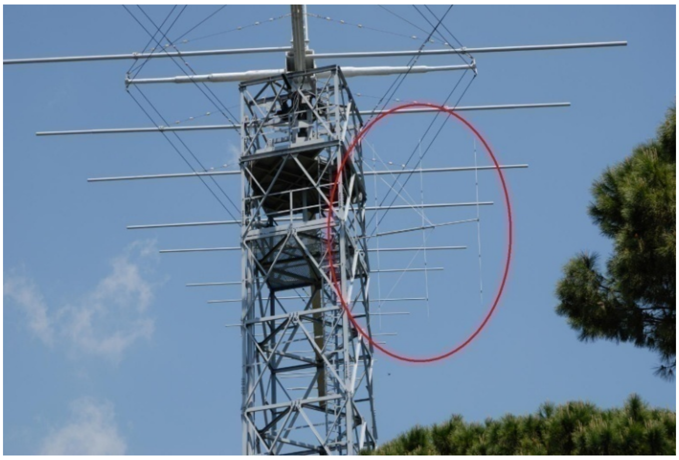
FIGURE 35

The "Marconi" building in the Vatican garden, seen from the antenna mast

The transmitter was a linear power amplifier, model BT01000-BETA-CW, with 1KW p.e.p. provided by TOMCO, an Australian RF amplifier manufacturer, driven by a DRM DMOD-2 Telefunken exciter. The multiplex was generated by a Fraunhofer CSR-4 Content Server, located in the Transmitting Centre of Santa Maria di Galeria, belonging to Vatican Radio and located about 20 km outside Rome. The multiplex was sent to the transmitter via an Ethernet network link. This set up was capable of a total transmitting power up to 80 W, fully adhering to the standard DRM transmitter spectrum mask. However, the test was carried out at a power of 30 W.

FIGURE 36

The 26 MHz antenna



Transmitter power, frequency, channel bandwidth and multiplex characteristics were:

Frequency	26 060 kHz
Power	30 W RMS
Antenna type	3 element Yagi
Antenna beam	110°
Polarization	Vertical
Channel bandwidth	20 kHz

DRM channel description; content server configuration:

DRM channel	
MUX ref. ID	MUX 26 MHz
Timeslot.	0000-2400
Robustness	MODE A
Channel BW	20 kHz
MSC	64 QAM
Protection level	EEP PL=0 [0.5]
SDC	4 QAM
Max net bit rate	45 840 bps
Unused bit rate	20 bps

Configured services on the DRM multiplex:

Service identification	RAI Radiodue	Radio Vaticana	RV World Service	
Audio codec	AAC[7]	AAC	CELP[8]	
Audio mode	Parametric stereo	Parametric stereo	Mono	
SBR	ON	ON	n.a.	
Sampling rate	24 kHz	24 kHz	8 kHz	
Error protection	EEP 0.5	EEP 0.5	EEP 0.5	
Audio bit rate	20 160 bps	20 160 bps	5 260 bps	
AFS	ON	ON	ON	
Bit rate	20 240 bps	20 240 bps	5 340 bps	
Total used bit rate				45 820 bps

7 AAC, Advanced Audio Coding.

8 CELP, Code Excited Linear Prediction.

A 3 element vertically polarised Yagi antenna (manufactured by SIRIO ANTENNE model SY27-3) was used. The antenna was originally designed to operate in the 27 MHz band and so was re-tuned by Radio Vatican to operate in the 26 MHz band. The antenna was installed on an existing mast, about 35 metres above the ground and 101 metres above sea level, beamed 110° from the North. A 7/16” coaxial feeder was used. This mast also supports a rotatable SW log periodic antenna at the top.

FIGURE 37

Detail of the transmitting antenna

3 Measurements

3.1 Outdoor measurements

These measurements were performed by the RAI Way Department ICSR, using:

– Volkswagen Sharan equipped and prepared by RaiWay and Officine Meccaniche Barberi s.n.c

– DRM monitoring receiver – Fraunhofer model DT700

– Calibrated antenna – Rohde&Schwarz model HE055

– GPS trimble.

