

EBU – Tech 3330



# TECHNICAL BASES FOR DRM SERVICES COVERAGE PLANNING

**Source: B/LMS**

**Status: Report**

Geneva  
June 2008



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## TECHNICAL BASES FOR DRM SERVICES COVERAGE PLANNING

<i>EBU Committee</i>	<i>First Issued</i>	<i>Revised</i>	<i>Re-issued</i>
SMC	2007, as BPN 082	Typo corrected 25 June 2008	June 2008, as Tech 3330

**Keywords:** DRM, Digital Radio Mondiale, Service Coverage Planning

## 1 Introduction

### 1.1 Purpose of the Document

Countries around the world are in the process of migrating from analogue to digital broadcasting techniques for both television and radio. This document looks at sound broadcasting in the bands below 30 MHz. It briefly examines the underlying reasons for the migration and looks at the technologies involved. Its focus is the DRM system; developed for use in the LF, MF and HF bands and currently being extended to cover higher frequencies.

The target reader of this document is any broadcaster contemplating transition from analogue to digital broadcasting in the low frequency bands. The document is intended to:

- Explain why and how a broadcaster might go digital;
- Be a reference technical document for DRM planning, supplementing various existing documents<sup>1</sup> with more detailed technical information needed to plan the introduction of services;
- Provide new information based on the experience of EBU members in DRM.

### 1.2 Why Digital? - Technical Considerations

A primary benefit of digitalisation is greater control over channel performance. The overall performance of an analogue communications channel is dictated largely by the characteristics of the channel itself. The scope for exploiting the ‘trade-offs’ implicit in Shannon’s Theorem (C. E. Shannon, *The Mathematical Theory of Information*. University of Illinois Press, 1949) is limited. By contrast, the overall performance of digital systems is largely governed by the quality of the conversion processes (analogue to digital and vice versa) provided that the capabilities of the channel are not exceeded. There is much greater scope for exploiting the ‘Shannon trade-offs’, particularly if error correction techniques are used. In effect, the performance of analogue systems tends to deteriorate as the channel performance deteriorates while digital systems remain as

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<sup>1</sup> - Broadcast User Manual (published by DRM consortium and available for downloading at: <http://www.drm.org/broadcastmanual/broadcastermanual.php>)

- ITU Handbook of LF/MF system design.

defined by the conversion processes until they fail completely. Unfortunately, this means that the subjective effects of channel performance on digital systems can be much more obtrusive when working close to the ultimate channel capacity.

Of seminal importance is the ability of digital systems to compress data into a smaller space. In the broadcasting context this means the use of compression coding techniques which allow much higher sound quality to be accommodated in the same channel bandwidth. A related benefit is the ability to trade between quality (which is dictated primarily by the degree of compression) and ruggedness more or less at will.

Further to this digital systems offer additional benefits. Firstly, the relatively easy addition of ancillary data services allows such features as automatic or semi automatic tuning, conditional access and the inclusion of supplementary (or even completely unrelated) data streams. Secondly, digital broadcasting techniques can offer credible 'single frequency networks'. This in its turn makes for even more efficient use of available spectrum, potentially opening the door to more audience choice.

### **1.3 Why Digital? - Commercial and Regulatory Considerations**

As already stated, the major commercial advantage of digital broadcasting is the ability to offer higher quality and diversity of services. Since this can be done without the need for additional spectrum and with lower transmitter power this is attractive from the broadcaster's perspective. New commercial opportunities will exist. The more consistent subjective quality can be a benefit to both providers and users, as can the ancillary services - like automatic re-tuning of a receiver.

There are, however, commercial drawbacks. For any individual broadcaster there is the cost of re-equipping and it is unlikely that this will be offset by increased revenue (advertising or subsidy). Persuading the audience to invest in new receivers is of fundamental importance to the venture. This cannot be stressed too highly and to do it, it is necessary either to offer a wider range of high quality programming or threaten to discontinue the analogue service.

### **1.4 How Digital? - Technical and Regulatory Considerations**

There is little compatibility between digital and analogue broadcast transmission systems. While this can cause some transition problems it is generally advantageous because the digital systems have been optimised against their own technical and financial drivers and are not compromised by having to be compatible with less advanced existing technologies. A limiting consideration with the familiar Zenith GE system for stereo radio was that it had to be backward compatible with existing mono FM receivers.

Any technical switchover strategy must work within certain commercial and regulatory imperatives. In essence any transition strategy will probably demand the continued availability of analogue versions of existing programme streams until a high proportion of the audience is able to receive the digital services by one delivery means or another (satellite, cable or terrestrial broadcast). Typically, this will mean that digital and analogue versions of the same programmes are broadcast simultaneously during the transition period. Various technical strategies can be and have been deployed to achieve this (e.g. simulcast).

With DRM, where the digital transmission can be made to occupy the same amount of spectrum and have the same interference impact as an analogue signal, it is possible simply to replace an existing analogue service with a digital one or to use an existing, unused allocation. In most bands there are few unused allocations and so this strategy relies on the existence of broadcasters who simultaneously transmit the same material on different channels (or even platforms) and are prepared to risk one (the smaller) audience re-tuning to the other frequency. This strategy is currently being used in the AM bands. In the HF bands there is less of a problem because there is



free allocation of channels through the various co-ordinating bodies. There are however, still problems with congestion in the lower frequency HF bands.

## 1.5 How Digital? - Commercial Considerations

It seems unlikely that there has been or will be any pressure from the audience to introduce digital services for their own sake. Audience take up is driven much more by the potential benefits:

- The availability of a wider range of services,
- Improved formats such as stereo in the 'AM bands',
- Improved and more consistent sound quality
- Programme associated data, metadata or even independent services like web pages
- Easier selection of programming - e.g. automatic switching between different LF, MF and HF transmitters or electronic programme guides.

These must be traded against the perceived cost of new equipment. It is essential therefore that the audience is presented with an attractive package of services and receivers at prices it is prepared to pay. The drivers for the industry are therefore the production of more and increasingly attractive programme content and the deployment of receivers at appropriate prices. The importance of programme content, while outside the scope of this report, cannot be stressed too highly.

Receiver price is driven by a number of factors, not least the willingness of the broadcaster or regulator to subsidise the cost in order to promote sales and uptake of the service. Any switch over strategy must recognise that, the user community can generally be divided in three in its willingness to invest in new technology.

The 'early adopters' tend to be enthusiastic about technological development and will invest in new machinery simply in order to have it at an early stage. Such people will typically be prepared to pay a high price for new equipment. In the early stages of product life, the manufacturers rely on this community to offset some of the high development costs of new consumer equipment.

The early adopters are followed by the 'mainstream'. These users will be much more circumspect about price and will compare the value they put on the new service with the cost of making the change before actually buying a new receiver, These people know that they intend to make the change but do so when the cost of the receiver has dropped (as it inevitably will) to the level they are prepared to pay. This is the most important group in driving the change over.

The third group, the 'unwilling' have typically decided that they will never change or they have sufficiently little interest in the subject that they are unaware of the development. These people will only change when they absolutely have to (perhaps because the analogue service is withdrawn) or when the price becomes so low that it is not important and digital has anyway become the standard.

This simplistic model of the market is clearly going to be distorted by factors such as subsidies and the threat of discontinuing the analogue services. The threat of discontinuation is a (market) driver that must be used with extreme caution. Public service broadcasters as well as the advertisers who fund a large part of the broadcasting industry will not be pleased to find themselves 'cut off' from an established audience if 'switch off' is contemplated before a substantial proportion of it is able to receive the new service. The community of broadcasters will be unwilling to turn any of their services off before the audience drops to the point where the transmission cost is not viable.

One thing can be stated with certainty. Continued technical development and an ever-expanding consumer base will mean that the cost of producing receivers will fall. This in turn will push down

the purchase price. Continuous development in the integrated technology IT sector means that systems of ever-greater complexity can be accommodated on small silicon chipsets. Receivers with diverse capabilities and single function machines can all use elements of the same chipset, the manufacturing cost of which depends far more on production volumes than on functionality. Stifled development of purely analogue receivers will mean that the time will come when they are more expensive than their much more capable digital brothers. At this point the pressure for switch over will be unstoppable.

While the broadcasters are potentially easier to persuade than the audience when it comes to deploying new equipment, the process is not cost free. If transition is to be achieved within realistic timescales and budgets, every effort must be made to re-use existing analogue plant if at all possible. Thankfully, as the digital services are to be mounted in existing frequency bands, the transmitters and antennas, which at the lower frequencies are usually expensive and difficult to replace, can often be adapted to work with the digital transmissions. Most of the DRM transmissions now currently being broadcast around Europe are carried on analogue transmitters that have been adapted. While these transmitters are not usually optimised for carrying digital transmissions, the design considerations are quite different, this strategy can allow the plant to continue to be used for analogue services as well as digital during the transition period. In addition the cost of mounting analogue and digital versions of the same programme material at the same time must not be ignored.

## 2 DRM system aspects

### 2.1 Key features of the system design

The DRM system is a flexible digital sound broadcasting system currently available for use in the terrestrial broadcasting bands below 30 MHz<sup>1</sup>. It offers the ability to trade between perceived audio quality and robustness of reception; an important consideration, especially for HF transmissions [1] [3].

The DRM system provides three different audio codecs that vary in quality, application and bit rate requirements. AAC<sup>2</sup> provides the highest quality, whilst CELP<sup>3</sup> and HVXC<sup>4</sup> require progressively lower bit rates but are designed for speech-only services. The performance of all three codecs can be enhanced by the optional use of SBR<sup>5</sup> coding. SBR improves perceived audio quality by a technique of higher baseband frequency enhancement using information from the lower frequencies as cues. Section 2.2 provides guidelines for choosing between the three codecs.

COFDM/QAM<sup>6</sup> is used for the channel coding and modulation, along with time interleaving and forward error correction (FEC) using multi level coding (MLC) based on a convolutional code. Pilot reference symbols are used to derive channel equalization information at the receiver. The combination of these techniques results in higher quality sound with more robust reception within the intended coverage area when compared with that of AM.

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<sup>1</sup> While DRM currently covers the broadcasting bands below 30 MHz, the DRM consortium decided in March 2005 to begin the process of extending the system to include VHF Bands I and II. The design, development and testing phases of this extension are currently underway (source: [www.drm.org](http://www.drm.org)).

<sup>2</sup> AAC: Advanced Audio Coding.

<sup>3</sup> CELP: Code Excited Linear Prediction.

<sup>4</sup> HVXC: Harmonic Vector eXcitation Coding.

<sup>5</sup> SBR: Spectral Band Replication.

<sup>6</sup> COFDM: Coded Orthogonal Frequency Division Multiplex  
QAM: Quadrature Amplitude Modulation

The DRM system is designed for use in different channel bandwidths: 4.5, 5, 9, 10, 18 and 20 kHz. Differences in detail on how much of the available bit stream for these channels is used for audio, for error protection and correction, and for data depend on the allocated band (LF, MF, or HF) and on the intended use (for example, ground wave, short distance sky wave or long distance sky wave). In other words, there are modal trade offs available so that the system can match the diverse needs of broadcasters worldwide. DRM provides four different propagation Modes and within these Modes a choice of modulation and coding rates. Section 2.3 provides detailed information about the robustness modes, the modulation types and the spectrum occupancy types. Theoretical data rates corresponding to the possible combinations of the latter are also provided.

The system design, based on the COFDM modulation with the use of guard interval added to each transmitted symbol, permits the use of the DRM system within a single frequency network (SFN). The system also provides the capability for automatic frequency switching, which is of particular value for broadcasters who send the same signals at different transmission frequencies. For example, large HF broadcasting organizations routinely use AM to increase the probability of at least one good signal in the intended reception area. The DRM system can enable a suitable receiver to automatically select the best frequency for a programme without any effort on the part of the listener.

A receiver should be able to detect which particular DRM system mode is being transmitted, and handle it appropriately. This is done by way of the use of many of the field entries provided in the transmitted information (within the FAC<sup>1</sup> and SDC<sup>2</sup>). Similarly, the receiver is also informed what services are present, and, for example, how source decoding of an audio service should be performed.

## 2.2 Audio Coding Guidelines

Figure 2.1 shows bit rate requirements for the different audio coders used in the DRM System and the data rates available for typical HF & MF broadcast channels

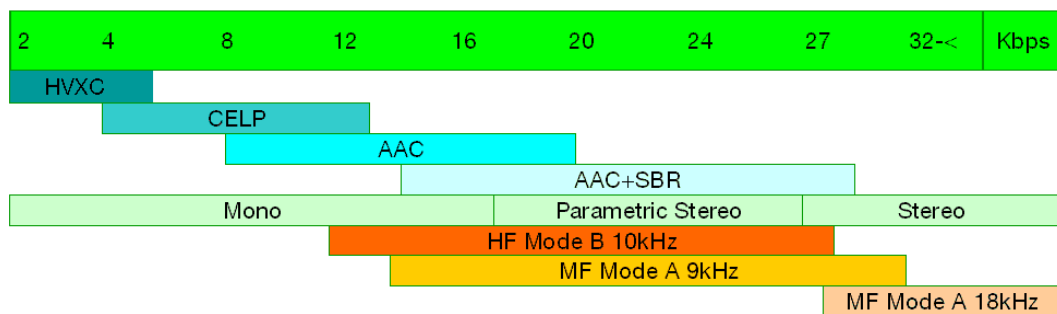


Figure 2.1 bit rate requirements for the different audio coders used in the DRM System

The following are the main features of these audio coders:

HVXC:

- Harmonic Vector Excitation Coding-developed by SONY -no licence is required.
- Designed for single voice only with some background noise- destroys any music and jingles
- Bit rate is 2000 - 6560 bit/s

<sup>1</sup> FAC: fast access channel.

<sup>2</sup> SDC: service description channel.

- SBR can be used to increase audio bandwidth from 4 kHz to 8 kHz
- Could be used for multi language news reports or with data traffic in a multiple service.

**CELP:**

- Coded Excited Linear Prediction developed by NEC- licence needed.
- Designed for studio derived voice commentary where there is no background noise, though can cope with a greater amount of noise than HVXC. Okay with music at higher bit rates.
- Useful bit rate is 3860 - 14000 bit/s.
- SBR can be used to increase audio bandwidth up to 14 kHz.
- Both CRC & Unequal Error Protection are available for additional error protection.

**AAC:**

- The successor to MP3 commonly known as MPEG-4 AAC. It is not defined as a single specification but a complex “toolbox” to perform a wide range of operations. A subset of the AAC “toolbox” was chosen to best suit the DRM system. No licence is required
- Sampling rate is 12 kHz or 24 kHz
- Bits rates between 8 & 20kbit/s increase audio bandwidth in steps from 4 to 6 kHz
- Versatile audio codec twice as efficient as MP3; would be used on HF channels which necessitate high levels of protection and in consequence lower data rates

**AAC+SBR:**

- Spectral Band Replication developed by Coding Technologies. A licence is required.
- Can be used on all types of audio codec to extend frequency range, SBR is mainly a post process, adding only 2 kbit/s per channel to the original data rate.
- 3 audio bandwidth limits:
  - (10875 Hz)-- 14000-18460 bit/s;
  - (13125 Hz)-- 18480-22460 bit/s;
  - (15375 Hz)-- 22480-28460 bit/s
- Most commonly used configuration for a standard HF channel. (17-21 kbit/s)

**Parametric Stereo:**

- Developed by Coding Technologies. A licence is required.
- Minimum bit rate is 16480 bit/s.
- 3 audio bandwidth limits as per SBR Mono.
- Only an additional 2 kbit/s required to convey a stereophonic image.
- Suitable for 9 kHz MF channels or benign single-hop HF channels.

**AAC+SBR Stereo:**

- Sampling rate is 24 kHz.
- Minimum bit rate is 26480 bit/s.
- 2 audio bandwidth limits:
  - (13125 Hz)-- 26480-28480 bit/s;
  - (15375 Hz)-- 28480 bit/s

- Suitable for double 9 kHz MF channels.

## 2.3 Transmission modes and data rates

### 2.3.1 DRM robustness modes

The digital phase/amplitude information on the RF signal is corrupted to different degrees as the RF signal propagates. Some HF channels provide challenging situations:

- Fairly rapid flat fading;
- Multipath interference that produces frequency selective fading;
- Large path delay spreads in time, and
- Ionospherically induced high levels of Doppler shift and Doppler spread.

The error protection and error correction incorporated in the DRM system design mitigates these effects to a great degree. This permits the receiver to decode the transmitted digital information accurately.

The DRM signal can be adjusted to cope with different channel conditions. For a high quality, "clean", channel, the DRM signal needs to be less "robust" than for a difficult, noisy and or distorted channel. Table 2.1 shows the possible robustness modes and the corresponding typical propagation conditions and the preferred frequency bands. The differences in robustness are obtained by a suitable selection of the OFDM parameters. For information, Table 2.2 shows the OFDM parameters for each robustness mode.

Table 2.1 DRM robustness modes

Robustness mode	Typical propagation conditions		Preferred frequency bands
A	Ground-wave channels, with minor fading	(Ground wave)	LF, MF
B	Time- and frequency-selective channels, with longer delay spread	(Sky wave)	MF, HF
C	As robustness mode B, but with higher Doppler spread	(Sky wave)	Only HF
D	As robustness mode B, but with severe delay and Doppler spread	(Sky wave)	Only HF

Audio services are transmitted in the main service channel (MSC) of the DRM multiplex. For all robustness modes two different modulation schemes (16- or 64-QAM) are defined for the MSC, which can be used in combination with one of two (16-QAM) or four (64-QAM) protection levels, respectively.

Each protection level is characterized by a specific parameter set for the two (16-QAM) or three (64-QAM) convolutional encoders, resulting in a certain average code rate for the overall multilevel encoding process in the modulator. For 16-QAM protection level, No. 0 corresponds to an average code rate of 0.5; No. 1 to 0.62. For 64-QAM the protection levels, Nos. 0 to 3 correspond to average code rates of 0.5, 0.6, 0.71 and 0.78.

The time-related OFDM symbol parameters are expressed in multiples of the elementary time period  $T$ , which is equal to  $83^{1/3}$   $\mu$ s. These parameters are:

- $T_g$  : duration of the guard interval;
- $T_s$  : duration of an OFDM symbol;
- $T_u$  : duration of the useful (orthogonal) part of an OFDM symbol (i.e. excluding the guard

interval).

The OFDM symbols are grouped to form transmission frames of duration  $T_f$ .

A certain number of cells in each OFDM symbol are transmitted with a predetermined amplitude and phase, in order to be used as references in the demodulation process. They are called "reference pilots" and represent a certain proportion of the total number of cells.

Table 2.2: OFDM symbol parameters

Parameters list	Robustness mode			
	A	B	C	D
$T$ (ms)	$83^{1/3}$	$83^{1/3}$	$83^{1/3}$	$83^{1/3}$
$T_u$ (ms)	$24(288 \times T)$	$211/3(256 \times T)$	$142/3(176 \times T)$	$91/3(112 \times T)$
$T_g$ (ms)	$2^{2/3}$ ( $32 \times T$ )	$5^{1/3}$ ( $64 \times T$ )	$5^{1/3}$ ( $64 \times T$ )	$7^{1/3}$ ( $88 \times T$ )
$T_g/T_u$	1/9	1/4	4/11	11/14
$T_s = T_u + T_g$ (ms)	$26^{2/3}$	$26^{2/3}$	20	$16^{2/3}$
$T_f$ (ms)	400	400	400	400

### 2.3.2 Spectrum occupancy types

For each robustness mode the occupied signal bandwidth can be varied dependent on the frequency band and on the desired application. The specified spectrum occupancy types are shown in Table 2.3.

The bandwidths in the last row of Table 2.3 are the nominal bandwidths for the respective spectrum occupancy types of the DRM signal and the values given in lines A to D are the exact signal bandwidths for the different robustness mode combinations.

TABLE 2.3: Bandwidths for DRM robustness mode combinations (kHz)

Robustness Mode ↓	Spectrum Occupancy type (Nominal Bandwidth)			
	0 (4.5 kHz)	1 (5 kHz)	2 (9 kHz)	3 (10 kHz)
A	4.208	4.708	8.542	9.542
B	4.266	4.828	8.578	9.703
C	-	-	-	9.477
D	-	-	-	9.536

### 2.3.3 DRM theoretical data rates

Tables 2.4 to 2.7 give the theoretical data rates for the different robustness modes. The highlighted columns refer to the typical use.

It should be noted that DRM can cope with bandwidths of up to 20 kHz, but that its use is practically limited to 9 & 10 kHz]

Table 2.4: Data rate (bit/s) in standard mode, Mode A (Ground wave)

Parameters ↓	Bandwidth (kHz)					
	4.5	5	9	10	18	20
64 QAM, $R_{all} = 0.5$	9392.5	10620	19695	22142.5	40935	45840
64 QAM, $R_{all} = 0.6$	11272.5	12740	23625	26570	49115	54995
64 QAM, $R_{all} = 0.71$	13305	15045	27892.5	31367.5	57982.5	64940
64 QAM, $R_{all} = 0.78$	14745	16660	30910	34770	64260	71970
16 QAM, $R_{all} = 0.5$	6262.5	7080	13125	14760	27285	30555
16 QAM, $R_{all} = 0.62$	7827.5	8850	16412.5	18452.5	34112.5	38200

Table 2.5: Data rate in standard mode, Mode B (Sky wave)

Parameters ↓	Bandwidth (kHz)					
	4.5	5	9	10	18	20
64 QAM, $R_{all} = 0.5$	7200	8280	15332.5	17477.5	31817.5	35760
64 QAM, $R_{all} = 0.6$	8640	9930	18402.5	20975	38180	42905
64 QAM, $R_{all} = 0.71$	10200	11730	21720	24750	45065	50660
64 QAM, $R_{all} = 0.78$	11300	12990	24075	27450	49950	56140
16 QAM, $R_{all} = 0.5$	4800	5520	10222.5	11655	21210	23835
16 QAM, $R_{all} = 0.62$	6000	6900	12777.5	14565	26515	29800

Table 2.6: Data rate in standard mode, Mode C (Sky wave)

Parameters ↓	Bandwidth (kHz)					
	4.5	5	9	10	18	20
16 QAM, $R_{all} = 0.5$	Not used			13785	Not used	28952.5
16 QAM, $R_{all} = 0.6$				16537.5		34745
16 QAM, $R_{all} = 0.71$				19520		41015
16 QAM, $R_{all} = 0.78$				21635		45470
16 QAM, $R_{all} = 0.5$				9187.5		19305
16 QAM, $R_{all} = 0.62$				11487.5		24127.5

Table 2.7: Data rate in standard mode, Mode D (Sky wave)

Parameters ↓	Bandwidth (kHz)					
	4.5	5	9	10	18	20
64 QAM, $R_{all} = 0.5$	Not used			9150	Not used	19500
64 QAM, $R_{all} = 0.6$				10977.5		23397.5
64 QAM, $R_{all} = 0.71$				12962.5		27625
64 QAM, $R_{all} = 0.78$				14365		30605
16 QAM, $R_{all} = 0.5$				6097.5		12997.5
16 QAM, $R_{all} = 0.62$				7625		16250

### 3 Modification of transmitters and antennas

This section:

- Deals with the principles of converting existing transmitters to digital operation:
  - Bandwidth for amplitude and phase components
- Analyzes the various types of transmitters that need to be converted to DRM:
  - Old Class B transmitters
  - PDM (Pulse Duration Modulation) transmitters
  - PSM (Phase Shift Modulation) transmitters
- Discusses the Vatican experience
- Deals with Spectrum Masks
- Deals with antenna constraints

#### 3.1 Principles of modifying existing transmitters - conversion to digital

In order to understand the various methods that can be used to modify an existing transmitter for use with DRM it is useful to recap a few modulation principles.

A DRM signal is an amplitude- and phase-modulated RF signal. It can be represented by the expression for a generic electrical signal,  $x(t)$ , as follows:

$$x(t) = A(t)\cos[\omega_0 t + \varphi(t)] = \Re\{A(t)e^{j\varphi(t)}e^{j\omega_0 t}\} = \Re\{X(t)e^{j\omega_0 t}\} \quad (3.1)$$

where:

$$X(t) = A(t)e^{j\varphi(t)} \quad (3.2)$$

represents the baseband modulating signal.

From the last expression it may be found that:

$$X(t) = A(t)e^{j\varphi(t)} = A(t)\cos\varphi(t) + jA(t)\sin\varphi(t) = I_c + jQ_s \quad (3.3)$$

where:

$$\begin{aligned} I_c &= A(t)\cos\varphi(t) \\ Q_s &= A(t)\sin\varphi(t) \end{aligned} \quad (3.4)$$

are known as ‘baseband analogue components’ of the full modulated signal,  $I_c$  represents the phase component and  $Q_s$  the quadrature component. Under certain conditions both components are bandwidth limited.

The fully modulated signal given in (3.1) can easily be generated from the two modulation components I/Q using a circuit that implements the operations shown in Figure 3.1, below.



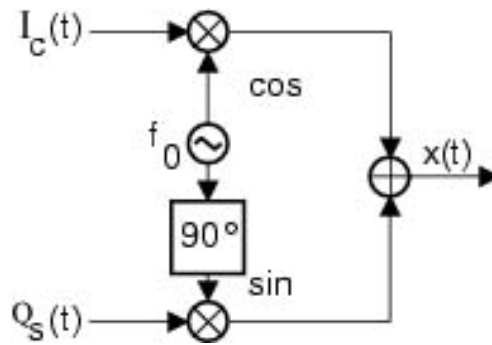


Figure 3.1. Signal generation using Phase and Quadrature components

The previous relations explain that a generic transmitter can be used for DRM if it can provide an RF signal that is simultaneously amplitude and phase modulated at its output. The methods needed to achieve this are very dependent on the transmitter’s circuitry and its original set of implemented functionalities.

One possible way of using an existing transmitter for DRM is to generate the fully modulated DRM signal (as in equation 3.1) outside the transmitter, which is then used as a linear amplifier.

In practice this method is only possible for lower power transmitters, where efficiency is not a significant cost factor. The high cost and poor efficiency of linear amplifiers makes them unaffordable as transmitter power is increased above 1 kW.

The optimum solution is to use ‘non-linear’ high efficiency RF amplifiers. To use these it is necessary to generate both the amplitude component  $A(t)$  (envelope) and the phase component  $\cos[\omega_0 t + \varphi(t)]$  (RF phase-modulated) outside the amplifier and use the existing modulation chain to generate the full signal. This approach is illustrated in Figure 3.2. It should be noted that the bandwidths of the individual envelope and RF phase-modulated components shown in Figure 3.2 are larger than the resulting transmission bandwidth, as indicated in Table 3.1.

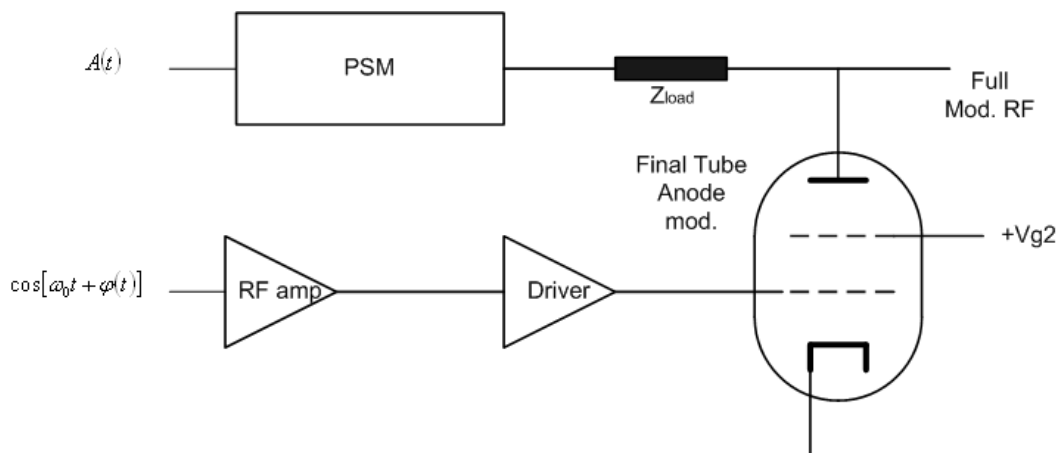


Figure 3.2. Signal generation using Amplitude and Phase components

Table 3.1 Necessary transmitter bandwidths

Nominal bandwidth	Bandwidth of the RF phase modulated component	Bandwidth of the envelope component
4.5 kHz, 5 kHz	20 kHz	15 to 20 kHz
9 kHz, 10 kHz	40 kHz	30 to 40 kHz
18 kHz, 20 kHz	80 kHz	60 to 80 kHz

DRM power is expressed as the average power output of the digital modulation. Since modulation peaks are high for COFDM transmission, the average power is significantly lower than for the same transmitter operating in the analogue AM mode. Under ideal conditions a DRM COFDM waveform has a peak to average ratio on the order of 10 to 12dB.

A transmitter with an analogue carrier power output of 100 kW and peak power of 400 kW would produce 40 kW DRM average power with 10dB (the most common value) of headroom for the modulation peaks. If the digital average power of such a 100 kW transmitter were increased by 2dB, the transmitter would clip the peaks of the amplified signal, causing in-band and out of band intermodulation products. The result would be excessive out of band emissions and non-compliant operation of the transmitter with the result that the spectrum mask constraints would not be fulfilled.

### 3.2 Converting different types of transmitter to DRM

Modern AM transmitters typically use non-linear techniques and have high efficiencies (defined as the ratio of RF power output to mains power input) in the range 70% (HF) to 85% (MF).

AM transmitters with Class B modulators can only be converted to class A linear mode. This involves a careful adjustment of the working conditions of the RF amplifier chain, including the final tube. The achievable results of such a conversion are summarised in Table 3.2:

Table 3.2: Result of converting an AM transmitter with a Class B modulator to DRM

RF Analogue power	100 kW	250 kW	500 kW
DRM power	< 10 kW	< 20 kW	< 40 kW

The overall efficiency of the transmitter is around 20%.

A PDM transmitter may be converted for DRM using an existing SSB capability. However the operation is very close to Class A operation.

If the PSM modulator has the required bandwidth to process the envelope signal, the transmitter can be converted to provide a fully modulated DRM RF signal (a high-level phase and amplitude modulated signal, as shown in Figure 3.1). However, due to the different time delays of the two circuits involved (PSM and RF amplifier chain) a specific time delay between the envelope and the RF phase modulated signals must be introduced by the DRM encoder-exciter in order to minimize the final signal distortion. In this situation, because no modification has been introduced in the bias of the amplifier chain, the original efficiency of the transmitter can be more or less maintained.

### 3.3 Coverage efficiency

The useful (information carrying) output from the DRM transmitter is likely to be greater than the sideband output from an AM transmitter operated with a typical average modulation rate. The fact that DRM is optimised for the RF channel should mean that greater coverage is achieved. A more useful measure of efficiency might be gained from looking at the coverage achieved for a given mains power level. Using this, DRM transmitters should routinely score higher than AM transmitters. Electrical efficiency figures are useful for comparing one DRM transmitter with another DRM transmitter and not for comparing DRM with analogue.

### 3.4 The experience of Vatican Radio

#### Modern solid-state MW transmitter:

In the first half of 2004, Vatican Radio modified a modern (1998) 50 kW solid-state MW transmitter that was installed in Santa Maria di Galeria. The entire modification was carried out under the manufacturer's supervision. The transmitter was originally equipped with an internal synthesizer that was capable of accepting the I/Q representation of the modulation signal. Due to the structure of the RF power stages no modification was required in the RF chain and the original high efficiency of the transmitter was conserved.

#### PDM SW Transmitter:

In the Vatican Transmitting Centre a short wave 500 kW PDM transmitter dating from 1985 was modified for DRM in about seven days. The work was done in cooperation with the manufacturer. In this specific situation, even though the switching frequency of the PDM was double the bandwidth of the envelope signal, it was insufficient to process the envelope signal.

Luckily, the transmitter in question was SSB capable and the processing circuits were found to be suitable for DRM. When this transmitter operates in SSB mode, tests showed the final stage to be quasi-linear, with the PDM modulator operating as a power supply. The transmitter was therefore fitted with an external DRM modulator-exciter that inserted a fully modulated DRM signal into the SSB processing chain.

The electrical efficiency obtained is less than that reached when the transmitter operates in AM mode; however, thanks to the original structure of the SSB chain of the transmitter, an electrical efficiency of approximately 40% has been reached (see also section 3.3 above).

#### First generation (GTO) PSM MW Transmitter:

A 600 kW PSM Medium Wave transmitter dating from 1989 and installed in Santa Maria di Galeria was also modified. The work was completed in about three weeks.

As explained above (section 3.1), in a PSM transmitter the best way to generate DRM is to modulate the transmitter with two signals: envelope and RF phase modulated components. This configuration is particularly suitable because the original class C or D amplification of the final stage remains unmodified and under these conditions the highest global efficiency can be reached. As in this transmitter the bandwidth of the PSM modulator was not large enough, the transmitter was fed with a fully modulated signal (provided by an external DRM encoder-exciter) and the PSM modulator used as a simple power supply for the final stage, which had been linearised. In this situation, of course, preliminary tests are required in order to verify the linearity of the amplification chain. Moreover, once linearised, this kind of power amplifier may become unstable and particular care is required.

#### Modern PSM (IGBT) SW Transmitter:

A modern Short Wave 500kW PSM transmitter, installed in 1997, was also modified in cooperation with the original manufacturer. The measured frequency response of the PSM modulator was close to that needed to process the envelope signal. The required bandwidth was achieved through small modifications to each module of the PSM modulator and through rebuilding its output line filter. All work was completed in four working weeks. The original manufacturer provided a new PSM control board to accept the I and Q components of the full DRM signal generated by an external DRM encoder-exciter. The control board evaluates the envelope  $A(t)$ <sup>\*</sup> signal, which then passes

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\*  $A(t) = \sqrt{I_c^2 + Q_s^2}$

through the PSM chain. At the same time the RF phase modulated  $\cos[\omega_0 t + \varphi(t)]$  component, externally generated by the encoder-exciter, passes through the RF chain. The phase modulated RF is applied to the grid of the final stage tube and the envelope is applied to the anode. The result is a high-level phase and amplitude modulated signal (the fully modulated DRM signal). The necessary delay between the envelope and the RF phase modulated signals was introduced by the DRM encoder-exciter in order to minimize the final signal distortion. Because the biasing of the amplifier chain was not changed, the original electrical efficiency of the transmitter has been more or less maintained.

### 3.5 Spectrum Mask

The permitted output spectrum of a DRM transmitter is defined according the mask described by the following equations and illustrated in Figure 3.3.

$$\begin{aligned}
 |f| \leq 0.5 \times B : & \quad P(f) = 0dB \\
 |f| = 0.53 \times B : & \quad P(f) = -30dB \\
 0.53 \times B < |f| < 2.98 \times B : & \quad P(f) = -30 - 40 \times \log_{10}(f / (0.53 \times B)) \\
 |f| \geq 2.98 \times B : & \quad P(f) = -60dB
 \end{aligned}$$

Where B is the nominal bandwidth and f is the current frequency.

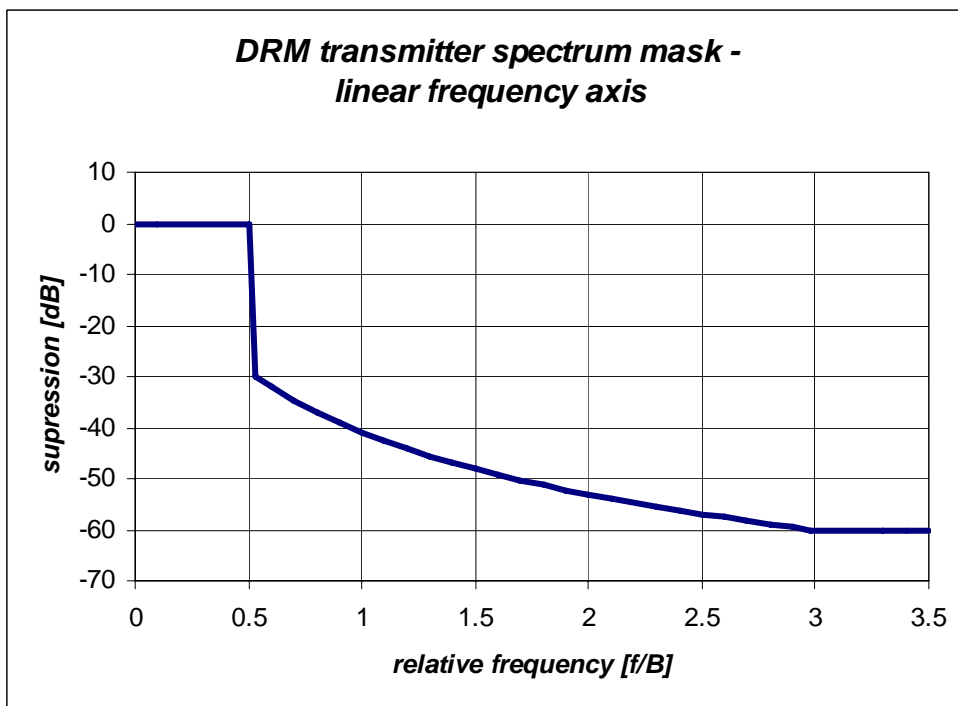


Figure 3.3. DRM transmitter spectrum mask

The spectrum mask is symmetrical about the channel centre.

### 3.6 Antenna constraints

For long and medium wave antennas, the frequency response of the impedance at the feeding point is of particular importance, since the bandwidth of the modulated signal is relatively large

compared to the carrier frequency. The influence of the asymmetry of the transmission on the quality of the amplitudes of a modulated oscillation is described with the aid of Figure 3.4.

Figure 3.4a shows the vector diagram of a pure amplitude modulation. The vector  $U_c$  represents the carrier, the vectors  $U_{LSB}$  and  $U_{USB}$  the lower and the upper sideband of the amplitude modulation. In this kind of representation, the vector of the carrier does not move, while the vectors of the sidebands rotate against each other depending on the frequency of the modulating input signal.

The size of these vectors is proportional to the amplitude of the signal. For this example it is assumed, for simplicity, that only one pure tone will be transmitted. The sum of the three vectors represents the instantaneous vector of the amplitude-modulated oscillation. The resulting vector changes its size, but not its phase, because the side band vectors are of the same size and they rotate exactly in opposite directions. In Figure 3.4a the resulting vector remains in the vertical line, which means a pure amplitude modulation.

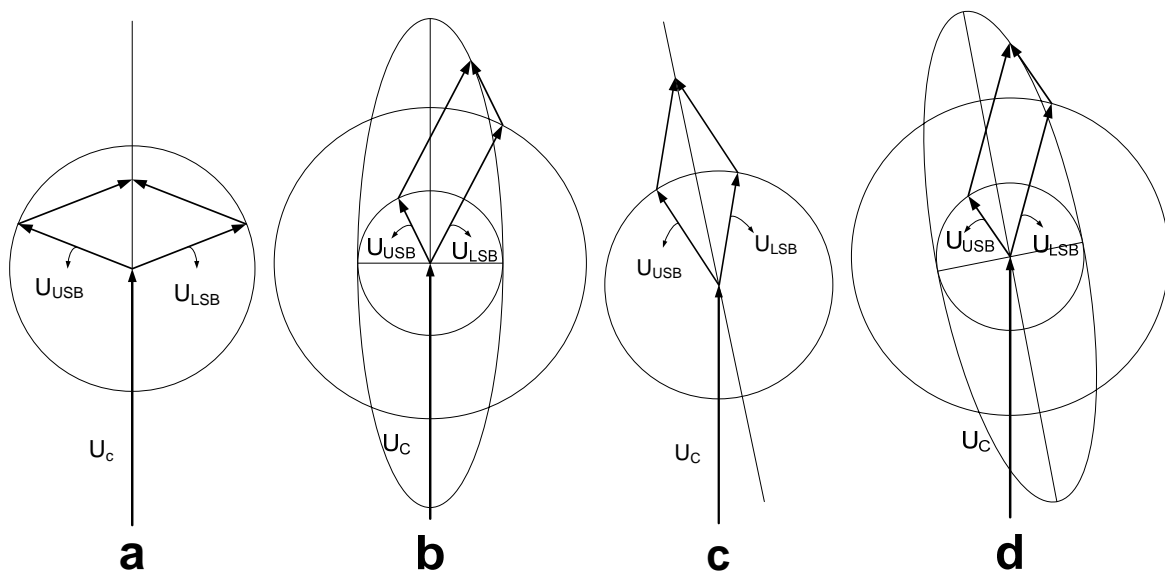


Figure 3.4; influence of the asymmetry of the transmission on the quality of the amplitudes of a modulated oscillation

In Figure 3.4b the sidebands are assumed to be of unequal amplitudes. As result a phase modulation occurs in addition to the pure amplitude modulation shown by the resulting vector that does not remain vertical as it was in Figure 3.4a.

Figure 3.4c shows the vectors with equal amplitudes but unequal phases of the sidebands. As in the preceding case, a phase modulation also occurs here in addition to the amplitude modulation.

Figure 3.4d shows the behaviour of the simultaneous occurrence of amplitude and phase errors. Again simultaneous amplitude and phase modulation occur.

In conclusion, unwanted phase modulation occurs during asymmetrical transmission of the sidebands. It is not significant whether this asymmetry occurs in the amplitude or in the phase of the transfer function.

Load impedance bandwidth:

$\pm 5$  kHz - symmetry of the load impedance presented to the final RF amplifier within the transmitter such that the standing wave ratio calculated for one sideband impedance, when normalized to the complex conjugate of the corresponding sideband impedance on the other side of carrier frequency, does not exceed 1.035:1.

$\pm 10$  kHz - the VSWR of the load impedance presented to the final RF amplifier within the transmitter should not exceed 1.20:1 when normalized to the carrier frequency impedance.

## 4 Coverage and Frequency planning

### 4.1 Introduction

As with all planning of radio services, the planning of DRM is based on two fundamental concepts:

- Minimum usable field strength
- Protection criteria (protection ratio)

#### 4.1.1 Minimum usable Field Strength

For proper reception of any radio service, the received field strength must be high enough to allow the demodulator to function in the prevailing noise environment. In general this defines the coverage area of the transmitter. It is to be expected that the strength of the wanted signal will decrease as the receiver moves further away from the transmitter (or the beam centre in the case of a directional antenna), while the noise will stay the same.

The ITU specifies reference receivers with defined characteristics and these are used for service planning. A real receiver might have better or worse characteristics than the reference but it would make no sense to have different planning parameters for each individual receiver or receiver type. The minimum usable field strength is that field strength which is necessary for the receiver to perform to a given (defined) level of performance. In the case of a DRM receiver this level of performance can be defined as a bit error rate (BER). If the BER is low enough, the error correction and other arrangements within the DRM system can reconstruct the audio signal.

#### 4.1.2 Protection Criteria

Major sources of 'noise' at the receiver input are other radio services operating at or near the desired transmission frequency. Unlike all other sources of noise (intrinsic receiver noise, man made noise, naturally occurring noise, etc.) interference from other radio services can and should be controlled by the planning process. The interfering station is subject to the same planning criteria as the 'victim' service and the victim service itself will always be an interferer to someone else. For any one station, the transmitter power along with the antenna gain and directivity are set such that the signal is sufficiently large that a reference receiver will demodulate the signal to the relevant defined quality standard:

- In the required (specified) service area and;
- When compared with the cumulative effect of all the potential interferers;

In the case of DRM, the quality standard is again set by the worst tolerable BER. Similarly, the transmitter power and antenna characteristics must also be set such that the cumulative effect of all interferers (including itself) does not rise above a prescribed limit for other transmissions in their own service area. Clearly, this can be a complicated multi-dimensional calculation.

An analogue, AM radio service (or any other for that matter) carries the information in the sidebands. It is therefore the ratio of wanted signal in the sidebands to noise and interference in the sidebands that defines the signal to noise ratio for the demodulated signal. With an AM radio signal it can reasonably be assumed that the ratio of sideband to carrier energy for one transmission is much the same as for another transmission. When assessing protection to and from other AM transmissions it is reasonable therefore simply to look at the relative levels of the carriers. Similarly, the 'sideband' characteristics of any one DRM transmission will be much the

same as for another and so the protection requirements can be assessed simply by looking at the overall power.

A DRM transmission, however:

- does not have a carrier component in the same way as does an AM transmission and
- It has very different power spectral density characteristics.

Assessing the protection criteria in a mixed environment (DRM into AM and vice versa) is therefore much less straightforward. It is necessary to determine the actual energy in the AM sideband and compare this with the total energy in the DRM signal. The energy in the sidebands of an AM transmission is heavily dependent on modulation depth, programme genre and the use (or not) of dynamic carrier control techniques. In part because of this, it is convenient (more consistent) when assessing protection criteria to compare the total energy in a DRM signal with the carrier energy in an AM signal. Since the sideband energy in the AM signal is considerably less than the carrier energy it is to be expected that the energy in a DRM signal will be similarly lower (than the AM carrier) to give the same level of interference. This is reflected in Table 4.20 in section 4.6.4, which defines the power 'back off' necessary to give an equivalent level of interference when an AM transmission is directly replaced with a DRM transmission. Care must be taken to protect the weakest AM signals.

Simply put, if a DRM transmission is introduced, it should not impose more interference on existing AM services than the analogue transmission it replaces.

In the HF bands, experience of introducing DRM transmissions into the already crowded spectrum suggests that there is an advantage in trying, whenever possible, to group the DRM transmissions together in the same part of a band. Within the informal regional coordination groups (HFCC/ASBU, ABU-HFC) frequency management organisations have been requested to take this into account, as far as possible, when planning and coordinating their seasonal broadcasting schedules.

## **4.2 LF/MF bands**

This section should be read in conjunction with the ITU LF/MF handbook [2] that describes many aspects in more detail.