FIGURE 38

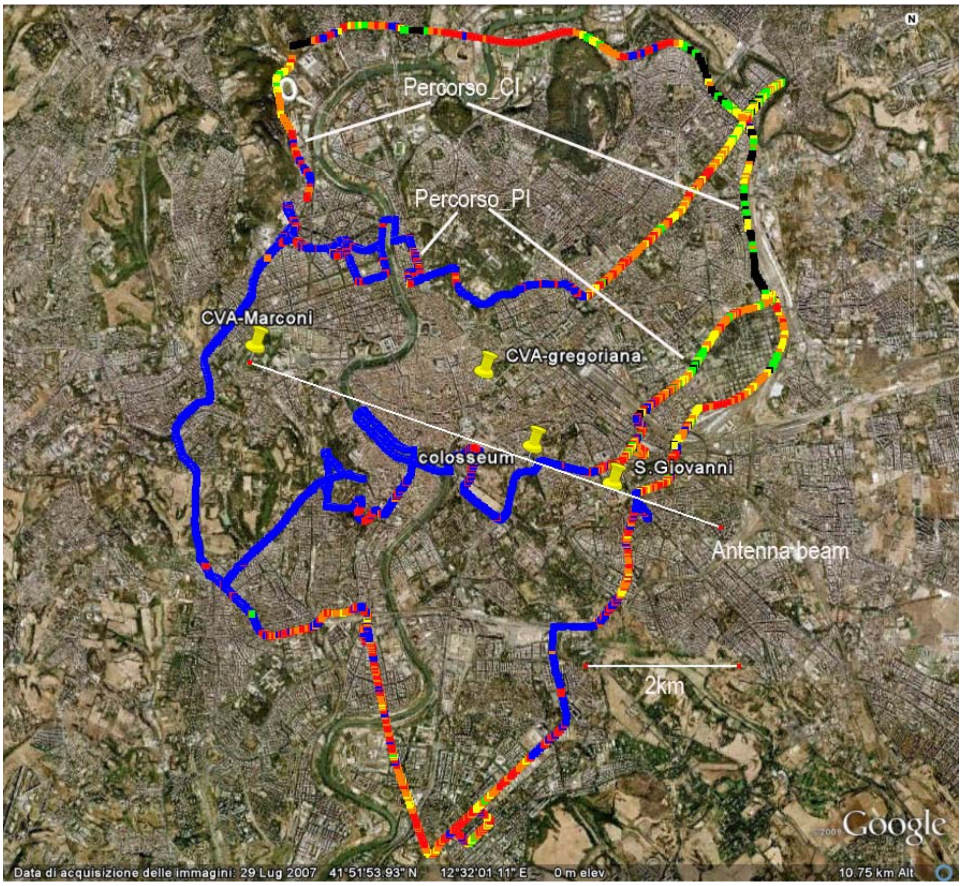
Equipped vehicle

A "Log File" containing all the required data (geographical, electromagnetic and audio errors) was kept, with one record stored for each DRM Frame (400 m/s).

During the monitoring session the mobile reception of the 26 060 kHz signal was examined on different routes. In this Report, two routes were considered. The first – "Percorso_CI" – is a ring road around the main centre of Rome. The second – "Percorso_PI" – crosses the centre of the city. The two routes were chosen because they were likely to be representative of mobile reception in the main target area. The results are set out below. Tunnels are not excluded, and so all percentage values indicated have to be seen as gross values; consequently effective results are better than those indicated. Figure 39 represents the electromagnetic field as measured:

FIGURE 39

Measured electromagnetic field



In the map six thresholds have been considered:

■ (blue)	EM > 50 dB(μV/m)	■ (red)	EM > 45 dB(μV/m)	■ (orange)	EM > 40 dB(μV/m)
■ (green)	EM > 30 dB(μV/m)	■ (yellow)	EM > 35 dB(μV/m)	■	EM <= 30 dB(μV/m)