### **4.2.1 Frequency bands allocated to LF and MF sound broadcasting**

Frequency bands at LF and MF have been allocated to sound broadcasting services in the three ITU Regions according to the provisions of Radio Regulations. Figure 4.1 shows the world distribution of the ITU Regions. The shared part is referred to as the Tropical Zone. Table 4.1 shows the frequency allocations made according to the Radio Regulations:

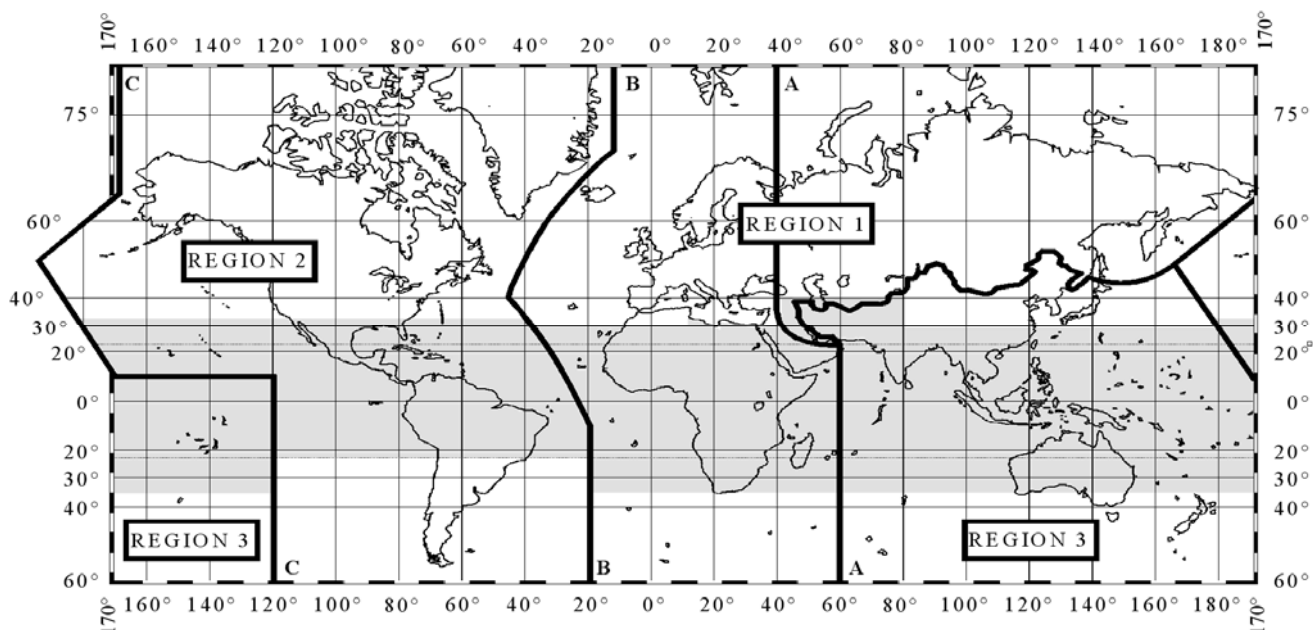


Figure 4.1: The ITU Regions

Table 4.1 ITU Frequency allocations - LF and MF bands

ITU Region (associated Agreements)	LF Band	MF Band
1 (GE75)	148.5 - 255.0 kHz 255.0 - 283.5 kHz (shared with aeronautical services)	526.5 - 1606.5 kHz
2 (RJ81) (RJ88)	-	525.0 - 535 kHz (shared with aeronautical services) 535.0 - 1605.0 kHz 1605.0 - 1625.0 kHz 1625.0 - 1705.0 kHz (shared with fixed and mobile services)
3 (GE75)	-	526.5 - 535 kHz (with mobile services on a secondary basis) 535.0 - 1606.5 kHz

## 4.2.2 Coverage

### 4.2.2.1 Coverage area

Daytime coverage in the long and medium wave bands uses ground wave propagation. It is anticipated that DRM coverage will be better or as good as that of AM at transmitted power levels of -7dB (emrp) (see CCRR/20 [8]) compared to that of an analogue assignment it has replaced. Sky wave propagation does not provide any daytime coverage.

Night time coverage in the long and medium wave bands is more complex. Ground wave generally provides night time coverage and may be supplemented by sky wave in some cases. Self-interference may be an issue. It is anticipated that DRM coverage will be better or as good as that of an AM service where transmitted DRM power levels are -7dB (see CCRR/20 [8]) compared to that of an analogue assignment it has replaced.



However due to high levels of sky wave interference particularly at the day to night transition and maybe to a lesser extent during the night, it is generally found that night time coverage is less than the daytime coverage.

The DRM system includes different digital modulation modes to enable the transmission operator to select a mode with a degree of robustness best suited to the expected propagation and reception conditions. Receivers are capable of automatically detecting which mode is in use. (See Section 2.1)

#### **4.2.2.2 Coverage concepts for DRM**

Coverage concepts applicable to long and medium wave broadcasting using analogue modulation are equally valid for DRM

##### **A. Single transmitter**

Where a service is required for a single area or town, a single transmitter may suffice. The placing of a transmitter may be critical to ensure night time coverage. Propagation effects such as conductivity, 'urban suck out' (Causebrook effect) may be equally critical. This equally applies to high or low power assignments utilised for large and small area coverage and apply to both DRM and AM.

##### **B. Single Frequency Networks (SFNs)**

Where it is desirable to have large area coverage and ensure spectrum efficiency, several transmitters can be operated on the same frequency. This can be true of an AM (long or medium wave) service (synchronous network) or a DRM service (SFN). The major difference is that the DRM system is able to provide contiguous coverage from a network of transmitters if correctly engineered<sup>1</sup> while the AM service would not provide contiguous coverage due to mutual interference<sup>2</sup>.

##### **C. Multi-Frequency Networks (MFNs)**

Where it is desirable to have large area coverage but an SFN may not be achievable due to frequency planning constraints, then an MFN may have to be utilised. This is equally true of both a long or medium wave AM service or an equivalent DRM service. The major advantage that such a DRM service would have over an equivalent AM service is a seamless coverage available through receiver design using AFS (Automatic Frequency Switching).

This is equally true of high or low power networks or combinations of both.

#### **4.2.2.3 Conversion of LF/MF AM assignment**

It might be expected that converting an existing or new LF/MF assignment to DRM in line with current ITU regulation would increase the coverage area due mainly to a reduction in Emin (see below).

- The minimum usable field strength (Emin or MUF<sub>S</sub>) is a key factor in coverage potential. This is calculated by the addition of the receiver noise floor and the required C/N for a satisfactory

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<sup>1</sup> Correct engineering includes GPS locking of transmitters' frequency, transmitters' radiated power, etc.

<sup>2</sup> This can be minimised by delay equalisation (usually optimised to facilitate coverage in specific areas) and phase locking of carriers (to ensure 'fading' is reduced on received signals). This is equally true of high or low power networks or combinations of both.

service.

ITU-R BS.703 [9] quotes  $E_{min}$  for AM transmission as:

$$LF = 66\text{dB}\mu\text{V}/\text{m}$$

$$MF = 60\text{dB}\mu\text{V}/\text{m}$$

ITU-R BS. 1615 [4] should be consulted for the many values of computed  $E_{min}$  for DRM for varying modes of operation

$$\text{AM } (E_{min}) \quad 23.5\text{dB } (\text{Rx Noise floor}^1) + 36.5\text{dB } (\text{C/N}) = 60\text{dB}\mu\text{V}/\text{m}$$

Examples of  $E_{min}$  for DRM (see Tables 4.2, 4.3 and 4.4):

$$\text{DRM } (E_{min}) \quad 24.5\text{dB } (23.5+ 1) (\text{Rx Noise floor}) + 8.6\text{dB } (\text{S/N}) = 33.1\text{dB}\mu\text{V}/\text{m}^2$$

$$\text{DRM } (E_{min}) \quad 24.5\text{dB } (23.5+ 1) (\text{Rx Noise floor}) + 17.1\text{dB } (\text{S/N}) = 41.6\text{dB}\mu\text{V}/\text{m}^3$$

Note: a more robust DRM mode (lower data rates) can tolerate a lower S/N and hence has a lower  $E_{min}$ .

The additional 1dB in the Rx Noise floor for DRM is due to the larger receiver IF bandwidth of DRM (10 kHz) compared to double sideband AM (8 kHz).

Section 4.5 provides further explanation on the calculation of the minimum usable field strength.

Table 4.2:

Minimum usable field strength (dB( $\mu\text{V}/\text{m}$ )) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode A with different spectrum occupancy types 0 or 2 (4.5 or 9 kHz) dependent on modulation and protection level scheme for the LF frequency band (ground-wave propagation)

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type	
			A/0 (4.5 kHz)	A/2 (9 kHz)
16-QAM	0	0.5	39.3	39.1
	1	0.62	41.4	41.2
64-QAM	0	0.5	44.8	44.6
	1	0.6	46.3	45.8
	2	0.71	48.0	47.6
	3	0.78	49.7	49.2

<sup>1</sup> The Rx Noise floor is given in Rec. ITU-R BS 1615 (2003) [4], see also section 4.5.1.2.

<sup>2</sup> 8.6dB C/N corresponds to A2 mode (9 kHz) using 16-QAM, CR 0.5 (see Table 4.3 and Annex 1).

<sup>3</sup> 17.1dB C/N corresponds to A2 mode (10 kHz) using 64-QAM, CR 0.71 (see Table 4.3 and Annex 1).

Table 4.3:

Minimum usable field strength (dB(μV/m)) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode A with different spectrum occupancy types dependent on protection level and modulation scheme for the MF frequency band (ground-wave propagation)

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type	
			A/0 (4.5 kHz) A/1 (5 kHz)	A/2 (9 kHz) A/3 (10 kHz)
16-QAM	0	0.5	33.3	33.1
	1	0.62	35.4	35.2
64-QAM	0	0.5	38.8	38.6
	1	0.6	40.3	39.8
	2	0.71	42.0	41.6
	3	0.78	43.7	43.2

Table 4.4

Minimum usable field strength (dB(μV/m)) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode A with different spectrum occupancy types dependent on protection level and modulation scheme for the MF frequency band (ground-wave plus sky-wave propagation)

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type	
			A/0 (4.5 kHz) A/1 (5 kHz)	A/2 (9 kHz) A/3 (10 kHz)
16-QAM	0	0.5	34.3	33.9
	1	0.62	37.2	37.0
64-QAM	0	0.5	39.7	39.4
	1	0.6	41.1	40.8
	2	0.71	44.2	43.7
	3	0.78	47.4	46.5

To protect an existing AM service from another co-channel AM interferer an RF protection ratio of 30dB is required. If that interferer is a co-channel DRM service the RF protection ratio must be increased by 6.6dB to 36.6dB for the same interference potential. Hence CCRR/20 [8] requires the DRM emrp to be -7dB on the AM carrier level to safeguard the existing AM service.

The expected increase in coverage potential when converting an AM assignment to DRM in accordance with CCRR/20 [8] will be relative to the severity of interference that limits the coverage of the AM assignment in the first place.

Figure 4.2 demonstrates a fictitious example of converting an AM transmitter assignment to an equivalent DRM assignment (-7dB emrp). The example is for five omni directional transmitters. Four are co-channel interferers varying in emrp from 100 to 400 W to demonstrate three distinct levels of interference potential and the wanted is 1000 W for AM or 200 W (-7dB) for DRM.

The prediction shown in Figure 4.2 is for ground-wave only with no receiving antenna discrimination. It is therefore representative of daytime reception. As the transmitters are

relatively close, minimal sky-wave propagation would occur at night so the coverage will change little. However note this is not representative of the ‘real world’ where sky-wave interference at night could severely limit coverage.

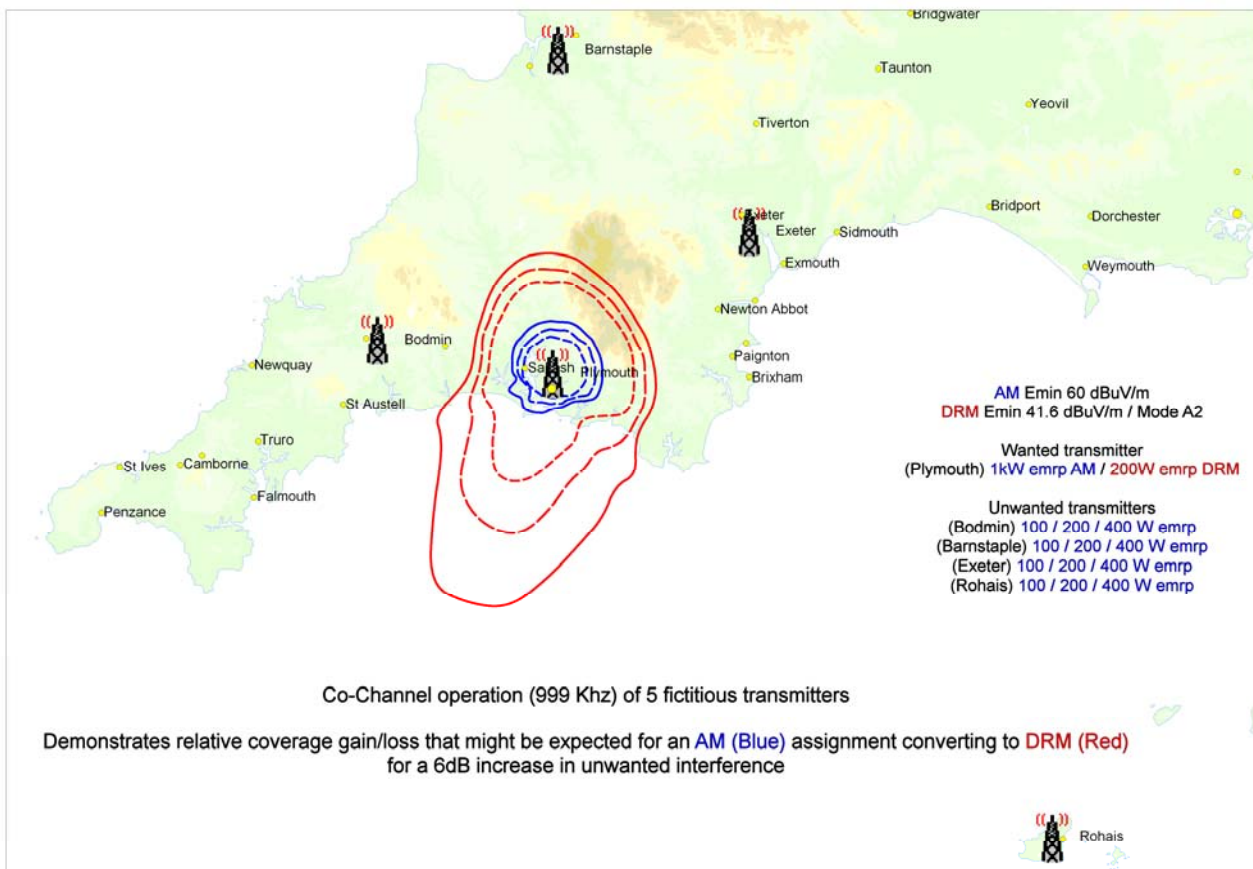


Figure 4.2: Example of converting an AM transmitter assignment to an equivalent DRM assignment

**4.2.2.4 Protection Ratios**

Protection ratios are described in detail in Recommendation ITU-R BS 1615 [4]. (“Planning parameters” for digital sound broadcasting at frequencies below 30 MHz). They are simply the minimum values that the wanted signal levels (assuming its a service to provide coverage) must exceed unwanted interfering signal(s).

For further details on protection ratios, see section 4.6.

**4.2.2.5 Noise**

Noise limits the performance of radio systems and relevant further information can be found in Recommendation ITU-R P 372-8 ‘Radio Noise’ [10].

**4.2.3 Propagation**

Propagation factors are used to define the mode of transmission required. This is described in detail in Recommendation ITU R BS 1615 [4] “Planning parameters” for digital sound broadcasting at frequencies below 30 MHz.

Propagation of the radio waves in the LF and MF bands are described in detail in the ITU LF/MF handbook [2] with particular note that propagation varies with latitude.

Recommendation ITU-R P.368-7 (1992) [25] provides a prediction method for ground-wave signals in the frequencies between 10 kHz and 30 MHz. Furthermore, a detailed comparison study between measured field strength values in rural and suburban environments and the predicted values given by Recommendation ITU-R P.368-7 is presented in ITU-R document 6E/175-E 18 March 2005 (Digital Radio Mondiale (DRM) daytime Medium Wave tests) [22] and summarized in Annex 3, section A3.1.

The following text is an extract from the LF/MF handbook [2]:

*The general subject of radio propagation is of fundamental importance to LF and MF broadcasting system engineering. It deals with the manner of transmission of radio signals from the transmitter site to each point in the reception area and describes the magnitude of the received signal at each such point in the desired service area and in the areas of potential interference.*

*It is important to perform valid propagation analysis for the broadcasting system for all points within the broadcasting service area, and in the service areas of other broadcasters using co-channel and adjacent channel frequencies. This is because noise and interference considerations determine the delivery characteristics of the broadcasting facility that are to be required throughout the broadcasting service area, and in the service areas of other broadcasters on the same and adjacent channels. In general, the quality of this signal is specified in terms of its electrical field strength, usually in V/m. When a broadcasting system is designed, the usual design objective is to guarantee that this received field strength will not fall below some required value, and will not cause interference to other operators.*

LF and MF signals propagate from the transmitting antenna to the receiver by two distinct propagation mechanisms: ground-wave and sky-wave propagation. In planning an LF or MF broadcasting system, one should remember that, especially at night, the signal received at any point in and around a broadcasting service area is always the vector sum of the ground wave and the sky wave. At some points, the ground wave will clearly dominate and the service provided will be constant and continuous. At other points, the sky-wave may dominate and the signal will be characterized by some degree of short and long term fading. In some areas, often within the service area, the ground-wave and sky-wave components of the received signal will be approximately equal. In these areas the signal will exhibit strong and continuous fading. Such a signal will usually not meet the required signal delivery standards. However, this phenomenon may be avoided by judicious design of the vertical pattern of the transmitting antenna, which places this fading zone either outside the broadcasting service area, or in a sparsely populated region within it.

*In the following sections (in the LF/MF handbook), the above mechanisms are described and the methodology for their calculations is presented. In the use of these methods, the broadcasting planning engineer must meet the objective of identifying the parameters required for the design and implementation of the transmitting facility (e.g. transmitter power and antenna pattern). This must be done in such a fashion as to provide the required service quality over the broadcasting service area, while simultaneously meeting the co-channel and adjacent channel protection requirements of the broadcasting ITU Region in which the facility will be implemented. The broadcasting system designer must keep in mind that the potential of sky waves for interference for both co-channel and adjacent channel is much greater than that of ground waves.*

*It is important to note that, for interference calculations purposes, propagation calculations performed in connection with the addition of a new assignment or the modification of an existing assignment to one of the regional assignment Plans must be in accordance with the propagation methods of those Plans. This text (in the LF/MF handbook) generally describes the ways in which the propagation methods used in the regional Plans differ from the ITU-R Recommendations.*

## 4.2.4 Frequency choice and co-ordination,

### *Frequency choice*

- New assignment
- Converting an existing assignment

Propagation varies dramatically with frequency in the LF and MF bands. There is no correct way to describe the correct frequency for a particular coverage requirement. Some simple rules may aid a planner's choice if there is one. If a frequency is available, generally the lower the frequency the larger the coverage with the smallest EMRP is achievable. Conversely it could be said that if the required coverage is smaller and if higher frequencies can be used, better spectral efficiency can be achieved. Software packages are now able easily to identify 'quiet' spectrum or usable channels and give an idea of the coverage potential and the likelihood of a successful co-ordination for a new assignment that may be suitable for the intended purpose.

Another consideration when converting an existing on air assignment is how suitable the antenna system is for DRM. It may be found that, due to the transmission characteristics of a DRM signal, less power than allowed by a simple conversion may be achievable.

### *Coordination*

All AM assignments in ITU Regions 1 and 3 are registered in the Geneva 75 Plan. This plan can be updated by any administration for a new or modified assignment by following the rules of procedure laid out in the ITU document 'The final acts of the GE 75 Plan' [11].

Each assignment is described by its basic transmission parameters that allows at the time of the inclusion of an assignment into the plan for it to have a separate day and night coverage defined by test points. There are eighteen test points used to describe coverage. They are arranged radially around the wanted transmitter site at 20° intervals starting at 0°/360°. Each point is defined in space by its latitude and longitude. This is achieved by working outwards along a radial from the wanted transmitter and calculating where the summation of the nuisance fields (field strength + protection ratio) of all the potential interferers is less than the wanted field strength providing the wanted field strength is adequate (limit of service) for a service. These points are used to facilitate co-ordination by the use of the 'half dB rule' for all except the low power channels as described in 'The final acts of the GE 75 Plan' [11].

At the time of writing, a DRM assignment is effectively registered as an AM assignment but operated under the conditions described in CCRR/20 [8] (Decisions of the RRB - Dec. 2002 regarding the rules of procedure GE75, see section 5.1.3.4). It is anticipated as more experience is gained of DRM transmissions the coexistence of AM and DRM in the LF and MF bands may yield modifications to the values used at present for planning DRM.

## 4.2.5 Reception

A listener can do much to improve the reception of a service if a portable receiver is used. This is explained in a bit more detail below.

The transmitter's coverage will almost certainly vary according to time of day. Daytime coverage does not mean night time is ensured. This is explained in more detail in the ITU LF/MF handbook [2].

**Portable reception:**

Use of the electrical field for reception

- Not normally used for portable reception at MF and LF
- The electrical field is more susceptible to degradation by man made noise and interference
- 'Telescopic rod' antennas for the reception of the electrical field by virtue of being nominally omni-directional do not reject unwanted signals

Use of the magnetic field for reception

- Most portable receivers utilise the magnetic field by using a ferrite rod antenna
- Ferrite rod antennas can be orientated to reject unwanted signals
- Ferrite rod antennas by virtue of being directional do not lend themselves to mobile reception.
- Rejection of sky wave interference more easily achieved by orientation of receiver

**Mobile reception:**

Use of the electrical field for reception

- 'Telescopic rod' antennas by virtue of being omni-directional lend themselves to mobile reception however they are generally not omni directional due to interaction with the vehicle.
- The electrical field is more susceptible to degradation by man made noise and interference

Use of the magnetic field for reception

- This is generally unused in the mobile environment except by professional monitoring and measuring equipment.

**Reception in general:**

The incident fields to a LF or MF receiver may vary due to modification by the local surroundings. This is most noticeable in the urban environment by a reduction in field strength (Causebrook effect) and increased likelihood of electrical interference. At LF and MF Doppler shift could be experienced due to the velocity difference between the receiver and the transmitter. This should be normally corrected within a DRM receiver unless high velocities are experienced.

Building penetration loss is an unknown factor at these frequencies. It is anticipated that such a loss might be small in general but local modification of the electrical and magnetic fields will be prevalent especially in urban areas or where man has disturbed the surroundings by buildings, roads and service infrastructure.

**4.2.6 Planning software**

At the time of writing there are a small number of software packages for DRM frequency & coverage planning in the LF & MF frequency bands commercially available. They are principally specialist software packages aimed at broadcasters. They generally implement ITU recommendations and use proprietary databases and may further utilise (ITU BRIFIC data). They generally use ITU conductivity data for computation. A broadcaster's own conductivity data for specific geographical areas can be utilised in some cases. Broadcasters with their own propagation algorithms are generally able to have them incorporated into such packages.