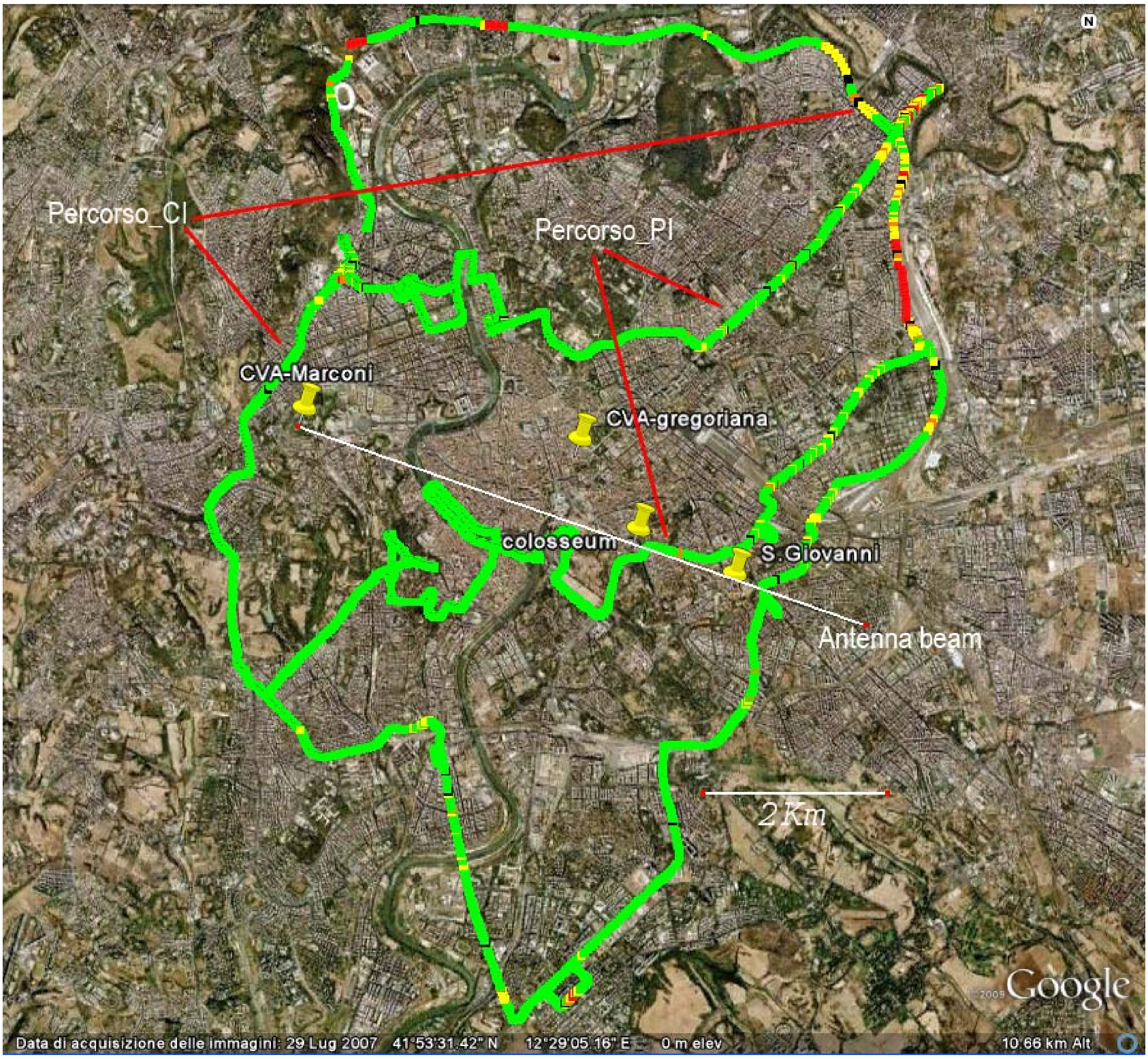
The field strength level of 35 dB(μV/m) was reached in 91% of the test points on the "Percorso_CI" route, and in 93% of the test points on the route "Percorso_PI".

Figure 40 shows the audio reception:

FIGURE 40

Audio reception

MAP 1



With the following thresholds related to DRM decoding process:

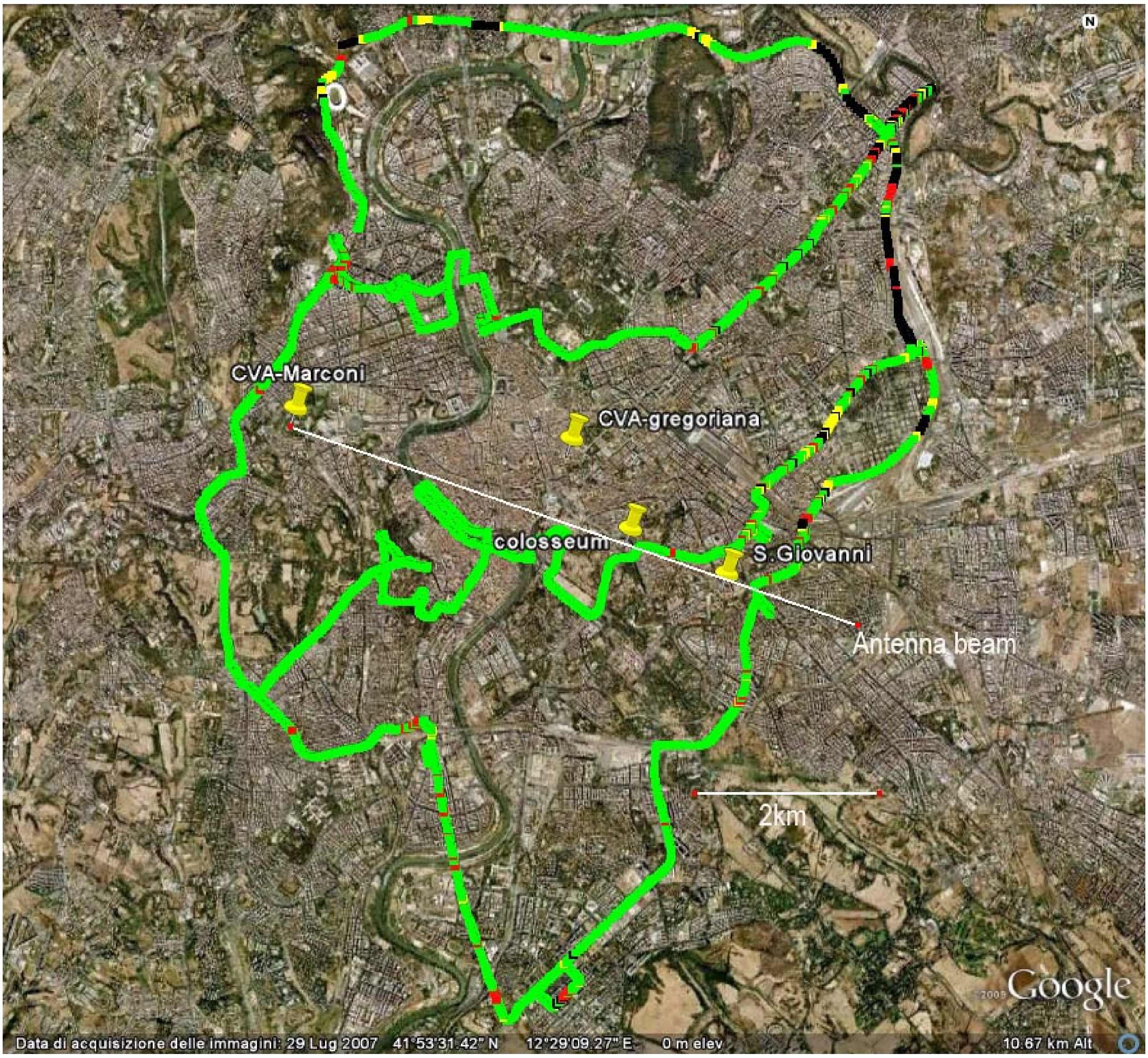
■	■	■	■	■
No Reception	Sync ok	FAC ok	SDC ok	Audio OK