Aspects of planning they facilitate:

- Database management
- Frequency selection
- Coverage planning (single Tx, SFN, MFN)
- Co-ordination

Any software package has a finite capability and should be used wisely. This is principally controlled by the accuracy of the data and how the algorithms used are at replicating the ‘real world’ propagation. Being very complex packages, the user needs to be competent and able to interpret the results correctly so as to capture anomalies in data or output to ensure worthwhile predictions.

## 4.3 HF band

### 4.3.1 Coverage

The HF bands are ideal for providing coverage of large areas at a distance<sup>1</sup> from the transmitting site via sky-wave propagation. It is also possible to provide coverage of large areas around a transmitting site using the lower HF frequency bands, again by using sky-wave propagation.

HF frequencies do propagate via ground-wave but the range is only up to a few tens of kilometres. There are some local HF services that use this mechanism to provide coverage of a very small area close to the transmitting site.

The coverage achieved by a single HF transmission using one hop via sky-wave propagation is primarily a function of the transmitting antenna characteristics. The width of the coverage area as seen from the transmitter is normally taken as the horizontal beamwidth of the antenna (-6dB reference maximum radiation) while the depth of the coverage area depends on the vertical beamwidth of the antenna. The distance of the centre of the coverage area from the transmitter is a function of the elevation angle of the maximum radiation of the antenna, of the density of the ionospheric layers and of the frequency; high angles provide coverage close to the transmitter and low angles provide coverage at long distances from the transmitter. This is repeated for subsequent hops if the ionosphere supports these. Using appropriate vertical radiation characteristics of the transmitting antenna, it is possible to provide almost seamless coverage between hops. This is often referred to as the antenna “footprint”. Recommendation ITU-R BS.705 [7] gives details of HF antennas as well as an antenna selection chart.

Once the most suitable antenna is selected, the transmitter power is calculated to achieve the wanted quality of service taking into account noise and potential interference from other transmissions on the same or adjacent frequencies within the wanted service area. As the HF bands are congested at peak broadcasting times, the actual coverage achieved is often much less than the antenna footprint. Increasing transmitter power does not lead to significant increase in the antenna footprint but does increase the practical coverage area within the “footprint”.

This is true for both analogue and digital modulation.

When planning a broadcasting service it may be necessary to consider more than one transmitter to provide the wanted level of service over the whole of the wanted service area.

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<sup>1</sup> Ranging from a few hundreds to several thousands kilometres.



## **A Synchronous networks and Single Frequency Network (SFN)**

There are two variations of network where transmitters are operating on the same frequency.

If the wanted service area is significantly larger than that which can be achieved using a single transmitter and directional antenna, it is possible to use additional transmission facilities on the same frequency to extend the service area. For example, if the wanted service area subtends an arc of 100° from the transmitter site, it is possible to use 2 or 3 antennas on different azimuths such that the edge of the beamwidth of one antenna is just overlapping the edge of another. Usually, the same transmitting site is used for all transmissions but the technique also works if two or more sites are used as long as they are not too far apart. This practice is referred to as synchronisation as the frequency of each transmitter must be kept the same to minimize mutual interference in the overlap area.

The second type is where two or more transmissions are used from different sites on the same frequency to the same wanted service area.

These techniques can be used with either analogue transmissions (synchronous network) or digital transmissions (SFN).

Section 4.8 describes an example of an SFN with two DRM transmitters, one located in Germany and the second in Portugal, in the HF band.

## **B Multiple Frequency Networks (MFN)**

Another technique used to increase the coverage area and improve the reliability of service is to use additional frequencies in different broadcast bands. This is often referred to as a multiple frequency network (MFN). This is particularly true when trying to serve a coverage area that extends across many hundreds of kilometres from the transmitting site.

If it is possible to cover the wanted service area using a single transmission, it is often necessary to use a second transmission in a different frequency band to improve the overall reliability of the service. As propagation conditions vary within the hour, day-to-day and month-to-month within a broadcasting season, reception of a single frequency will vary significantly. Provision of a second frequency in a different band means that one of the two frequencies providing the service is likely to provide adequate reception over the range of propagation conditions likely to occur during the season.

### **4.3.2 Protection ratios**

Protection ratios are described in detail in Recommendation ITU-R BS 1615 [4] (“Planning parameters” for digital sound broadcasting at frequencies below 30 MHz).

For further details on protection ratios, including the specific values used for HF coordination, see section 4.6.

### **4.3.3 Propagation**

The optimum frequency band for the transmission can be determined by using Recommendation ITU-R P.533. This allows the field strength, angle of elevation and other relevant parameters to be predicted for the path from the transmitter to a point within the wanted service area for each HF broadcast band for each hour for the month and sunspot number selected. One parameter is the maximum useable frequency (MUF), which is the highest frequency that will provide a service for 50% of the time. To achieve a more reliable transmission, the frequency band closest to 15% below the MUF is normally selected for the transmission. Choosing a band below this can also provide a service but the delivered field strength is likely to be much less than that provided by the optimum

band. In fact, the lower the band below the optimum band, the lower the field strength achieved, to the extent that the transmission may not be able to overcome the noise level in the wanted service area. Again, this is true for analogue and digital transmissions.

Outside urban areas in the Tropical Zone, the noise level can often be higher than experienced elsewhere. During daytime, HF signals also suffer from high levels of . Extra care is therefore required to select the appropriate transmission facilities to provide acceptable coverage of the wanted service area. If a relatively local service is required, special antennas are usually required to maximise the radiation at high elevation angles. These antennas are referred to as tropical band antennas and are fully described in Recommendation ITU-R BS.705.

Although Recommendation ITU-R P.533 [12] is able to predict the likely optimum frequency band for a particular service for both analogue and digital services, additional information is required, such as Doppler shifts, propagation delays etc, to select the best transmission mode for a digital transmission. ITU-R Study Group 3 is currently extending Recommendation ITU R P.533 [12] to provide such information.

#### 4.3.4 Frequency choice and coordination

For the allocation of frequencies the world has been divided into three Regions as shown in Figure 4.1. The shaded part represents the Tropical Zones as defined in the ITU Radio Regulations.

The HF frequency bands available for broadcasting from 1st April 2007 are shown in the following Table.

Table 4.5: HF frequency bands available for broadcasting from 1st April 2007

Metre Band	From (kHz)	To (kHz)	Notes
90	3200	3400	Tropical Zone only
75	3900	4000	Region 3 only
75	3950	4000	Region 1 only
60	4750	4995	Tropical Zone only
60	5005	5060	Tropical Zone only
49	5900	6200	
42	7100	7300	Regions 1 & 3 only <sup>1</sup>
42	7300	7350	<sup>2</sup>
31	9400	9900	
25	11600	12100	
22	13570	13870	
19	15100	15800	
16	17480	17900	
15	18900	19020	
13	21450	21850	
11	25670	26100	

<sup>1</sup> 7200 kHz to 7300 kHz and 7400 kHz to 7450 kHz from 30th March 2009

<sup>2</sup> 7300 kHz to 7400 kHz from 30th March 2009

The bands above 5900 kHz are planned under the provisions of Article 12 [13] while the bands below 5900 kHz are shared with other services and come under the provisions of Article 11 [14]. Articles 12 and 11 are explained hereafter.

### **Article 12**

Article 12 “*Seasonal planning of the HF bands allocated to the broadcasting service between 5900 kHz and 26100 kHz*” was adopted by the World Radio Conference held in 1997 (WRC-97). This identifies two broadcasting seasons each year as follows:-

- Schedule A: Last Sunday in March to last Sunday in October.
- Schedule B: Last Sunday in October to last Sunday in March.

and encourages the concept of informal coordination to resolve potential mutual interference.

Under Article 12, organisations responsible for planning HF broadcasting services choose the frequencies they require to satisfy their broadcasting requirements for each broadcasting season. These organisations are referred to as Frequency Management Organisations (FMO) and are registered under Article 12 with the ITU-BR.

With the FMOs free to choose frequencies, it is likely that there will be a number of interference problems. Article 12 encourages FMOs to resolve these potential interference problems at informal face-to-face meetings between the FMOs. It also encourages the formation of Regional coordination groups to manage this informal coordination process. Consequently, there are four coordination groups registered with the ITU:-

- Arab States Broadcasting Union (ASBU)
- Asia-Pacific Broadcasting Union - High Frequency Conference (ABU-HFC)
- High Frequency Coordination Conference (HFCC)
- African Regional Coordination Group (URTNA)

HFCC and ASBU hold two joint meetings each year. ABU-HFC holds one meeting a year but coordinates the second season via Email. These three groups currently hold a joint meeting once every two years but are considering holding joint meetings once a year in the future.

The coordination process developed within the coordination groups can appear to be a complex and daunting process but is, in fact, relatively simple in practice.

For each of the 2 broadcasting seasons per year, the process has the following steps:-

- Prior to the closing date agreed for submission of requirements, all member organisations send their frequency requirements via Internet to a central database. An initial automated examination identifies requirements that are incomplete;
- The field strength for each requirement is calculated at each of the 912 test points using Recommendations ITU-R P.533 and BS.705. For each requirement, the CIRAF Zone quadrants where the signal strength achieved is above a predetermined level are identified. Potential incompatibilities are identified where more than one requirement has the same CIRAF Zone quadrants at the same time and on the same or  $\pm 5$  kHz frequency. A list of these calculated incompatibilities (collisions) is made available for each organisation together with the database of requirements;
- Organisations then try to resolve as many of these collisions as possible prior to the meeting by making changes to the affected requirements if at all possible;
- At the meeting, organisations discuss each collision with the other organisation involved to

agree a solution. A solution could involve one organisation changing frequency, time or technical parameters to avoid or reduce the potential interference. It is also possible for both parties to agree that there is no problem in practice. Occasionally, a solution to a problem between two organisations can involve other organisations agreeing to change their requirements to help;

- Organisations are encouraged to submit any changes to the database in case these impact other requirements. New documentation is available via the internet on a regular basis during the day;
- After the meeting, organisations continue to amend their schedules in light of new and changed broadcasting requirements and continue to try to resolve the remaining collisions.

### **Article 11**

As the bands below 5900 kHz are shared with other services, use of any frequency in these bands is subject to approval by the administration on whose territory the transmitting site is located. This is to ensure there are no interference problems between the different services. If international recognition and protection of the frequency is required, the details of the transmission can be registered with the ITU using the procedures given in Article 11. This is normally done by the administration unless they have authorised the FMO to act on their behalf.

### **4.3.5 Reception**

Reception of an HF transmission is usually via a portable receiver with a built-in short whip antenna. Reception is therefore very dependent on the location of the receiver.

Usually, there are few problems if the receiver is being used in the open air, outside of a city or town that has a number of metal-framed buildings. Man-made noise levels are usually low enough to permit adequate reception of the wanted transmission intended for that reception area.

However, if used inside a building, it is sometimes impossible to receive the wanted transmission. This can be due to two principal reasons:-

- The noise level inside the room is high due to electrical appliances including fluorescent lighting;
- The building material attenuates the signal.

It is often the case that reception can be improved within a building by locating the receiver next to a window, preferably one that is facing the direction of the transmitting site, or by attaching an external antenna located outside the building to the receiver whip antenna.

The absorption of radio waves within buildings is referred to as building penetration loss. From experimental results, it has been shown to be an average of 11dB across the HF bands (see Recommendation ITU-R BS.705 [7]).

### **4.3.6 Planning software**

There are a number of software implementations of Recommendation ITU-R P.533 [12] available.

The ITU publishes a CD-ROM containing the results of all requirements submitted each season. This has a graphical interface that shows the coverage achieved by each requirement for each hour.

The software is available on subscription from the ITU website at the following URL:  
<http://www.itu.int/ITU-R/terrestrial/broadcast/hf/cd-rom/index.html>.

Several software tools are used by members of the coordination groups:

- HFWIN32 available free from the Institute for Telecommunication Sciences (ITS, USA);- <http://elbert.its.blrdoc.gov>
- FIELDPLOT available from Microdata (Estonia) for a small fee - [www.microdata.ee](http://www.microdata.ee);
- WPLOTF2000 available free (requires password) from Norbert Schall (Germany)- [www.nschall.de](http://www.nschall.de).

#### **4.4 Required S/N ratios for DRM reception**

To achieve a sufficiently high quality of service for a digital audio programme transmitted via DRM, a BER of about  $1 \times 10^{-4}$  is needed. In Annex 1 values of S/N ratios required to achieve this BER are given for typical propagation conditions on the relevant frequency bands. The values are taken from Recommendation ITU-R BS.1615 (2003) [4]. They were derived by tests with receiver equipment developed on the basis of the DRM specification published as TS 101 980 (V1.1.1) in September 2001 by the European Telecommunications Standards Institute (ETSI) [15]. These S/N values can be used to calculate the corresponding minimum usable field strengths.

Information on measurements of S/N values in real world situations can be found in [20][22][23] and [24].

#### **4.5 Minimum usable field strength values for planning**

##### **4.5.1 Procedure for estimation of the minimum usable field strength**

On the basis of these S/N values shown in Annex 1, the minimum usable field strength can be computed applying the procedure proposed in Rec. 1615 [4] and given in the following sections.

###### **4.5.1.1 Reference Receiver**

Receiving by receivers using built-in antenna, as defined in Recommendation ITU-R BS.703 - Characteristics of AM sound broadcasting reference receivers for planning purposes [9].

###### **4.5.1.2 Receiver sensitivity**

The Method of calculation of the minimum required field strength, also expressed as the receiver sensitivity, is explained in Table 4.6.

Table 4.6: Method of calculation of the minimum required field strength

		Double sideband (DSB) (AM)		Digital		
1	Required receiving quality	Audio frequency S/N: 26dB with 30% (-10.5dB) modulation (Rec. ITU R BS.703 [9])		BER = $1 \times 10^{-4}$		
2	C/N for required quality (dB)	26 + 10.5 = 36.5		x		
3	Receiver IF bandwidth (kHz)	8		10 (1dB higher receiver intrinsic noise than DSB)		
4	Receiver sensitivity for the above C/N (dB( $\mu$ V/m))	LF	66	Required in Rec. ITU-R BS.703 [9]	30.5 + x	(xdB above the receiver intrinsic noise)
		MF	60		24.5 + x	
		HF	40		4.5 + x	
5	Receiver intrinsic noise related to field strength, for the above sensitivity (dB( $\mu$ V/m))	LF	29.5	(36.5dB (C/N) below the sensitivity)	30.5	(1dB higher than DSB)
		MF	23.5		24.5	
		HF	3.5(*)		4.5	

(\*) This value, 3.5dB( $\mu$ V/m), is also indicated in Annex 4 to Rec. ITU-R BS.560 [16].

*NOTE 1* In the case of the digital receiver, the expression S/N should be used instead of C/N, which is used for the analogue DSB receiver.

*NOTE 2* Intrinsic noise of the reference DSB receiver can be calculated as 36.5dB below the sensitivity.

*NOTE 3* Intrinsic noise of the reference digital receiver is estimated about 1dB higher than DSB due to IF bandwidth difference. And the sensitivity of the reference digital receiver for xdB S/N is calculated as xdB above that.

*NOTE 4* The increase of antenna loss for any receiver that uses a small-sized built-in antenna directly increases the receiver intrinsic noise related to the field strength. This should be taken into account.

### 4.5.1.3 Other factors to be considered

The external noise level (increasing man-made noise) and the pulse nature of some of the external noise have to be considered. Recommendation ITU-R P.372 [10] deals with radio noise, including some information on impulsive noise. This provides some indication of the noise levels encountered by a digital system. The integrated effects of distant thunderstorms are also included and the statistical characteristics of the amplitude probability density function are modelled. The method of applying the information is given in Recommendation ITU-R P.372 [10].

### 4.5.2 Computation of minimum usable field strength

The relevant resulting values can be found in Tables 4.7 to 4.10.

For the LF and MF bands (Tables 4.7 to 4.9), only results for the DRM robustness mode A are included. If one of the other robustness modes is to be used in these bands, the corresponding field strength values can be computed with the help of S/N values for these modes given in Annex 1.

TABLE 4.7: Minimum usable field strength (dB(μV/m)) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode A with spectrum occupancy types 0 or 2 (4.5 or 9 kHz) dependent on modulation scheme and protection level for the LF frequency band (ground-wave propagation)

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type	
			A/0 (4.5 kHz)	A/2 (9 kHz)
16-QAM	0	0.5	39.3	39.1
	1	0.62	41.4	41.2
64-QAM	0	0.5	44.8	44.6
	1	0.6	46.3	45.8
	2	0.71	48.0	47.6
	3	0.78	49.7	49.2

Table 4.8: Minimum usable field strength (dB(μV/m)) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode A with different spectrum occupancy types dependent on protection level and modulation scheme for the MF frequency band (ground-wave propagation)

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type	
			A/0 (4.5 kHz) A/1 (5 kHz)	A/2 (9 kHz) A/3* (10 kHz)
16-QAM	0	0.5	33.3	33.1
	1	0.62	35.4	35.2
64-QAM	0	0.5	38.8	38.6
	1	0.6	40.3	39.8
	2	0.71	42.0	41.6
	3	0.78	43.7	43.2

\* A3 (10 kHz) is not applicable to GE75.

Table 4.9: Minimum usable field strength (dB(μV/m)) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode A with different spectrum occupancy types dependent on protection level and modulation scheme for the MF frequency band (ground-wave plus sky-wave propagation)

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type	
			A/0 (4.5 kHz) A/1 (5 kHz)	A/2 (9 kHz) A/3* (10 kHz)
16-QAM	0	0.5	34.3	33.9
	1	0.62	37.2	37.0
64-QAM	0	0.5	39.7	39.4
	1	0.6	41.1	40.8
	2	0.71	44.2	43.7
	3	0.78	47.4	46.5

\* A3 (10 kHz) is not applicable to GE75.

Table 4.10: Range of minimum usable field strengths (dB(μV/m)) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode B with spectrum occupancy types 1 or 3 (5 or 10 kHz) dependent on protection level and modulation scheme for the HF frequency band

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type	
			B/1 (5 kHz)	B/3 (10 kHz)
16-QAM	0	0.5	19.2 - 22.8	19.1 - 22.5
	1	0.62	22.5 - 25.6	22.2 - 25.3
64-QAM	0	0.5	25.1 - 28.3	24.6 - 27.8
	1	0.6	27.7 - 30.4	27.2 - 29.9

Table 4.10 shows the range for minimum usable field strength needed to achieve the BER target on HF channels using robustness mode B. This range arises from varying propagation channel conditions (see section 4.4 and Annex 1 for the values of S/N corresponding to the different channel models). Mode A is not applicable to HF transmission because of the lack of robustness in the OFDM parameters (length of the guard interval and frequency spacing of the subcarriers).

In contrast to the entries in Tables 4.7 to 4.9, results for protection level Nos. 2 and 3 in combination with 64-QAM are not included in Table 4.10 for HF bands, due to the occurrence of bit error floors even at higher S/N, which are caused by the weak error protection. Therefore these protection levels are not recommended for HF transmission on channels with strong time - and/or frequency-selective behaviour.

### 4.5.3 Feedback from field tests

Several measurement campaigns (see references [22][23][24] in section 7) have been carried out in order to evaluate the performance of the DRM system in the MF band and to verify the planning parameters specified in the relevant ITU Recommendations (see section 4.5 and Annex 1). Summary and main conclusions of these tests are also given in Annex 3.

The measurements indicate that the reception environment (Urban, Suburban or Rural) has a considerable influence on the requirements in terms of field strength.

For rural and suburban environments, results are provided by a DRM measurement campaign in Madrid and surrounding regions of central Spain (see reference [22] in section 7) in the MF band. Several DRM modes were tested and the results suggest minimum field strength values similar to those proposed by the ITU-R in Recommendation ITU-R BS.1615 for DRM mode A/64/16/0.6/S<sup>1</sup> and to slightly higher values for modes B/64/16/0.5/L and A/16/4/0.5/S.

***For actual planning, the network operator may therefore choose to add a small margin to the ITU figures for minimum field strength in the MF band.***

For urban environments, the main factor affecting the reception in the MF band is man-made noise. It should be noted that the man-made noise level might vary considerably from one city to another, depending on the density of urbanisation and the level of industrial activity. Measurements carried

<sup>1</sup> A/64/16/0.6/S means:

- DRM mode A
- Modulation used for the MSC channel: 64-QAM
- Modulation used for the SDC channel: 16-QAM
- Code rate 0.6
- Interleaver: Short



out in Mexico City (see references [20][23] in section 7 and section A3.2) showed that the median of the measured values was around 40dB higher than the ITU-R reference for the MF band. Other measurements made in Madrid have shown man-made noise levels 10dB higher than ITU-R reference levels.

***Reception environmental factors must therefore be taken into account for planning purposes.***

An example of how to plan for urban environments, taking into account the environmental factors mentioned above, can be found in the results of measurements carried out in the north-west part of Italy (see reference [24] in section 7).

Some specific factors that may affect DRM reception:

- Power lines, including those used for public transports (Tramway) in urban environments.
- Power line transmission systems
- Fluorescent tubes used in signs
- Ignition devices in vehicles
- Power plants,
- Bridges and tunnels.

It should be noted finally that the receiver performance may be a determining factor in defining the minimum field strength required for planning and the resulting reception quality. This performance depends on the following receiver characteristics:

- Sensitivity (including receiving antenna performance);
- Selectivity;
- Behaviour in overloading conditions.

## **4.6 RF Protection Ratios**

### **4.6.1 Relative Protection Ratios**

#### **4.6.1.1 Rationale**

The figures for protection ratio given in Rec. ITU-R BS 1615 [4] are relative values and not absolute values. The underlying objective is to find the absolute protection ratio at a particular receiver location. This is the relative (power) level of an unwanted signal that can be tolerated while maintaining a specified quality level (wanted to unwanted ratio) for a wanted signal. In the case of medium frequency AM signals, the target wanted-to-unwanted ratio - absolute protection ratio - at the audio output (AF) of the receiver is > 30dB (adopted by RRC 75 - Geneva).

It is generally assumed that the average sideband energy in any one analogue AM signal is much the same as in any other. Therefore, because everything scales in the same way, where the interfering signal is itself an AM signal, on the same (carrier) channel as the wanted signal, the RF wanted to unwanted ratio is the same as the AF ratio. The carrier power of the unwanted signal must be 30dB lower than the wanted signal at the receiver input. The receiver treats the wanted and unwanted signals in the same way.

Where there is a frequency offset between the wanted and unwanted signals, the situation is more complicated. Where the frequency offset is half of the channel bandwidth, (5 kHz in the case of HF for example), only half of the sideband power from the unwanted signal - one sideband only -

appears in the pass band of the receiver. This suggests that the receiver should be able to tolerate an unwanted signal that is approximately 3dB stronger and retain the same performance. The reasons that this is “approximate” are:

- That there will inevitably be some ‘out of band’ emissions from the unwanted transmitter - in the symmetrical (co-channel) case, these would be irrelevant, but now they effectively add separate components to the upper and lower sidebands as perceived by the receiver demodulator;
- The receiver IF and AF filtering is less than perfect and components falling outside the receiver passband (including the carrier of the interferer) will appear at the demodulator input.

The precise level depends upon the (unwanted) transmitter performance and the receiver filtering. The (interfering) transmitter spectrum mask should define an upper limit and the ITU specifies the characteristics of a receiver to be used for planning purposes.

If the frequency offset is greater than half the channel bandwidth, the amount of interference appearing at the receiver input depends on the performance of the ‘unwanted’ transmitter, but again, the spectrum mask determines the worst case.

In practice, other values for the AF wanted to unwanted ratio might be appropriate. For HF transmissions 17dB is used instead of 30dB. Also it might be known that the wanted audio signal is not as ‘loud’ as the unwanted one and so might need additional protection. In such cases, relative protection ratios are useful. This is a factor in dB that can be added to the required AF ratio to give the RF ratio. In the example cited above - HF AM interfering with HF AM with similar loudness - the relative protection ratio for the co-channel case is 0dB and for the 5 kHz offset it is -2.5dB. These figures are given in Table 4.9.

In the case of AM into AM relative protection ratios are rarely used because it can usually be assumed that any one AM signal has similar characteristics to any other and so there are few variables to consider. This cannot be said of a DRM signal interfering with another DRM signal or for a DRM signal interfering with an analogue signal. The various DRM modes (see section 2.3.1) typically define ‘robustness’; certain modes defend themselves better against high levels of noise and interference and so perform differently in the presence of the same level of interference. An analogue signal has most of its power in the single frequency carrier while the DRM signal has its power distributed evenly across the channel with no predominant centre frequency carrier component at all and so the effect of analogue on DRM is quite different from the effect of DRM on analogue.

#### 4.6.1.2 Examples

An interesting example of the application of relative protection ratio with different signals is the effect of (unwanted) DRM on (wanted) analogue transmissions. While the transition from analogue to digital takes place, this situation will arise as analogue transmitters are converted to digital. From the point of view of an analogue receiver, the DRM signal will seem like random noise. Clearly, the intrusive effect of the digital signal will depend on the loudness, or modulation depth, of the analogue signal; the louder the analogue, the greater the level of DRM interference that can be tolerated. Annex A2 tabulates values for relative protection ratio in Table A2.2. These values assume the modulation depth of the analogue signal to be 53% rms - see Annex 4 for the definition of the rms Modulation Depth. In practice, this is much louder than any real AM transmission [17] [18] and so a correction will typically be needed to account for this.

As an example of the use of Table A2.2, consider a typical HF DRM signal using mode B3 interfering with a speech based analogue signal on the same channel (co-channel situation). Three factors are involved:

- The wanted AF signal to interference ratio for such an analogue transmission is 17dB - the Figure adopted for HFBC planning by WARC HFBC-87 for AM interfered with by AM.
- The relative protection ratio necessary to defend against a DRM signal with mode B3 is 6dB. This comes from Table A2.2 and must be added to the AF protection ratio. It recognises that a DRM signal distributes its power evenly across the channel while an AM signal concentrates most of its power in the carrier leaving relatively little in the information carrying sidebands.
- The modulation adjustment. The relative protection ratios in Table A2.3 are tabulated for a wanted AM signal with an rms modulation depth of 53%. A further factor must therefore be added to account for the difference between this nominal value and the actual value of rms modulation depth for the signal it is required to protect. Work carried out by the BBC in 2006 [18] suggests that AM transmissions, using modern transmission processors (compressor / limiters) exhibit modulation depths between 20% rms and 40% rms depending on programme genre. A typical speech based transmission will have a modulation depth of about 22% rms; 6dB lower than the 53% proposed in Table A2.2.

Taking all these factors together, the absolute protection ratio necessary for this, speech based, transmission will be

$$PR = 17\text{dB (AF protection ratio)} + 6\text{dB (relative protection ratio)} + 6\text{dB (modulation adjustment)}$$

$$\text{i.e. } PR = 29\text{dB}$$

Where the DRM replaces an existing analogue transmission the power of which is known not to exceed the required protection ratio for AM into AM, the sum of the relative protection ratio (6dB) and the modulation adjustment (6dB) gives the power 'back off' (12dB) necessary to ensure that the DRM transmitter causes no greater interference than the analogue signal that is being replaced. The total rms power of the DRM transmitter must be 12dB lower than the carrier power of the analogue transmission being replaced. Table 4.20 gives figures for power back off. These are identical to the relative protection ratios because no account is taken of modulation depth adjustment in the Table.

As another example of the use of Table A2.3, consider a typical MF DRM signal using mode A2, interfering with a pop music based analogue signal on the adjacent channel.

The required AF protection ratio (for MF) is 30dB. The relative protection ratio (from Table A2.3) is -29.8dB and the modulation correction (assuming the pop music to be modulation the transmitter to 40% rms) is 2.4dB. This gives a value of:

$$PR = 30 \text{ (AF protection ratio)} - 29.8\text{dB (relative protection ratio)} + 2.4\text{dB (modulation adjustment)}$$

$$\text{i.e. } PR = 2.6\text{dB}$$

Because the only part of the DRM transmission that affects the analogue is the 'out of band / spurious' elements, which are relatively small, the wanted signal can tolerate a high level of interference.

#### 4.6.2 Values of relative protection ratios

The values of protection ratios given in the following sections, extracted from ITU-R BS 1615 [4], are provisional according to the Radiocommunication Assembly 2003. They should be reviewed at a future World Radiocommunication Conference.

The combinations of spectrum occupancy types and robustness modes lead to several transmitter RF spectra, which cause different interference and therefore require different RF protection ratios. The applied calculation method is described in detail in ITU-R BS 1615 [4]. The differences in

protection ratios for the different DRM robustness modes are quite small. Therefore, the RF protection ratios presented in the following Tables are restricted to the robustness mode B. More calculation results are presented in ITU-R BS 1615 [4].

Table 4.11 shows calculation results for AM interfered with by digital and Table 4.12, digital interfered with by AM. These values are calculated for AM signals with high compression. The RF protection ratios for digital interfered with by digital are given in Table 4.13. Correction values for DRM reception using different modulation schemes and protection levels are given in Table 4.14.

The values in Tables 4.11 to 4.13 represent relative RF protection ratios,  $ARF_{relative}$ . For the pure AM case, the relative protection ratio is the difference in dB between the protection ratio when the carriers of the wanted and unwanted transmitters have a frequency difference of  $D_f$  Hz and the protection ratio when the carriers of these transmitters have the same frequency (Recommendation ITU R BS.560 [16]), i.e. the co-channel RF protection ratio, ARF, which corresponds to the audio frequency (AF) protection ratio, AAF. In the case of a digital signal, its nominal frequency instead of the carrier frequency is the relevant value for the determination of the frequency difference. For spectrum occupancy types 2 and 3 the nominal frequency corresponds to the centre frequency of the OFDM block, for the types 0 and 1 the centre frequency is shifted about 2.2 and 2.4 kHz, respectively, above the nominal frequency. Due to the fact that the spectrum of the interference signal is different from the AF spectrum of analogue AM, the values for relative RF protection ratio in the case of co channel interference are not equal to zero.

To adjust Table 4.11 to a given AM planning scenario, the relevant AF protection ratio has to be added to the values in the Table to get the required RF protection ratio (See ITU-R BS 1615 [4]). Relevant values may be determined taking into account:

- for HF, the AF protection ratio of 17dB, which was adopted for HFBC planning by WARC HFBC-87 for AM interfered with by AM;
- for LF/MF, the AF protection of 30dB, which was adopted by the Regional Administrative LF/MF Broadcasting Conference for Regions 1 and 3 (Geneva, 1975) for AM interfered with by AM.

With DRM as the wanted signal, the AF protection ratio as a parameter for the quality of service has to be replaced by the S/I required to achieve a certain BER. A BER threshold of  $1 \cdot 10^{-4}$  is supposed for the calculations (see ITU-R BS 1615 [4]). The protection ratio values in Tables 4.12 and 4.13 are based on 64-QAM modulation and protection level No. 1. For other combinations the correction values in Table 4.14 have to be added to the S/I values given in the Tables.

Table 4.11: Relative RF protection ratios between broadcasting systems below 30 MHz (dB)  
AM interfered with by digital

Wanted signal	Unwanted signal	Frequency separation, $f_{\text{unwanted}} - f_{\text{wanted}}$ (kHz)												Parameters		
		-20	-18	-15	-10	-9	-5	0	5	9	10	15	18	20	$B_{\text{DRM}}$ (kHz)	AAF <sup>(1),(2)</sup> (dB)
AM	DRM_B0 <sup>(3)</sup>	-50.4	-50.4	-49	-35.5	-28.4	6.4	6.6	-30.9	-46.7	-48.2	-50.4	-50.4	-50.4	4.5	-
AM	DRM_B1 <sup>(4)</sup>	-51	-50.5	-47.6	-32	-23.8	6	6	-31.1	45.7	47.4	-51	-51	-51	5	-
AM	DRM_B2	-48.8	-46.9	-43.5	-34.4	-29.7	3.4	6.5	3.4	-29.7	-34.4	-43.5	-46.9	-48.8	9	-
AM	DRM_B3	-47.2	-45.3	-41.9	-32	-25.9	3	6	3	-25.9	-32	-41.9	-45.3	-47.2	10	-

$B_{\text{DRM}}$ : nominal bandwidth of DRM signal  
DRM\_B0: DRM signal, robustness mode B, spectrum occupancy type 0

- (1) The RF protection ratio for AM interfered with by digital can be calculated by adding a suitable value for the AF protection ratio according to a given planning scenario to the values in the Table.
- (2) The values presented in this Table refer to the specific case of high AM compression. For consistency with Table 4.12, the same modulation depth, namely that associated with high compression, has been assumed for the AM signal. In order to offer adequate protection to AM signals with normal levels of compression (as defined in ITU-R BS 1615 [4]), each value in the Table should be increased to accommodate the difference between normal and high compression.
- (3) The centre frequency of DRM\_B0 transmission is shifted about 2.2 kHz above the nominal frequency.
- (4) The centre frequency of DRM\_B1 transmission is shifted about 2.4 kHz above the nominal frequency.

Table 4.12: Relative RF protection ratios between broadcasting systems below 30 MHz (dB)  
Digital (64-QAM, protection level No. 1) interfered with by AM

Wanted signal	Unwanted signal	Frequency separation, $f_{\text{unwanted}} - f_{\text{wanted}}$ (kHz)													Parameters	
		-20	-18	-15	-10	-9	-5	0	5	9	10	15	18	20	$B_{\text{DRM}}$ (kHz)	S/I (dB)
DRM_B0 <sub>(1)</sub>	AM	-57.7	-55.5	-52.2	-46.1	-45	-36.2	0	-3.5	-30.9	-41.1	-46.9	-50.6	-53	4.5	4.6
DRM_B1 <sub>(2)</sub>	AM	-57.4	-55.2	-51.9	-45.9	-44.7	-36	0	-0.2	-22	-37.6	-46	-49.6	-52	5	4.6
DRM_B2	AM	-54.6	-52.4	-48.8	-42.8	-33.7	-6.4	0	-6.4	-33.7	-42.8	-48.8	-52.4	-54.6	9	7.3
DRM_B3	AM	-53.9	-51.5	-48	-39.9	-25	-3.1	0	-3.1	-25	-39.9	-48	-51.5	-53.9	10	7.3

S/I: signal to interference ratio for a BER of  $1 \cdot 10^{-4}$

(1) The centre frequency of DRM\_B0 transmission is shifted about 2.2 kHz above the nominal frequency.

(2) The centre frequency of DRM\_B1 transmission is shifted about 2.4 kHz above the nominal frequency.

Table 4.13: Relative RF protection ratios between broadcasting systems below 30 MHz (dB)  
 Digital (64-QAM, protection level No. 1) interfered with by digital

Wanted signal	Unwanted signal	Frequency separation, $f_{\text{unwanted}} - f_{\text{wanted}}$ (kHz)												Parameters		
		-20	-18	-15	-10	-9	-5	0	5	9	10	15	18	20	$B_{\text{DRM}}$ (kHz)	S/I (dB)
DRM_B0	DRM_B0	-60	-59.9	-60	-55.2	-53.2	-40.8	0	-40.8	-53.2	-55.2	-60	-59.9	-60	4.5	16.2
DRM_B0	DRM_B1	-60.1	-60	-59.5	-52.5	-50.4	-37.4	0	-40	-51.6	-53.6	-59.8	-60	-60.1	5	15.7
DRM_B0	DRM_B2	-57.4	-55.7	-52.9	-46.7	-45.1	-36.6	0	-0.8	-35.6	-38.4	-47.7	-51.5	-53.6	9	13.2
DRM_B0	DRM_B3	-55.2	-53.6	-50.7	-44.5	-42.9	-33.1	0	-0.1	-13.6	-36.2	-45.5	-49.3	-51.4	10	12.6
DRM_B1	DRM_B0	-59.4	-59.5	-59.5	-55	-53	-40.8	0	-37.9	-51.7	-53.9	-59.4	-59.5	-59.4	4.5	16.2
DRM_B1	DRM_B1	-60	-60	-59.5	-52.8	-50.8	-37.8	0	-37.8	-50.8	-52.8	-59.5	-60	-60	5	16.2
DRM_B1	DRM_B2	-57.1	-55.4	-52.6	-46.4	-44.9	-36.4	0	-0.1	-13.7	-36.8	-46.6	-50.5	-52.7	9	13.2
DRM_B1	DRM_B3	-55.5	-53.8	-51	-44.8	-43.3	-33.5	0	-0.1	-8.1	-35.2	-45	-48.9	-51.1	10	13.2
DRM_B2	DRM_B0	-57	-56.8	-54.8	-43.4	-39.1	-0.7	0	-40.6	-52.2	-53.9	-57	-57	-57	4.5	15.9
DRM_B2	DRM_B1	-56.9	-56.1	-52.7	-40.2	-14.1	-0.1	0	-39.7	-50.8	-52.5	-56.9	-57	-57	5	15.4
DRM_B2	DRM_B2	-55.1	-53.1	-49.5	-40.7	-38.1	-3.7	0	-3.7	-38.1	-40.7	-49.5	-53.1	-55.1	9	15.9
DRM_B2	DRM_B3	-52.9	-51	-47.4	-38.6	-16.6	-3.2	0	-3.2	-16.6	-38.6	-47.4	-51	-52.9	10	15.4
DRM_B3	DRM_B0	-56.4	-56.2	-53.8	-41.1	-14.1	-0.1	0	-37.7	-50.9	-52.8	-56.4	-56.4	-56.4	4.5	15.9
DRM_B3	DRM_B1	-56.8	-55.7	-52.1	-38.2	-8.2	-0.1	0	-37.6	-50.1	-51.9	-56.7	-57	-57	5	15.9
DRM_B3	DRM_B2	-54.3	-52.3	-48.6	-39.3	-16.7	-3.1	0	-3.1	-16.7	-39.3	-48.6	-52.3	-54.3	9	15.9
DRM_B3	DRM_B3	-52.7	-50.7	-47	-37.7	-11.1	-3.1	0	-3.1	-11.1	-37.7	-47	-50.7	-52.7	10	15.9





Table 4.14: S/I correction values in Tables 4.12 and 4.13 to be used for other combinations of modulation scheme and protection level No.

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type	
			B/0 (4.5 kHz) B/1 (5 kHz)	B/2 (9 kHz) B/3 (10 kHz)
16-QAM	0	0.5	-6.7	-6.6
	1	0.62	-4.7	-4.6
64-QAM	0	0.5	-1.3	-1.2
	1	0.6	0.0	0.0
	2	0.71	1.7	1.8
	3	0.78	3.3	3.4

### 4.6.3 RF protection ratios used for HF coordination

For the purpose of HF coordination, Resolution 543 (WRC03) [6] provides Provisional RF protection ratio values for analogue and digitally modulated emissions in the HF broadcasting service. Most of the content of the following sections is taken from this Resolution.

#### 4.6.3.1 Standard values

RF protection ratio values to be used for seasonal planning under the provisions of Article 12 are contained in Table 4.15.

The values are consistent with those in Recommendation ITU R BS.1615 [4].

The characteristics of the digital emission are based on the 64-QAM modulation system, protection level No. 1, robustness mode B, spectrum occupancy type 3 (as contained in Recommendation ITU-R BS.1514 [5]), which will be used extensively for HF sky-wave broadcasting in 10 kHz channels.

The characteristics of the analogue emission are based on double-sideband modulation as summarized in Part A of Appendix 11 of the Radio regulations [19], with 53% modulation depth.

Table 4.15: Relative RF protection ratios (dB) associated with digitally modulated emissions in the HF bands allocated to the broadcasting service

Wanted signal	Unwanted signal	Frequency separation $f_{\text{unwanted}} - f_{\text{wanted}}$ ( kHz)								
		-20	-15	-10	-5	0	5	10	15	20
AM	Digital	-47	-42	-32	3	6	3	-32	-42	-47
Digital	AM	-54	-48	-40	-3	0	-3	-40	-48	-54
Digital	Digital	-53	-47	-38	-3	0	-3	-38	-47	-53

In the case of an amplitude modulation (AM) signal interfered with by a digital signal, the protection ratios are determined by adding 17dB (audio-frequency protection ratio) to the relative RF protection ratios in Table 4.15.

In the case of a digital signal interfered with by an AM signal, the protection ratios are determined by adding 7dB (signal-to-interference ratio for a bit error ratio (BER) of  $10^{-4}$ ) to the relative RF protection ratios in Table 4.15.

In the case of a digital signal interfered with by a digital signal, the protection ratios are determined by adding 16dB (signal-to-interference ratio for a BER of  $10^{-4}$ ) to the RF relative protection ratios in Table 4.15.

### 4.6.3.2 Correction for AM modulation depth

RF protection ratios for a wanted AM signal interfered with by a digital signal depend on the AM modulation depth. A modulation depth of 53% is used as a default value in this text. If a different modulation depth is used, a correction value for RF protection ratio is required. Table 4.16 provides correction values for typical modulation depths.

Table 4.16: Correction values (dB) to be used for other AM modulation depths in respect of wanted AM signal

Modulation depth (%)	20	25	30	38	53	M
Correction value (dB)	8.5	6.5	5	3	0	$20 \log (53/m)$

Measurements made by one organization in 2006 indicate that modulation depths for real AM transmitters lie in the range 20% (rms) for speech and 35% (rms) for speech and 35% (rms) for Pop music from the 1960s [18]. These measurements were made using modern transmission processors, typical of those used by AM broadcasters.

### 4.6.3.3 Correction for AM Audio quality

RF protection ratios for a wanted AM signal interfered with by a digital signal depend on the required audio quality grade. If another quality grade is used, correction values of RF protection ratios as in Table 4.17 shall be added.

Table 4.17: Correction values (dB) to be used for other audio quality grades in respect of wanted AM signal

Audio quality grade	3	3.5	4
Correction value (dB)	0	7	12

### 4.6.3.4 Correction for Digital modulation scheme, protection level number and robustness mode

RF protection ratios for a wanted digital signal interfered with by an analogue or digital signal depend on the digital modulation scheme and mode. If any combination different from the default value in section 4.6.3.1 is used, correction values of RF protection ratios as in Table 4.18 shall be added.

Table 4.18: Correction values (dB) to be used for other combinations of digital modulation scheme, protection level number and robustness mode in respect of wanted digital signal

Modulation scheme	Protection level number	Robustness mode		
		B	C	D
16-QAM	0	-7	-6	-6
	1	-5	-4	-4
64-QAM	0	-1	-1	0
	1	0	0	1

NOTE 10 kHz nominal bandwidth. Protection levels Nos. 2 and 3 and robustness mode A are not recommended for use in HF and are therefore not described here.

#### 4.6.4 RF power reduction for DRM

For the introduction of a digitally modulated signal in an existing environment, it has to be ensured that this new signal will not cause more interference to other AM stations than the AM signal which is replaced by the digitally modulated signal. Values for the required power reduction to fulfill this requirement can easily be found when the RF protection ratios for AM interfered with by AM and AM interfered with by digital are known.

The RF protection ratio is the required power difference between the wanted and the unwanted signal that ensures a stated quality (either analogue audio or digital S/N). When the wanted audio quality for AM interfered with by AM is comparable to AM interfered with by digital, the difference in RF protection ratio is the required power reduction.

Recommendation ITU-R BS.560 [16] contains relative RF protection ratios for AM interfered with by AM (see Table 4.19).

Table 4.19: Relative RF protection ratios for AM interfered with by AM

Wanted signal	Unwanted signal	Frequency separation $f_{\text{unwanted}} - f_{\text{wanted}}$ ( kHz)												
		-20	-18	-15	-10	-9	-5	0	5	9	10	15	18	20
AM	AM	55.4	53.3	49.5	35.5	29.0	-2.5	0.0	-2.5	29.0	35.5	49.5	53.3	55.4

With that knowledge, the required power reduction for the different DRM modes can be calculated as the difference in the values of Table 4.11 and of Table 4.19. The result is given in Table 4.20.

Table 4.20: Required power reduction

Replac ed signal	New signal	Frequency separation $f_{\text{unwanted}} - f_{\text{wanted}}$ ( kHz)													Parameter	
		-20	-18	-15	-10	-9	-5	0	5	9	10	15	18	20	$B_{\text{DRM}}$ (kHz)	$A_{\text{AF}}$ (dB)
AM	DRM_B0	5	2.9	0.5	0	0.6	8.9	6.6	28.4	17.7	12.7	0.9	2.9	5	4.5	-
AM	DRM_B1	4.4	2.8	1.9	3.5	5.2	8.5	6	28.6	16.7	11.9	1.5	2.3	4.4	5	-
AM	DRM_B2	6.6	6.4	6	1.1	0.7	5.9	6.5	5.9	0.7	1.1	6	6.4	6.6	9	-
AM	DRM_B3	8.2	8	7.6	3.5	3.1	5.5	6	5.5	3.1	3.5	7.6	8	8.2	10	-

In Table 4.20 it can be seen that for some modes the required power reduction necessary to restrict the interference to AM transmissions at certain frequency separations is somewhat higher than the co channel value.

In these cases it has to be determined if the digitally modulated signal appears somewhere as an interferer with one of these frequency separations and if it is the strongest interferer. If this is proved to be the case, the higher value has to be taken into account.

Rec. ITU-R BS 1615 [4] gives more details about the method of calculation of RF protection ratios, including the method of measurement and determination of these protection ratios.

### 4.7 The specific case of the 26 MHz band

The 25670 - 26100 kHz frequency band (herein called the 26 MHz band) is exclusively allocated to the broadcasting service in the ITU Radio Regulations. This band comes under the provisions of RR Article 12, which includes an informal coordination procedure. This band is not heavily used for transmissions with analogue modulation for the following reasons:

- The sparse availability of suitable receivers capable of receiving this band;
- The periods of propagation that support reliable long distance transmission may be limited (sunspot cycle, seasonal, diurnal);

Recent experimental broadcasting using DRM in the 26 MHz band has provided local coverage similar to that achieved in Band II (VHF FM). In this context the signals require RF bandwidths of 10 kHz for parametric stereo, and 20 kHz for full stereo;

Use of the 26 MHz band for local coverage requires low power transmitters and directional down-tilted antennas (for sky-wave suppression). Typical coverage areas are within a 15-20 km radius. The transmitting antenna height is expected to be a crucial factor.