Audio was decoded at 86% of the test points on the “Percorso_CI” route, and at 94% of the test points on the route “Percorso_PI”.

In order to show the test results more clearly, a new presentation of the data was prepared. A value of 37 dB(μV/m) for field strength was used as a reference, and at the points where this was achieved the success in the audio decoding process is shown. The result is presented in Fig. 41, where the audio coverage related to field strength is displayed:

FIGURE 41

Audio coverage related to the field strength



With the following colour correspondence Table:

■ (green)	Audio decoded & EMF>=37 dB(μV/m)	■ (red)	NO Audio decoded & EMF>=37 dB(μV/m)
■ (yellow)	Audio decoded & EMF<37 dB(μV/m)	■ (black)	NO Audio decoded & EMF<37 dB(μV/m)

NOTE:

– at the test points marked in green, the audio was properly decoded, with a field strength higher than 37 dB(μV/m);

– at the test points marked in yellow, the audio was properly decoded, even though the field strength was below 37 C; at these points it is likely that ambient noise was particularly low;

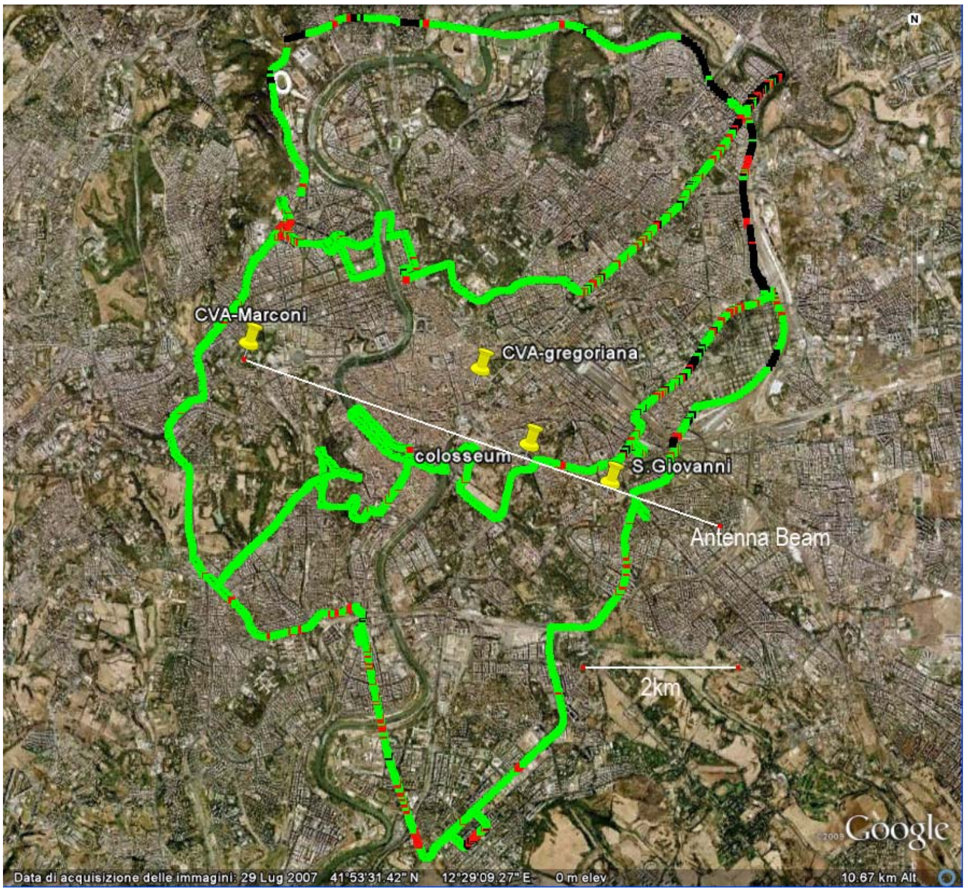
– at the test points marked in red, audio decoding was not successful, despite the signal strength being higher than 37 V; this is probably due to higher ambient noise;