Transmit antennas have been designed that support local coverage. Nevertheless, there is concern that unwanted sky-wave emissions may cause harmful interference to other stations on the same frequency using the 26 MHz band for local coverage;

Four issues should be considered with regard to the use of the 26 MHz band for local coverage:

1. Selection of suitable technical parameters is required among the large number of possible combinations of the DRM system parameters.
2. Antennas: Appropriate antenna radiation characteristics are needed to avoid long-distance harmful interference to other stations.
3. Propagation: Suitable prediction methods are needed to calculate the relevant coverage distances.
4. Regulations: Appropriate rules for coordination are required in order to provide a reliable local service for each station, taking into account the possibility of harmful interference caused by distant stations.

These issues will be subject to further developments in future releases of the present document. It is nonetheless useful to note here the main characteristics and outcome of two trials, conducted in Mexico and Brasilia in 2005 and 2006, respectively [20][26].

### ***In Mexico:***

One transmitter was used to determine audio reliability as a function of S/N and field strength, with the following characteristics:

Site altitude: 2560 m (300 m over the average altitude of the City).  
 Antenna height: 40 m above ground level.  
 Frequency: 25.620 MHz  
 Output Power: 200 W rms  
 Antenna: 3 element Yagi-Uda  
 Antenna Gain: 7dBi

Three system variants were tested, all having 18 kHz bandwidth<sup>1</sup>:

1. DRM Mode A, 64-QAM, code-rate 0.6 offering a data rate of 48.64 kbit/s
2. DRM mode B, 64-QAM, code-rate 0.6 offering a data rate of 38.18 kbit/s
3. 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.

It requires a minimum SNR of 18dB<sup>2</sup> and minimum field strength of 37dB ( $\mu\text{V}/\text{m}$ ). This value is higher than the ITU reference Figure of minimum field strength (which should be in the range 21.7dB ( $\mu\text{V}/\text{m}$ ) - 25.1dB ( $\mu\text{V}/\text{m}$ ), see foot note), this increase was probably required in order to overcome several sources of noise and interference that affect the reception in urban environment (Voltage transformation plants, traffic, interference sources from other transmission facilities and in some cases signal dropouts caused by Aircraft).

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<sup>1</sup> 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 along with the 10 kHz channelling to be used in the 26 MHz broadcasting band.

<sup>2</sup> According to Recommendation ITU-R. BS 1615 [4], the S/N figure required for mode B with spectrum occupancy 3 (10 kHz), 16-QAM modulation and 0.5dB average code rate is in the range 14.6 - 18.0dB depending on the channel model. Theoretically, the S/N figure for 18 kHz bandwidth should also be in the same range. On the other hand, according to [4], the corresponding minimum usable field strength with 10 kHz bandwidth in the HF band is in the range 19.1 - 22.5dB ( $\mu\text{V}/\text{m}$ ). For 18 kHz bandwidth, the minimum usable field strength should be 2.6dB higher, which gives a range of 21.7 - 25.1dB ( $\mu\text{V}/\text{m}$ ).

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

**In Brasilia:**

Similar tests were carried out, using another antenna type: a TCI Unbalanced Dipole.

Again, the recommended system variant was (Mode B, 16-QAM, CR 0.5)

The results showed a better performance of this Mode in Brasilia, with a SNR threshold of 12 - 13dB instead of 18dB in Mexico. The estimated power required to cover the whole city of Brasilia is 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 relevant ITU recommendation (ITU-R P.372 [10]) are valid in a “quiet” environment such as Brasilia.

**4.8 Example of SFN use in Broadcasting below 30 MHz**

Deutsche Welle conducted tests in the summers of 2005 and 2006 with a two-transmitter SFN in the HF band. One transmitter was located in Germany and the second in Portugal. The tests were conducted daily from 0700 - 0900 UTC at a frequency of 7265 kHz [21].

**4.8.1 System Setup**

Transmitter details and the predicted SFN service area are shown in Figure 4.3.

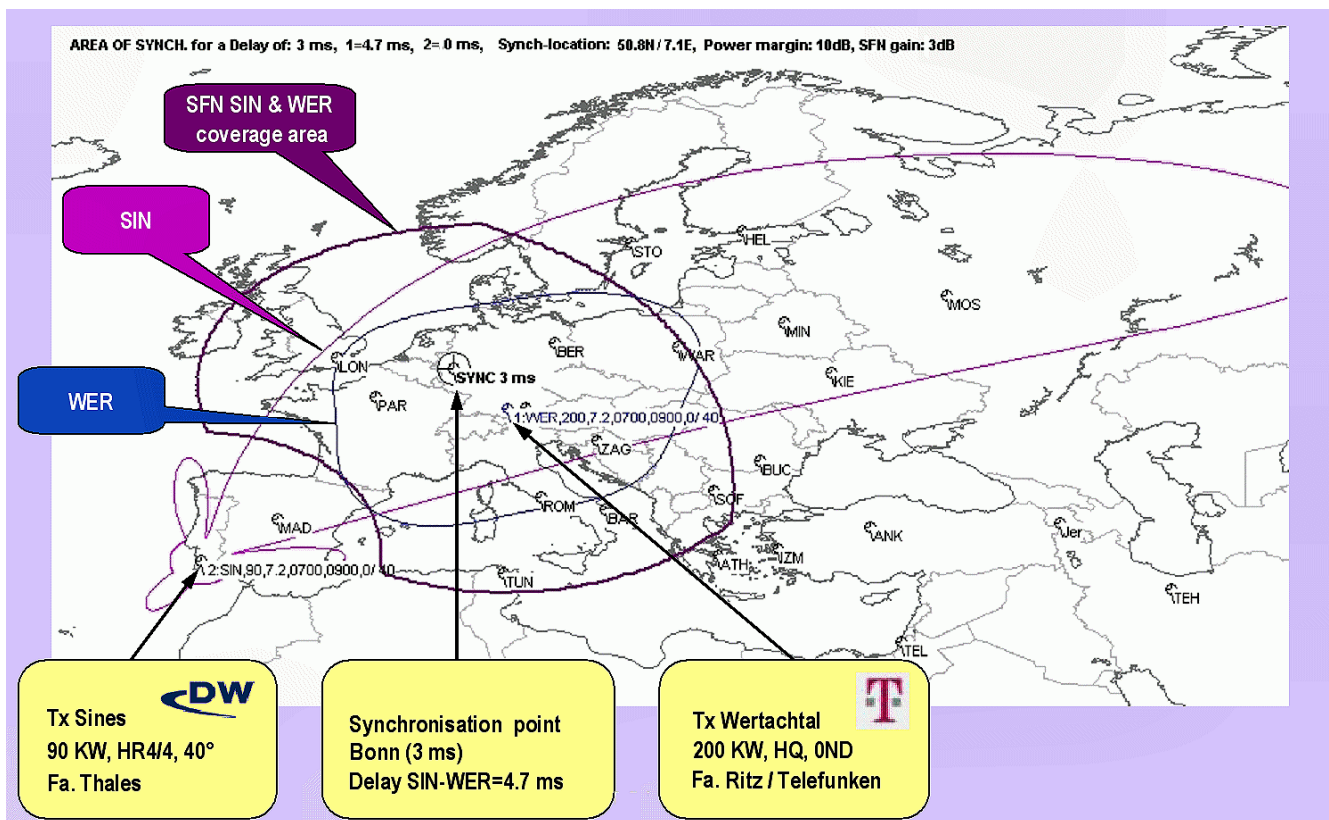


Figure 4.3: Transmitter details and predicted SFN service area

The SFN coverage area is determined by the guard interval of 5.3 ms (Mode B). The spread delay is of the order of 2.3 ms. The synchronisation point was set at Bonn. Therefore the value of 3 ms was selected as the maximum delay between the two transmitters in order not to exceed the guard interval of 5.3 ms. The Wertachtal signal had to be delayed by 4.7 ms to compensate the delay due to the different distances of the two stations from Bonn.

A further issue concerned propagation conditions experienced during sunrise:

- Propagation from Sines in Portugal degraded due to an increasing attenuation of the signal
- Propagation from Wertachtal in Germany improved due to a decreasing skip distance.

In short: Sines degraded but Wertachtal improved during the test period.

The DRM multiplex was generated at Deutsche Welle in Bonn and sent via satellite as an IP data channel. It was important to ensure that the DRM streams transmitted by Sines and Wertachtal were identical and synchronised. GPS was used to synchronise all equipment, as shown in Figure 4.4.

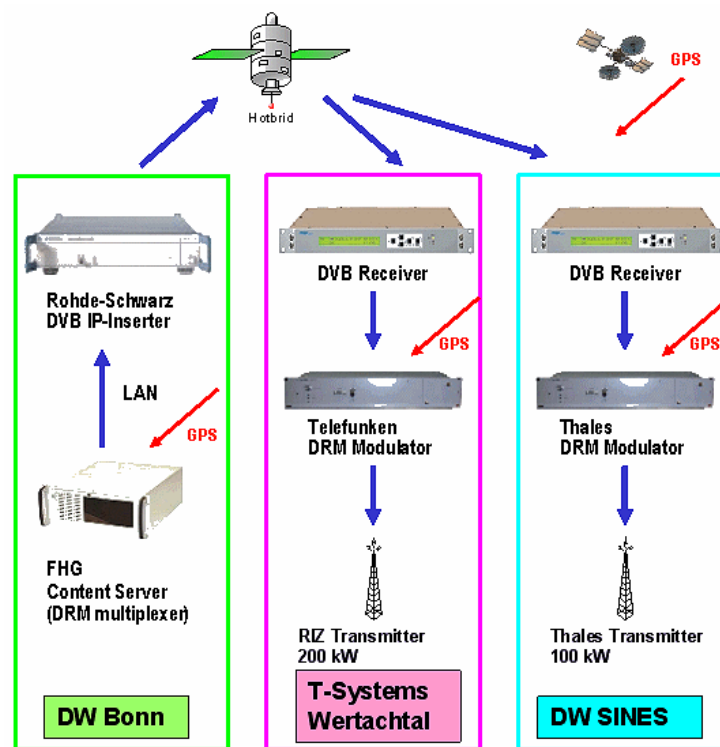


Figure 4.4 DRM Multiplex coding and contribution

Twenty-five stations within the Deutsche Welle DRM monitoring network (DRMMon, see Figure 4.5) were used to receive and evaluate the SFN transmissions. The usual purpose of the DRMMon network is to determine the coverage and availability of Deutsche Welle and other DRM services and each station can monitor a radius of about 150 km. The primary measurement value was that of availability, the ratio of the duration of correct reception to the total duration of the test period.



Figure 4.5: Monitoring Network

### 4.8.2 Stand-alone versus SFN transmitter operation

The initial tests were run from July to October 2005. As well as contributing to the SFN, the transmitters were individually measured on different weekdays. Table 4.21 shows the change in reliability between the individual operation of the transmitters and their operation in SFN.

Table 4.21: Reliability between individual operation and SFN

Transmitting Stations	Weekdays of Operation	>99.8% Reliability obtained at
SIN only	Tue, Sat	13 Monitoring Stations
WER only	Thu, Sun	7 Monitoring Stations
SIN & WER in SFN	Mon, Wed, Fri	16 Monitoring Stations

The monitored results matched the prediction. The two transmitters effectively filled each other’s gap. The Sines transmitter had the greater impact, especially at 0700 - 0800 UTC. Differences between time slots are compensated by interplay of both transmitters. Signal availability improved significantly at three sites to a level that would not have been obtained individually.

A disadvantage of a SFN is that it can degrade otherwise good reception if the relative delay between the individual signals exceeds the guard interval. Successful interplay of medium and short distance transmitter operation on one frequency was nevertheless demonstrated.

### 4.8.3 Long-term test

The goal of the second stage of the SFN test in Summer 2006 was to obtain wide area coverage providing constantly high availability over the whole season. An analysis of the results showed very good coverage throughout the year from April to October 2006.

Sites outside the synchronised area get poor reception, as expected; Bilbao is a good example of this. Prague and Vienna were also problem sites, as they are a bit too far from Sines and too close



to Wertachtal. However, Rome is a good example of the benefits of an SFN: It is not well covered by a single transmitter but served well by SFN operation.

Constantly high availability on all measurement days was reached. Seamless service (100% availability) is the required goal. For example, in October 2006 up to 20 sites reach more than 99% availability and most exceeded 99.9% availability. Rennes obtained 100% availability, whilst Bonn and Munich nearly achieved 100% availability on all but one day.

#### 4.8.4 Conclusion

SFN operation increases the availability in a well-defined service area and additionally it is spectrum efficient. SFN offers a constantly high availability for nearly all reception sites inside the synchronised area from April to October. The probability of achieving a seamless service is higher through the use of SFN than with stand-alone transmitter operation.

The DRM equipment of different manufactures interoperates, but SFN operation is more complicated and demanding. For example, if synchronisation, GPS, MDI routing or delay constant is lost, reception is damaged inside the whole target area.

## 5 International regulations

As explained in section 4, LF/MF in Regions 1 and 3 are governed by Regional Agreements, while HF has no plan but is planned under provisions of Article 12 of Radio Regulations, which relies on seasonal coordination.

### 5.1 The Planning Process: Assignment Planning for LF/MF

#### 5.1.1 Special study regarding the use of digital modulation in the LF and MF bands governed by the Regional Agreements GE75, RJ81 and RJ88

At its meeting in March 2002, Study Group 6 considered various issues related to digital modulation in the broadcasting bands below 30 MHz, including practical arrangements for the introduction of digital modulation in these bands, bearing in mind the current Regional Agreements. In this connection, Study Group 6 addressed a note to the Director, BR by which it requested the Director, BR, “ to initiate the special study referred to in No.13.15 of the Radio Regulations [19] with a view to evaluating the possibilities of introducing digital modulation in the bands governed by the Regional Agreements GE75 and RJ81, using the currently available texts of Study Group 6:

- Doc. 6/250 - draft revision of Recommendation ITU-R BS.1514 [5]
- Preliminary draft new Recommendation on planning parameters for digital broadcasting below 30 MHz

It is important to note that Study Group 6 said that it “*believes that appropriate consideration should be given to approach whereby the Agreements are complemented with suitable Rules of Procedure, which would permit digital modulation to be used in the LF and MF broadcast bands if so desired by any broadcaster.*”

Study Group 6 also indicated: “*If the mechanism of complementing the Regional Agreements with suitable Rules of Procedure proves to be difficult to implement, then other possibilities need to be considered, including the possibility of making the required adjustments to the relevant Agreements by way of regional conferences. One such conference would be required for Regions 1 and 3, and another one for Region 2. Such conferences would be of a short duration and could be associated with another WRC.*”

The BR has conducted the requested study in response to this request from Study Group 6 and the results of these studies, together with the draft Rules of Procedure, where appropriate, are communicated to administrations for comments, in accordance with No. 13.14 of the Radio Regulations [19].

### 5.1.2 Regulatory considerations

The use of the LF/MF bands by the broadcasting service is governed by the following Regional Agreements:

- Regional Agreement concerning the use by the broadcasting service of frequencies in the MF bands in Regions 1 and 3 and in the LF bands in Region 1, Geneva, 1975 (referred to hereafter as GE75);
- Regional Agreement for the MF broadcasting service in Region 2, Rio de Janeiro, 1981 (referred to hereafter as RJ81);
- Regional Agreement for the use of the band 1605 - 1705 kHz in Region 2, Rio de Janeiro, 1988 (referred to hereafter as RJ88).

These Agreements specify the technical criteria that are applicable with respect to each frequency band governed by the respective Agreement, as well as the relevant procedures for modifications to the concerned plans, associated with each of the respective Agreements. In addition, these Agreements specify provisions for the revision of the Agreements themselves.

The sections hereafter summarize the relevant regulatory provisions from each of the respective Agreements, with a particular emphasis on the provisions dealing with modulation techniques.

### 5.1.3 Regional Agreement GE75

Annex 2 to the GE75 Agreement contains “Technical Data used in the preparation of the Plan and to be used in the application of the Agreement”. Chapter 4 of this Annex specifies the broadcasting standards and Section 4.1 contains the following condition: “*The Plan is established for a system with double sideband amplitude modulation with full carrier (A3E).*”

Article 14 of the GE75 Agreement contains provision No. 2 which stipulates: “*The Agreement shall remain in force until it is revised by a competent conference of the Members of the Union in Regions 1 and 3.*”

The GE75 Conference adopted Resolution No. 8 Relating to the use of bandwidth saving modulation systems. With this Resolution, the GE75 Conference resolved as follows:

1. “*that broadcasting stations may provisionally use bandwidth saving modulation methods on condition that interference in the same or adjacent channels concerned does not exceed the interference resulting from the application of double sideband modulation with full carrier (A3E);*”
2. “*that any administration which envisages using these methods of emission shall seek the agreement of all affected administrations by following the procedure specified in Article 4 of the Agreement.*”

The frequency assignment plan annexed to the Regional Agreement GE75 (Annex 1 to the Agreement) contains the particulars of the frequency assignments entered into the Plan. The values related to the necessary bandwidth vary from 9 kHz to 20 kHz. The values related to the necessary bandwidth for DRM system A2 and B2 vary from 8.542 to 8.578 kHz. The values related to the necessary bandwidth for IBOC DSB system range from 20 kHz (all digital mode) to 29.4 kHz (hybrid mode).

In the opinion of the Radiocommunication Bureau, the above elements permit the provisional introduction of digital modulation (DRM A2 or B2) in the bands governed by the GE75 Agreement, without a formal revision of the Agreement as stipulated in Article 14 of the Agreement, provided that the conditions stipulated in Resolution 8 of the GE75 Conference are satisfied and the Plan modification procedure, as specified in Article 4 of the Agreement, is completed in a satisfactory manner. Consequently, the approach of complementing the Regional Agreement GE75 with a suitable Rule of Procedure could be considered. Based on the current ITU R texts, as detailed in § 3 of this study, the Radiocommunication Bureau concluded that the relevant conditions are achievable and has prepared the following:

- 1) A draft Rule of Procedure dealing with the notification, under Article 11 of the Radio Regulations, of the LF/MF assignments to the broadcasting services in the bands governed by the GE75 Agreement, which are related to digital modulation without undergoing the Plan modification procedure (see 5.1.3.2), and
- 2) A draft Rule of Procedure dealing with the treatment of the submissions for Plan modification procedure, under Article 4 of the GE75 Agreement, related to frequency assignments using digital modulation (see 5.1.3.3).

Both rules are independent but may be combined into a single rule. They are given in the following sections

**5.1.3.1 Technical considerations**

In Annex 2 of Recommendation ITU-R BS.1615 [4] the Table 5.1 (reproduced below) shows the bandwidth for DRM mode combinations.

ITU-R BS.1615 Table 5.1: Bandwidths for DRM mode combinations ( kHz)

Robustness mode	Spectrum occupancy type			
	0	1	2	3
A	4.208	4.708	8.542	9.542
B	4.266	4.828	8.578	9.703
C				9.477
D				9.536
Nominal Bandwidth( kHz)	4.5	5	9	10

For the GE75 planning area, the systems to be considered are systems A2 and B2 using 9 kHz nominal bandwidth and moderate robustness.

The RF protection ratios applicable to the protection of analogue transmissions from DRM transmissions shall be deduced from Table 5.2, an extract of which is given below:

ITU-R BS.1615 Table 5.2:  
RF protection ratios between broadcasting systems below 30 MHz (dB)  
AM interfered with by Digital

Wanted signal	Unwanted signal	Frequency separation $f_{unwanted}-f_{wanted}$ ( kHz)					Parameters	
		-18	-9	0	9	18	$B_{DRM}$ ( kHz)	$A_{AF}$ (dB)
AM	DRM_B2	-29.9	-12.7	23.5	-12.7	-29.9	9	17
AM	DRM_B2	-16.9	+0.3	+36.5	+0.3	-16.9	9	30

AM	AM	-23	0	30	0	-23		30
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*DRM\_B2: DRM signal, robustness mode B, spectrum occupancy type 2*

*B<sub>DRM</sub>: Nominal bandwidth of DRM signal*

*A<sub>AF</sub>: Audio frequency protection ratio<sup>1</sup>*

The values in the Table correspond to the protection ratio of 17dB adopted for HFBC planning. GE75 is based on a 30dB co-channel protection ratio. Thus, the required protection ratio for co-channel interference from DRM to AM is 36.5dB and the adjacent channel protection ratio is 0.3dB. It can be concluded that the interference from a transmitter using digital modulation (DRM) is less than the interference from an AM transmitter with a power greater than the DRM transmitter by 7dB. It should also be noted that there is no significant difference between different DRM modulation schemes using the same bandwidth.

### 5.1.3.2 Rule of Procedure related to Resolution N°8 of the GE75 Agreement

Resolution No. 8 of the Regional Conference, Geneva, 1975, states:

1. *“that broadcasting stations may provisionally use bandwidth saving modulation methods on condition that interference in the same or adjacent channels concerned does not exceed the interference resulting from the application of double sideband modulation with full carrier (A3E);*
2. *that any administration which envisages using these methods of emission shall seek the agreement of all affected administrations by following the procedure specified in Article 4 of the Agreement.”*

After consideration of the relevant ITU-R studies, the Board decided that any frequency assignment for AM broadcasting in the Plan may provisionally be used with digital modulation DRM A2 or B2, provided the radiation is reduced by at least 7dB in all directions, compared to the radiation of the AM modulated frequency assignment in the Plan.

Therefore, when examining the conformity to the GE75 Plan of a notice received under Article 11 of the Radio Regulations, the Bureau shall accept such a notice as being in conformity to the Plan. A note should indicate that the favourable finding is provisional.

### 5.1.3.3 Rule of Procedure related to Annex 2 to the GE 75 Agreement

Chapter 4 of Annex 2 to the GE 75 Agreement gives the broadcasting standards applicable to the Agreement. In particular:

4.1 *Class of Emission:* The Plan is established for a system with double sideband amplitude modulation with full carrier (A3E).

4.2 *Power:* The power of a transmitter is the carrier power in the absence of modulation.

4.3 *Radiated Power:* The radiated power is assumed to be the product of the nominal power of the transmitter and the gain of the antenna (relative to a short vertical antenna) without taking into account any losses. It is expressed either by the cymomotive force (c.m.f. in V or in dB relative to 300 V) or by the effective monopole radiated power (emrp in kW or in dB relative to 1 kW).

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<sup>1</sup> The value of 17 dB is used as an example to derive the RF protection ratios and should be substituted by other values as required. The difference to 17 dB has to be added to the respective table values.

4.4 *Protection Ratios*: In applying the Agreement, the values of the co-channel and adjacent channel protection ratios given below should be used unless otherwise agreed between the administrations concerned. In the case of fluctuating wanted or unwanted signals, the values of the protection ratio apply for at least 50% of the nights of the year at midnight.

However, Resolution No. 8 of the Regional Conference, Geneva, 1975, states:

1. *“that broadcasting stations may provisionally use bandwidth saving modulation methods on condition that interference in the same or adjacent channels concerned does not exceed the interference resulting from the application of double sideband modulation with full carrier (A3E);*
2. *that any administration which envisages using these methods of emission shall seek the agreement of all affected administrations by following the procedure specified in Article 4 of the Agreement.”*

After consideration of the relevant ITU-R studies, the Board decided that frequency assignments using digital modulation DRM A2 or B2 may provisionally be introduced into the Plan, in application of Article 4 of the Agreement.

The power of the transmitter to be notified in case of digital modulation shall be the total power within the necessary bandwidth.

In the examination of the probability of interference from notices related to assignments using digital modulation, the Bureau shall use a co-channel protection ratio increased by 7dB, and an adjacent channel protection ratio increased by 1dB compared to the one applicable to the interfered transmitter.

When the proposed assignment using digital modulation is recorded into the Plan following the application of Article 4, it shall bear a symbol indicating that the recording is provisional. The reference situation shall be determined as if it were an AM transmission using an audio-frequency modulating signal of 4.5 kHz and a high degree of compression.

#### **5.1.3.4 Decisions of the RRB - Dec. 2002**

The RRB (Radio Regulatory Board) approved the Rules of Procedure as proposed with the following amendments:

- Amend the fourth paragraph of the Rule relating to Resolution 8 (Annex 1 to CCRR/20) and the ninth paragraph of the Rule relating to Annex 2 (Annex 2 to CCRR/20) as follows: "After consideration of the relevant ITU-R studies, the Board decided that any frequency assignment for AM broadcasting in the Plan may provisionally be used with digital modulation (transmission types DRM\* A2 or B2), provided the radiation is reduced by at least 7dB in all directions, compared to the radiation of the AM modulated frequency assignment in the Plan".

\*The DRM system is described in Recommendation ITU-R BS-1514

- Add a new sentence at the end of each rule as follows: "This Rule of Procedure is of a provisional nature until such time that it is confirmed by a competent conference empowered to deal with the subject matter."
- The Board noted the comments and support from a number of administrations for the desirability of facilitating the introduction of digital modulation, while preserving the integrity of the Plan. The Board also considered comments from other administrations that suggested that issues dealt with in the Rules should be subject to consideration by a Conference.
- The Board concluded that, given the current schedule of conferences, such a consideration is not envisaged in the foreseeable future.

There is another system (IBOC) defined in ITU-R BS 1514 [5], but it is not usable in Regions 1 and 3 because the channel bandwidth is not suitable.

### 5.1.3.5 CEPT position regarding the introduction of DRM in the LF/MF

The CEPT (European Conference of Postal and Telecommunications Administrations, see [www.cept.org](http://www.cept.org)) has set up a working group to study the transition to digital sound broadcasting in the LF/MF bands. The group has already produced a draft report on the subject (see draft ECC report 117 on [www.ero.dk](http://www.ero.dk)). The final report is expected in February 2008. The following text is extracted from the executive summary of the draft report in its version available in November 2007:

*"All the necessary regulatory provisions, in particular the Rules of Procedure associated with the GE75 Agreement, are already in place to allow the deployment of DRM within the existing GE75 Plan and to allow a progressive analogue to digital transition for sound broadcasting in the LF and MF bands. Thanks to these Rules of Procedure, a significant number of DRM transmissions are currently 'on air' as advertised or experimental services. Therefore, no action is currently required in this area.*

*Further work will be needed, however to review the necessary technical parameters, such as minimum usable field strength and protection ratio, for which the current values are partly based on the results of theoretical studies.*

*Given the improvement in quality available with DRM, there will be pressure to introduce stereo and other potential enhancements, some of which will require a greater transmission bandwidth. The GE 75 Plan has some assignments with bandwidths wider than the standard 9 kHz channel and the DRM standard encompasses similarly wider bandwidth modes. There will be a need for suitable DRM planning parameters for the wider bandwidth modes.*

*In the longer term, as more and more transmissions migrate to 'digital', the matter of protecting analogue transmission will become less important and the planning environment may need to be reconsidered, based on the experience gained from practical implementation. It may then be possible to enhance the existing regulatory provisions in order to take advantage of wider bandwidth modes and improved planning parameters as they become available. This may also be the time to consider a new Planning Conference, but such a Conference is not needed in the foreseeable future.*

*All concerned broadcasters and Administrations within CEPT are encouraged to consider the transition from analogue to DRM digital transmissions in order to benefit from the improved quality of service which is already available."*

### 5.1.4 Regional Agreement RJ81

Section 4.2 of the RJ81 Agreement specifies the following conditions for the class of emission: *"The Plan is based upon double-sideband amplitude modulation with full carrier A3E. Classes of emission other than A3E, for instance to accommodate stereophonic systems, could also be used on condition that the energy level outside the necessary bandwidth does not exceed that normally expected in A3E emission and that the emission is receivable by receivers employing envelope detectors without increasing appreciably the level of distortion."*

Section 4.3 of the RJ81 Agreement specifies the following conditions on the bandwidth of emission: *"The Plan assumes a necessary bandwidth of 10 kHz, for which only a 5 kHz audio bandwidth can be obtained. While this might be appropriate value for some administrations, others have successfully employed wider bandwidth systems having occupied bandwidths of the order of 20 kHz without adverse effects."*

Article 12 of the RJ81 Agreement contains provision No. 12.2 which stipulates: “*The Agreement shall remain in force until it is revised by a competent administrative radio conference of Region 2.*”

The frequency assignment plan annexed to the Regional Agreement RJ81 (Annex 1 to the Agreement) contains the particulars of the frequency assignments entered into the Plan. The values related to the necessary bandwidth notified under Article 11 vary from 8 kHz to 20 kHz.

In the opinion of the Radiocommunication Bureau, the current regulatory provisions of the RJ81 Agreement are rather inflexible and do not permit the introduction of digital modulation in the bands governed by the RJ81 Agreement, without a formal revision of the Agreement as stipulated in Article 12 of the Agreement.

### **5.1.5 Regional Agreement RJ88**

Section 3.2 of the RJ88 Agreement specifies the following conditions for the class of emission: “*The Plan is based on double-sideband amplitude modulation with full carrier (A3E). Classes of emission other than A3E may also be used, (...), on condition that the energy level outside the necessary bandwidth does not exceed that normally expected in A3E emission.*”

Section 3.3 of the RJ88 Agreement specifies the following conditions on the bandwidth of emission: “*The Plan is based on a necessary bandwidth of 10 kHz, for which only 5 kHz audio bandwidth can be obtained. While this may be an appropriate value for some administrations, others may wish to employ wider bandwidth systems with necessary bandwidths of the order of 20 kHz. However, the protection ratios selected allow operation with 20 kHz occupied bandwidth without an appreciable increase in interference (...).*”

Article 14 of the RJ88 Agreement stipulates: “*The Agreement shall remain in force until revised by a competent administrative radio conference of Region 2.*”

The Master International Frequency Register contains particulars of frequency assignments that correspond to the allotments from the RJ88 Plan. The values related to the necessary bandwidth are 10 kHz for all frequency assignments notified up to now.

In the opinion of the Radiocommunication Bureau, the above elements would permit the introduction of digital modulation (DRM A3 or B3) in the bands governed by the RJ88 Agreement, without a formal revision of the Agreement as stipulated in Article 14 of the Agreement, provided that the conditions stipulated in No. 3.2 of Annex 2 to the RJ88 Agreement are satisfied.

## **5.2 Coordination for HF**

### **5.2.1 The HFBC Framework**

WARC-79 allocated additional HF spectrum to the broadcasting service on condition that this extra spectrum should be subject to a new planning system. Two HFBC World Administrative Radio Conferences were convened in 1984 and 1987 to agree a new planning system. Although the technical parameters and outline planning method were approved, the resulting test plans were unacceptable to administrations, as they could not accommodate all requirements.

Work then started on developing a new regulatory procedure to take account of the agreed technical criteria and the informal coordination process that had been shown to be successful in reducing mutual interference in the HF broadcasting bands. The result was Article 12, which was adopted by WRC-97 and came into force on 1st January 1999.

## 5.2.2 The Article 12 procedure

Article 12 has three sections. Section I is the introduction, which notes that the procedure is based on coordination between administrations. It also notes that administrations can authorise broadcasters to do this coordination where the broadcaster is the organisation responsible for the choice of frequency.

Section II defines the principles to be taken into account when following the procedure.

The procedure is described in Article 12 Section III (S12.15 to S12.45). A flowchart contained in Resolution 535 (WRC-97) provides the information needed for the application of Article 12. Broadcasters are required to submit their frequency requirements to the ITU-BR twice a year for two defined broadcasting seasons each year. The ITU-BR is then required to perform a compatibility analysis in accordance with the Rules of Procedure and publish the results.

Broadcasters are encouraged to coordinate their requirements with other organisations with a view to resolve or reduce as much as possible, incompatibilities identified by the compatibility analysis. The procedure encourages the formation of regional coordination groups to facilitate coordination. The coordination process is seen as a continuous process as broadcasters are urged to continue coordinating requirements by any means possible even after the broadcasting season has started. The ITU-BR can convene meetings of all the Coordination Groups, if necessary, to improve the process.

## 6 Conclusions

### 6.1 DRM is already operational

- DRM is the only worldwide fully specified system for digital sound broadcasting in frequencies from 150 kHz to 30 MHz. Future specifications would cover also VHF Bands I and II.
- DRM offers:
  - Improved Audio quality compared to AM for the same spectrum occupancy
  - Flexibility (trade-off between capacity and robustness);
  - Additional services (automatic or semi automatic tuning, the inclusion of supplementary (or even completely unrelated) data streams and conditional access);
  - Spectrum Efficiency (single frequency networks)
  - Economic benefits (reduced RF power compared to AM for the same coverage)

but, DRM requires:

- New investment in transmission facilities and delivery;
  - Attractive services to motivate people to go digital;
  - Attractive low price digital receivers;
  - Appropriate marketing to raise awareness.
- Transmission equipment is available;
  - Receivers are available, and their prices are decreasing while their performance is increasing;
  - Regulatory provisions are available and allow for introduction of DRM transmissions in LF/MF and HF bands;
  - Technical planning parameters are defined and allow operators who wish so to implement DRM networks and offer digital services immediately for international or national audiences.



## 6.2 Technical and regulatory information related to DRM services coverage planning that are compiled in this document

This document gathers in one structured text the information contained in separate documents from the following sources:

- Technical and regulatory ITU-R documents
- Technical documents from DRM consortium
- Experience from trials carried out by EBU and DRM members

## 6.3 Feedback from operational and experimental transmissions is available

- International broadcasting in the HF bands: DRM is already used in many countries
- National/local broadcasting in the HF 26 MHz band: results of field trials are very promising: A specific mode in 20 kHz channel (DRM mode B with 16-QAM and 0.5 average code, offering 23.835 kbit/s) has given good results in terms of robustness and data capacity. On the other hand, it was verified that man-made noise is close to the reference ITU value. However, some issues are still to be solved, mainly with regard to transmitting antenna optimisation to reduce sky wave and with regard to the need for appropriate rules for coordination.
- National broadcasting using the MF band: results of field trials show that for rural and suburban environments, a small margin should be added to the ITU reference figures for minimum field strength. On the other hand, coverage in urban environments may require a higher margin in order to overcome the high man-made noise levels.
- Single Frequency networks: DRM SFN can be used, in LF/MF and HF bands, to:
  - Extend the coverage, including for contiguous areas, without using additional frequencies;
  - Improve the availability of service within a given coverage area

Trials made in HF and MF show that DRM SFN networks operate in a satisfactory manner. They need to be engineered with care, however.

## 6.4 And next...

- For the Broadcasters:
  - To continue demonstrating through operational transmissions and trials that the DRM system is a viable system for the future.
- For the network operators:
  - To further assess noise levels in urban environments;
  - To study the impact of topography in LF/MF propagation prediction;
  - To pursue studies and tests related to 26 MHz;
  - To consider DRM+ in bands I and II;
  - To further assess SFN limitations.
- For the manufacturers:
  - Improvement of the receivers (antenna, sensitivity, implementation of Automatic Frequency Selection, ...)

## 7 References and List of Terms (Abbreviations)

### 7.1 References

- [1] DRM broadcast user manual. Available for free downloading from [www.drm.org](http://www.drm.org)
- [2] LF/MF system design. ITU handbooks. Edition of 2001.
- [3] ETSI ES 201 980 V2.2.1 (2005-10). Digital Radio Mondiale (DRM) system specification.
- [4] Recommendation ITU-R BS 1615 (2003). "Planning parameters" for digital sound broadcasting at frequencies below 30 MHz
- [5] Recommendation ITU-R BS 1514-1 (2002). System for digital sound broadcasting in the broadcasting bands below 30 MHz.
- [6] Resolution 543 (WRC-03). Provisional RF protection ratio values for analogue and digitally modulated emissions in the HF broadcasting service.
- [7] Recommendation ITU-R BS.705-1 (1995). HF transmitting and receiving antennas characteristics and diagrams
- [8] ITU-R Circular Letter CCRR/20 (Special study, under No. 13.15 of the Radio Regulations, in relation to the Regional Agreements GE75, RJ81 and RJ88) and associated RRB (Radio Regulations Board) decision in Document RRB02/343-E, 13 December 2002
- [9] Recommendation ITU-R BS.703 (1990). Characteristics of AM sound broadcasting reference receivers for planning purposes.
- [10] Recommendation ITU-R P.372-8 (2003). Radio noise.
- [11] Final Acts of the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3). Geneva, 1975.
- [12] Recommendation ITU-R P.533-7 (2001). HF propagation prediction method.
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## 7.2 List of terms (abbreviations)

AAC	Advanced Audio Coding
ABU	Asia-Pacific Broadcasting Union
ACI	Adjacent Channel Interference
AF	Audio Frequency
AFS	Alternate Frequency Switching
AM	Amplitude Modulation
ASBU	Arab States Broadcasting Union
BER	Bit Error Ratio
BR	Bureau des Radiocommunications (ITU)
BRIFIC	BR International Frequency Information Circular
C/N	Carrier to Noise ratio
CEPT	Conférence Européenne des Postes et Télécommunications
CCRR	ITU circular Letters concerning Radio Regulations
CELP	Code Excited Linear Prediction
CIRAF	Conferencia Internacional de Radiodifusión por Altas Frecuencias
COFDM	Coded Orthogonal Frequency Division Multiplexing
DAB	Digital Audio Broadcasting
DRM	Digital Radio Mondiale
DSB	Double Side Band
ECC	Electronic Communications Committee
EMRP	Effective Monopole Radiated Power
ETSI	European Telecommunications Standards Institute
FAC	Fast Access Channel
FEC	Forward Error Correction
FM	Frequency Modulation
FMO	frequency management Organisation
GE75	Final Acts of the Regional Radiocommunication Conference, Geneva 1975
GPS	Global Positioning by Satellite
GTO	Gate Turn Off
HF	High Frequency
HFCC	High Frequency Coordination Conference
HVXC	Harmonic Vector Excitation Coding
IBOC	In Band On Channel System
IF	Intermediate Frequency
IGBT	Isolated Gate Bipolar Transistor
ITU	International Telecommunications Union
LF	Low frequency
LW	Long Wave
MDI	Multiplex Distribution Interface
MER	Modulation Error Ratio
MF	Medium Frequency
MFN	Multiple Frequency network
MLC	Multi Level Coding

MSC	Main Service Channel
MUFS	Minimum Usable Field Strength
MW	Medium Wave
PDM	Pulse Duration Modulation
PSM	Pulse-Step Modulation
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quaternary Phase Shift Keying
RDS	Radio Data System
RF	Radio Frequency
RJ81	Final Acts of the Regional Radiocommunication Conference, Rio De Janeiro 1981
RJ88	Final Acts of the Regional Radiocommunication Conference, Rio De Janeiro 1988
rms	root mean square
RRB	ITU Radio Regulations Board
RRC	Regional Radiocommunication Conference
Rx	Receiver
SBR	Spectral Band Replication
SDC	Service Description Channel
SDC	Service Description Channel
SFN	Single Frequency Network
S/N or SNR	Signal to Noise Ratio
SSB	Single Side Band
SW	Short Wave
Tx	Transmitter
URTNA	Union of National Radio and Television Organizations of Africa
UTC	coordinated universal time
VHF	Very High Frequency
WRC	World Radiocommunication Conference

## Annex 1 Required S/N values for DRM reception

### A1.1 S/N values for LF/MF bands

In Appendix 3 to Annex 1 to ITU-R Rec. BS-1615 [4], a detailed description of transmission channel models used to evaluate the system performance can be found.

Channel model No. 1 represents the typical behaviour of a transmission channel with ground-wave propagation during daytime in LF and MF bands.

Channel model No. 2 represents a wave propagation model for MF bands at night-time including a delayed sky wave in addition to the ground wave.

Channel models No. 3, 4, 5 and 6: channels with strong time- and/or frequency-selective behaviour. They are suited for HF bands.

Channel model No. 5: channel where the fast-fading on the two paths is dominant.

Channel model No. 6 channel with extremely long path delays and Doppler spreads, which is a typical example for tropical-near-vertical incidence sky-wave propagation.

In Table A1.1 the required S/N for the different robustness modes and their typical spectrum occupancy types (2 for mode A, i.e. nominal channel bandwidth of 9 kHz, and 3, i.e. 10 kHz, for the others) to achieve a BER of  $1 \cdot 10^{-4}$  on channel model No 1 is given.

Table A1.1:  
S/N (dB) to achieve BER of  $1 \cdot 10^{-4}$  for all DRM robustness modes with spectrum occupancy types 2 or 3 (9 or 10 kHz) dependent on modulation scheme and protection level for channel model No. 1

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type			
			A/2 (9 kHz)	B/3 (10 kHz)	C/3 (10 kHz)	D/3 (10 kHz)
16-QAM	0	0.5	8.6	9.3	9.6	10.2
	1	0.62	10.7	11.3	11.6	12.1
64-QAM	0	0.5	14.1	14.7	15.1	15.9
	1	0.6	15.3	15.9	16.3	17.2
	2	0.71	17.1	17.7	18.1	19.1
	3	0.78	18.7	19.3	19.7	21.4

For real transmissions based on ground-wave propagation only, the use of robustness mode A is recommended because of the higher achievable service data rate. The values for the other modes are included in Table A1.1 only for reference. The degradation of their performance in S/N compared with mode A can be explained by the fact that the ratio between the numbers of data and pilot subcarriers is varying from mode to mode. With the robustness of the mode the number of pilot subcarriers, which are boosted in power in comparison with data subcarriers, also increases and therefore the average usable power of the remaining data subcarriers decreases.

For simulcast applications in a nominal channel bandwidth of 9 or 10 kHz, DRM spectrum occupancy types 0 and 1 are suitable. Only robustness modes A and B are providing this feature. The corresponding S/N values for channel model No. 1 can be found in Table A1.2.

Table A1.2:

S/N (dB) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness modes A and B with spectrum occupancy type 0 or 1 (4.5 or 5 kHz) dependent on modulation scheme and protection level for channel model No. 1

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type	
			A/0 (4.5 kHz)	B/1 (5 kHz)
16-QAM	0	0.5	8.8	9.5
	1	0.62	10.9	11.5
64-QAM	0	0.5	14.3	14.9
	1	0.6	15.8	16.2
	2	0.71	17.5	17.9
	3	0.78	19.2	19.5

For the application of robustness mode A with spectrum occupancy types 1 or 3 or mode B with 0 or 2 the S/N values in Tables A1.1 and A1.2 are also recommended, because differences in performance are less than 0.1dB.

In contrast to channel model No. 1 the channel model No. 2 represents a wave propagation model for MF bands at night-time including a delayed sky wave in addition to the ground wave. The required S/N for this channel model is shown in Table A1.3. Only results for the relevant robustness modes A and B are given (also for lower spectrum occupancy types).

Table A1.3:

S/N (dB) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness modes A and B with different spectrum occupancy types dependent on modulation scheme and protection level for channel model No. 2

Modulation scheme	Protection level No.	Average code rate	Robustness mode/spectrum occupancy type			
			A/0 (4.5 kHz)	A/2 (9 kHz)	B/1 (5 kHz)	B/3 (10 kHz)
16-QAM	0	0.5	9.8	9.4	10.3	10.2
	1	0.62	12.7	12.5	13.2	13.1
64-QAM	0	0.5	15.2	14.9	15.8	15.6
	1	0.6	16.6	16.3	17.3	16.9
	2	0.71	19.7	19.2	20.4	19.7
	3	0.78	22.9	22.0	22.8	22.3

Compared with pure ground-wave propagation the system performance degrades due to the increased frequency-selectivity and especially the slowly time-selective channel behaviour caused by the sky wave. The values indicate the correlation between the strength of the channel coding and the S/N impairment, i.e. with increasing coding rate, the impairment increases, too. But for correct interpretation of the results, it has to be considered that under the assumption of the same noise power as for pure ground-wave propagation, the additional sky-wave power would lead to a gain in received signal power of approximately 1dB, i.e. the resulting impairment in that case is

only marginal, at least for a sufficient strength of the applied error protection scheme (protection levels Nos. 0 and 1).

### A1.2 S/N values for HF bands

In Tables A1.4 to A1.7 the S/N values for the three robustness modes suited for HF transmission are given for channel models Nos. 3 to 6. Mode A cannot be applied for HF due to the lack of robustness in the OFDM parameters (length of the guard interval and frequency spacing of the subcarriers). In the case of mode B, results both for spectrum occupancy type 1 and 3 are included. Only robustness mode D is applicable also for channels with extremely long path delays and Doppler spreads as defined with channel model No. 6, which is a typical example for tropical-near-vertical incidence sky-wave propagation.

Table A1.4:  
S/N (dB) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode B with spectrum occupancy type 1 dependent on modulation scheme and protection level for channel model Nos. 3 to 6

Modulation scheme	Protection level No.	Average code rate	Channel Model No.			
			3	4	5	6
16-QAM	0	0.5	18.3	16.2	14.7	-
	1	0.62	21.1	19.3	18.0	-
64-QAM	0	0.5	23.8	21.5	20.6	-
	1	0.6	25.9	23.7	23.2	-
	2	0.71	29.0 <sup>(1)</sup>	27.0 <sup>(1)</sup>	29.4 <sup>(1)</sup>	-
	3	0.78	31.2 <sup>(1)</sup>	30.0 <sup>(1)</sup>	-	-

<sup>(1)</sup> Protection levels not recommended for use in HF propagation conditions with severe time- and frequency-selective fading.

Table A1.5:  
S/N (dB) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode B with spectrum occupancy type 3 dependent on modulation scheme and protection level for channel model Nos. 3 to 6

Modulation scheme	Protection level No.	Average code rate	Channel Model No.			
			3	4	5	6
16-QAM	0	0.5	18.0	16.0	14.6	-
	1	0.62	20.8	19.0	17.7	-
64-QAM	0	0.5	23.3	21.3	20.1	-
	1	0.6	25.4	23.5	22.7	-
	2	0.71	28.3 <sup>(1)</sup>	26.8 <sup>(1)</sup>	27.0 <sup>(1)</sup>	-
	3	0.78	30.9 <sup>(1)</sup>	29.7 <sup>(1)</sup>	-	-

<sup>(1)</sup> Protection levels not recommended for use in HF propagation conditions with severe time- and frequency-selective fading.