– at the test points marked in black, there was probably insufficient field strength to achieve the minimum S/N ratio.

A statistical analysis of the data, showed that with at least 16.8 dB of S/N ratio, reception was possible with a 99% probability in both paths. This means that if at least 16.8 dB of S/N ratio is achieved, audio decoding could be successful. A reference value of 16.8 dB for S/N has therefore been taken into account and a new presentation of the results prepared. This is given in Fig. 42:

FIGURE 42

S/N values



Where:

■ (green)	S/N > 16.8 dB	■ (red)	S/N< 16.8 dB & EMF>=37 dB(μV/m)
		■ (black)	S/N< 16.8 dB & EMF<37 dB(μV/m)

The test points marked in green mean that the minimum S/N was achieved and the audio was consequently decoded. In addition, Figs 40 and 41 could be more or less superimposed and there is substantial correspondence between the two maps:

– Most of the test points marked in red in Fig. 41 correspond to those marked in red in Fig. 42, suggesting that 37 dB(μV/m) was not adequate to reach the minimum S/N ratio required for audio decoding; probably the result of local noise.
– Most of the test points marked in green and yellow in Fig. 41 correspond to those marked in green in Fig. 42. At these points, 37 dB(μV/m) (or a little less in some samples) was enough to achieve the minimum S/N ratio.

4 Conclusions

The analysis of the results of the mobile reception study, using a professional receiver, showed that:
– with the reference DRM power of 30W, mobile reception was possible in an area of 80 km^2, representative of the main centre of Rome;
– with the considered modulation parameter mode A, 64 QAM, code rate 0.5, two stereo and one low quality mono programmes were carried by the multiplex;
– at 99.1% of the test points, where at least 16.8 dB of S/N ratio was evident, the audio was decoded.

On the first route, "Percorso_CI", the required minimum S/N ratio for audio decoding was achieved, at 87% of the test points where a field strength of 37 dB(μV/m) was measured. This route is the ring road around the main centre of Rome.

On the second route, "Percorso_PI", the required minimum S/N ratio for audio decoding was archived at 93% of test points, where a field strength of 37 dB dB(μV/m) was measured.

This data could be a useful indication of the outdoor noise floor level in the centre of Rome, in the 26 MHz HF broadcasting band.

5 Future developments

The analysis of data showed that the mobile reception area (with a professional receiver) is limited by a field strength threshold level of 37 dB(μV/m). This corresponds to the ability to reach the minimum S/N ratio of 16.8 dB, which is needed to decode the audio. Future tests will consider the use of a different modulation scheme (Mode A 16QAM code rate 0.5) in order to reduce the minimum required S/N ratio required to decode the audio. In this way, it is expected the service area will be enlarged, with the same field strength level. In this situation it will not be possible to carry two full stereo programs. Measurements with a commercial receiver will also be carried out.

In order to get more information on planning parameters, it is necessary to evaluate the following:
– height loss: field strength measurements are easy at ground level (1.5 or 2 m) but the planning field strength is calculated at 10 m above ground level;
– building penetration loss: statistical evaluation is to be provided in order to consider the proper planning field strength needed to guarantee the required location percentage for satisfactory indoor reception;
– receiving antenna loss: for planning purposes it is necessary to evaluate the median user receiving antenna loss compared with a reference planning antenna.