Table A1.6:

S/N (dB) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode C with spectrum occupancy type 3 dependent on modulation scheme and protection level for channel model Nos. 3 to 6

Modulation scheme	Protection level No.	Average code rate	Channel Model No.			
			3	4	5	6
16-QAM	0	0.5	18.0	16.5	14.6	-
	1	0.62	20.9	19.1	17.6	-
64-QAM	0	0.5	23.6	21.3	20.2	-
	1	0.6	25.6	23.7	22.3	-
	2	0.71	29.0 <sup>(1)</sup>	26.8 <sup>(1)</sup>	26.4 <sup>(1)</sup>	-
	3	0.78	32.3 <sup>(1)</sup>	29.6 <sup>(1)</sup>	33.3 <sup>(1)</sup>	-

<sup>(1)</sup> Protection levels not recommended for use in HF propagation conditions with severe time- and frequency-selective fading.

Table A1.7:

S/N (dB) to achieve BER of  $1 \times 10^{-4}$  for DRM robustness mode D with spectrum occupancy type 3 dependent on modulation scheme and protection level on channel model Nos. 3 to 6

Modulation scheme	Protection level No.	Average code rate	Channel Model No.			
			3	4	5	6
16-QAM	0	0.5	18.5	16.9	15.3	16.0
	1	0.62	21.2	19.9	18.3	19.2
64-QAM	0	0.5	24.2	22.2	20.8	22.1
	1	0.6	26.3	24.5	22.9	25.2
	2	0.71	29.2 <sup>(1)</sup>	27.6 <sup>(1)</sup>	27.2 <sup>(1)</sup>	29.3 <sup>(1)</sup>
	3	0.78	32.1 <sup>(1)</sup>	31.7 <sup>(1)</sup>	35.5 <sup>(1)</sup>	32.5 <sup>(1)</sup>

<sup>(1)</sup> Protection levels not recommended for use in HF propagation conditions with severe time- and frequency-selective fading.

For 16-QAM modulation and also for 64-QAM with strong error protection (protection levels Nos. 0 and 1) robustness mode B achieves the best performance, i.e. the lowest S/N values are required to achieve high quality audio transmission. On channel model No. 5, where the fast fading on the two paths is dominating, the better robustness of mode C and D in view of synchronization and channel estimation plays a more and more important role in the case of reduced coding strength.

Nevertheless, the results for protection level Nos. 2 and 3 in combination with 64-QAM show an increasing performance degradation due to the occurrence of a bit-error floor even at higher S/N. Therefore these protection levels are not recommended for HF transmission on channels with strong time- and/or frequency-selective behaviour like channel models Nos. 3 to 6. It also has to be kept in mind that the results given in the different Tables may represent typical bad cases for HF transmission, but not necessarily the worst ones. The S/N values for HF and also for MF with sky wave propagation have to be seen as a useful index for the achievement of the required quality of service, but cannot guarantee it under all circumstances.



## Annex 2 Information related to RF protection ratios

### A2.1 Introduction

In this section, more information on calculated RF protection ratios, which are required for AM and DRM reception, is given. Detailed information on the calculation method and parameters can be found in ITU-R BS 1615 [4].

### A2.2 Calculation parameters

#### A2.2.1 Analogue signal

##### *AM transmitter*

Cut-off frequency or bandwidth:	$F_{tx} = 4.5$ kHz, i.e. $B = 9$ kHz
Low-pass AF filter slope:	-60dB/octave, starting with 0dB at $F_{tx}$
Harmonic distortion:	$k_2 = 0$ $k_3 = 0.7\%$ (-43dB)
Intermodulation:	$d_3 = -40$ dB
Noise floor:	-60.3 dBc/ kHz

With the above parameters the calculated RF spectrum is compliant with the spectrum mask included in Recommendation ITU-R SM.328.

##### *AM modulation*

Modulating signal for unwanted wave:	Coloured noise according to Recommendation ITU R BS.559
Modulation depth:	$m_{rms} = 25\%$ (corresponds to a programme signal with normal compression)
High compression:	Increases the sideband power by 6.5dB with normal compression

##### *AM receiver*

- Selectivity curve:  $B_{af} = 2.2$  kHz, slope = 35dB/octave,
- Audio signal evaluation: rms used for signal evaluation<sup>1</sup>
- AF protection ratio: Desired value.

#### A2.2.2 DRM signal

The DRM specification allows for several robustness modes (A to D) and spectrum occupancy types (0 to 5) of DRM signals. Only certain combinations of robustness modes (A to D) and spectrum occupancy types (0 to 3) are used in this Appendix. The parameters for the used mode combinations, i.e. the respective number of subcarriers and the corresponding subcarrier spacing in OFDM signal lead to the bandwidths in rows A to D of Table A2.1.

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<sup>1</sup> Psophometric weighting according to Recommendation ITU-R BS.468.

Table A2.1: BANDWIDTHS FOR DRM MODE COMBINATIONS ( kHz)

Robustness mode	Spectrum occupancy type			
	0	1	2	3
A	4.208	4.708	8.542	9.542
B	4.266	4.828	8.578	9.703
C				9.477
D				9.536
Nominal bandwidth (kHz)	4.5	5	9	10

The bandwidths in the last row of Table A2.1 are the nominal bandwidths for the respective spectrum occupancies of the DRM signal, and the values given in lines A to D are the exact signal bandwidths for the different mode combinations.

**Transmitter for digital signals**

- *Bandwidths:* see Table A2.1
- *Spectrum masks:* calculated according to Recommendation ITU-R SM.328, § 6.3.3 of Annex 1 using the exact bandwidths F of Table A2.1. This includes a 30dB attenuation at ±0.53 F, beyond this point there is a slope of -12dB/octave to -60dB. Examples of the masks for spectrum occupancy types 1 (5 kHz) and 3 (10 kHz) are given in Figs. A2.1 and A2.2 (also including the filter curves for AM and digital receivers).

**Receiver/demodulator for digital signals**

- *Bandwidths:* see Table A2.1
- *Shoulder distance:* 52dB<sup>1</sup>
- *Additional IF filter:* BIF = nominal DRM bandwidth + 6 kHz, slope = 35dB/octave4
- *Selectivity curve:* see Figures A2.1 and A2.2
- *Required S/I for a BER = 1 x 10<sup>-4</sup>:* valid for 64-QAM, protection level No. 1

**A2.2.3 Values for RF protection ratios**

The combinations of spectrum occupancy types and robustness modes lead to several transmitter RF spectra, which cause different interference and therefore require different RF protection ratios. The applied calculation method is described in detail in ITU-R BS 1615 [4].

Table A2.2 shows calculation results for AM interfered with by digital and Table A2.3, digital interfered with by AM. These values are calculated for AM signals with high compression. The RF protection ratios for digital interfered with by digital are given in Table A2.4 for all the digital mode combinations, but only for identical mode combination pairings, e.g. digital mode B3 (robustness mode B, spectrum occupancy 3) interfered with by digital B3. Table A2.5 shows RF protection ratios between identical and different spectrum occupancies, but only for the robustness mode B. Correction factors for the different modulation schemes are given in Tables A2.6 and A2.7.

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<sup>1</sup> These parameters were chosen to approximate the calculated RF protection ratios to the measured values

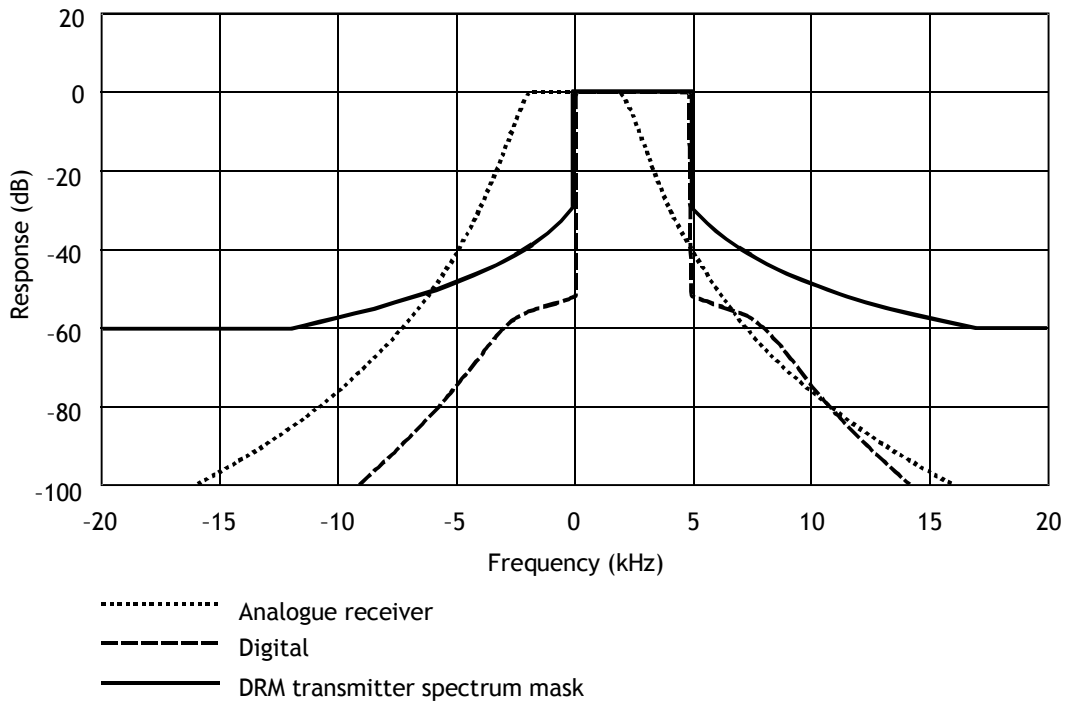


Figure A2.1: Transmitter spectrum mask and receiver/modulator selectivity curves for DRM robustness mode B and spectrum occupancy type 1 (5 kHz)

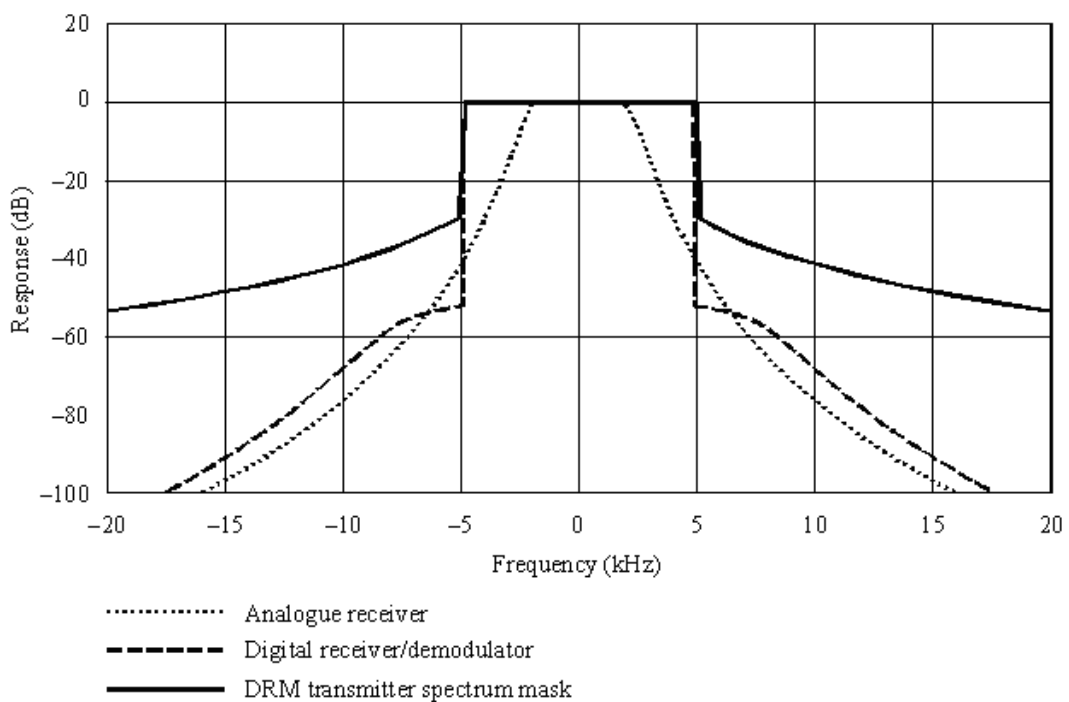


Figure A2.2: Transmitter spectrum mask and receiver/modulator selectivity curves for DRM robustness mode B and spectrum occupancy type 3 (10 kHz)

Table A2.2: Relative RF protection ratios between broadcasting systems below 30 MHz (dB) AM interfered with by digital

Wanted signal	Unwanted signal	Frequency separation, $f_{\text{unwanted}} - f_{\text{wanted}}$ (kHz)													Parameters	
		-20	-18	-15	-10	-9	-5	0	5	9	10	15	18	20	$B_{\text{DRM}}$ (kHz)	$A_{\text{AF}}^{(1)(2)}$ (dB)
AM	DRM_A0	-50.4	-50.4	-49.1	-35.6	-28.5	6.5	6.6	-31.1	-46.9	-48.3	-50.4	-50.4	-50.4	4.5	-
AM	DRM_A1	-50.9	-50.6	-47.9	-32.5	-24.5	6.1	6.1	-31.3	-46	-47.7	-50.9	-50.9	-50.9	5	-
AM	DRM_A2	-48.9	-47	-43.6	-34.5	-29.8	3.4	6.6	3.4	-29.8	-34.5	-43.6	-47	-48.9	9	-
AM	DRM_A3	-47.4	-45.5	-42.1	-32.4	-26.5	3.1	6.1	3.1	-26.5	-32.4	-42.1	-45.5	-47.4	10	-
AM	DRM_B0	-50.4	-50.4	-49	-35.5	-28.4	6.4	6.6	-30.9	-46.7	-48.2	-50.4	-50.4	-50.4	4.5	-
AM	DRM_B1	-51	-50.5	-47.6	-32	-23.8	6	6	-31.1	-45.7	-47.4	-51	-51	-51	5	-
AM	DRM_B2	-48.8	-46.9	-43.5	-34.4	-29.7	3.4	6.5	3.4	-29.7	-34.4	-43.5	-46.9	-48.8	9	-
AM	DRM_B3	-47.2	-45.3	-41.9	-32	-25.9	3	6	3	-25.9	-32	-41.9	-45.3	-47.2	10	-
AM	DRM_C30	-47.5	-45.6	-42.2	-32.6	-26.7	3.1	6.1	3.1	-26.7	-32.6	-42.2	-45.6	-47.5	10	-
AM	DRM_D31	-47.4	-45.5	-42.2	-32.4	-26.5	3.1	6.1	3.1	-26.5	-32.4	-42.2	-45.5	-47.4	10	-

AAF: audio frequency protection ratio

DRM\_A0: DRM signal, robustness mode A, spectrum occupancy type 0

- (1) The RF protection ratio for AM interfered with by digital can be calculated by adding a suitable value for the AF protection ratio according to a given planning scenario to the values in this Table.
- (2) The values presented in this Table refer to the specific case of high AM compression. For consistency with Table A2.4, the same modulation depth, namely that associated with high compression, has been assumed for the AM signal. In order to offer adequate protection to AM signals with normal levels of compression, each value in the Table should be increased to accommodate the difference between normal and high compression.

Table A2.3: Relative RF protection ratios between broadcasting systems below 30 MHz (dB)

Wanted signal	Unwanted signal	Frequency separation, $f_{\text{unwanted}} - f_{\text{wanted}}$ (kHz)												Parameters		
		-20	-18	-15	-10	-9	-5	0	5	9	10	15	18	20	$B_{\text{DRM}}$ (kHz)	S/I (dB)
DRM_A0	AM	-57.7	-55.5	-52.2	-46.2	-45	-36.7	0	-3.5	-31.2	-41.1	-47	-50.7	-53	4.5	4.2
DRM_A1	AM	-57.5	-55.2	-52	-45.9	-44.8	-36.6	0	-0.6	-22.8	-38.4	-46.1	-49.8	-52.2	5	4.2
DRM_A2	AM	-54.7	-52.4	-48.8	-42.9	-34	-6.5	0	-6.5	-34	-42.9	-48.8	-52.4	-54.7	9	6.7
DRM_A3	AM	-54	-51.7	-48.1	-40.6	-25.8	-3.6	0	-3.6	-25.8	-40.6	-48.1	-51.7	-54	10	6.7
DRM_B0	AM	-57.7	-55.5	-52.2	-46.1	-45	-36.2	0	-3.5	-30.9	-41.1	-46.9	-50.6	-53	4.5	4.6
DRM_B1	AM	-57.4	-55.2	-51.9	-45.9	-44.7	-36	0	-0.2	-22	-37.6	-46	-49.6	-52	5	4.6
DRM_B2	AM	-54.6	-52.4	-48.8	-42.8	-33.7	-6.4	0	-6.4	-33.7	-42.8	-48.8	-52.4	-54.6	9	7.3
DRM_B3	AM	-53.9	-51.5	-48	-39.9	-25	-3.1	0	-3.1	-25	-39.9	-48	-51.5	-53.9	10	7.3
DRM_C3	AM	-54	-51.7	-48.1	-40.9	-26.1	-3.8	0	-3.8	-26.1	-40.9	-48.1	-51.7	-54	10	7.7
DRM_D3	AM	-54	-51.7	-48.1	-40.7	-25.8	-3.6	0	-3.6	-25.8	-40.7	-48.1	-51.7	-54	10	8.6

Table A2.4: Relative RF protection ratios between broadcasting systems below 30 MHz (dB)  
 Digital (64-QAM, protection level No. 1) interfered with by digital (identical robustness modes and spectrum occupancy types)

Wanted signal	Unwanted signal	Frequency separation, $f_{\text{unwanted}} - f_{\text{wanted}}$ (kHz)													Parameters	
		-20	-18	-15	-10	-9	-5	0	5	9	10	15	18	20	$B_{\text{DRM}}$ (kHz)	S/I (dB)
DRM_A0	DRM_A0	-60.1	-60	-60	-55.4	-53.4	-41.2	0	-41.2	-53.4	-55.4	-60	-60	-60.1	4.5	15.8
DRM_A1	DRM_A1	-60	-60	-59.7	-53.3	-51.3	-38.4	0	-38.4	-51.3	-53.3	-59.7	-60	-60	5	15.8
DRM_A2	DRM_A2	-55.1	-53.1	-49.6	-40.8	-38.3	-3.8	0	-3.8	-38.3	-40.8	-49.6	-53.1	-55.1	9	15.3
DRM_A3	DRM_A3	-53	-51	-47.3	-38.1	-12.1	-3.2	0	-3.2	-12.1	-38.1	-47.3	-51	-53	10	15.3
DRM_B0	DRM_B0	-60	-59.9	-60	-55.2	-53.2	-40.8	0	-40.8	-53.2	-55.2	-60	-59.9	-60	4.5	16.2
DRM_B1	DRM_B1	-60	-60	-59.5	-52.8	-50.8	-37.8	0	-37.8	-50.8	-52.8	-59.5	-60	-60	5	16.2
DRM_B2	DRM_B2	-55.1	-53.1	-49.5	-40.7	-38.1	-3.7	0	-3.7	-38.1	-40.7	-49.5	-53.1	-55.1	9	15.9
DRM_B3	DRM_B3	-52.7	-50.7	-47	-37.7	-11.1	-3.1	0	-3.1	-11.1	-37.7	-47	-50.7	-52.7	10	15.9
DRM_C3	DRM_C3	-53.2	-51.1	-47.5	-38.3	-12.6	-3.2	0	-3.2	-12.6	-38.3	-47.5	-51.1	-53.2	10	16.3
DRM_D3	DRM_D3	-53	-51	-47.4	-38.1	-12.2	-3.2	0	-3.2	-12.2	-38.1	-47.4	-51	-53	10	17.2

Table A2.5: Relative RF protection ratios between broadcasting systems below 30 MHz (dB)  
 Digital (64-QAM, protection level No. 1) interfered with by digital

Wanted signal	Unwanted signal	Frequency separation, $f_{\text{unwanted}} - f_{\text{wanted}}$ (kHz)													Parameters	
		-20	-18	-15	-10	-9	-5	0	5	9	10	15	18	20	$B_{\text{DRM}}$ (kHz)	S/I (dB)
DRM_B0	DRM_B0	-60	-59.9	-60	-55.2	-53.2	-40.8	0	-40.8	-53.2	-55.2	-60	-59.9	-60	4.5	16.2
DRM_B0	DRM_B1	-60.1	-60	-59.5	-52.5	-50.4	-37.4	0	-40	-51.6	-53.6	-59.8	-60	-60.1	5	15.7
DRM_B0	DRM_B2	-57.4	-55.7	-52.9	-46.7	-45.1	-36.6	0	-0.8	-35.6	-38.4	-47.7	-51.5	-53.6	9	13.2
DRM_B0	DRM_B3	-55.2	-53.6	-50.7	-44.5	-42.9	-33.1	0	-0.1	-13.6	-36.2	-45.5	-49.3	-51.4	10	12.6
DRM_B1	DRM_B0	-59.4	-59.5	-59.5	-55	-53	-40.8	0	-37.9	-51.7	-53.9	-59.4	-59.5	-59.4	4.5	16.2
DRM_B1	DRM_B1	-60	-60	-59.5	-52.8	-50.8	-37.8	0	-37.8	-50.8	-52.8	-59.5	-60	-60	5	16.2
DRM_B1	DRM_B2	-57.1	-55.4	-52.6	-46.4	-44.9	-36.4	0	-0.1	-13.7	-36.8	-46.6	-50.5	-52.7	9	13.2
DRM_B1	DRM_B3	-55.5	-53.8	-51	-44.8	-43.3	-33.5	0	-0.1	-8.1	-35.2	-45	-48.9	-51.1	10	13.2
DRM_B2	DRM_B0	-57	-56.8	-54.8	-43.4	-39.1	-0.7	0	-40.6	-52.2	-53.9	-57	-57	-57	4.5	15.9
DRM_B2	DRM_B1	-56.9	-56.1	-52.7	-40.2	-14.1	-0.1	0	-39.7	-50.8	-52.5	-56.9	-57	-57	5	15.4
DRM_B2	DRM_B2	-55.1	-53.1	-49.5	-40.7	-38.1	-3.7	0	-3.7	-38.1	-40.7	-49.5	-53.1	-55.1	9	15.9
DRM_B2	DRM_B3	-52.9	-51	-47.4	-38.6	-16.6	-3.2	0	-3.2	-16.6	-38.6	-47.4	-51	-52.9	10	15.4
DRM_B3	DRM_B0	-56.4	-56.2	-53.8	-41.1	-14.1	-0.1	0	-37.7	-50.9	-52.8	-56.4	-56.4	-56.4	4.5	15.9
DRM_B3	DRM_B1	-56.8	-55.7	-52.1	-38.2	-8.2	-0.1	0	-37.6	-50.1	-51.9	-56.7	-57	-57	5	15.9
DRM_B3	DRM_B2	-54.3	-52.3	-48.6	-39.3	-16.7	-3.1	0	-3.1	-16.7	-39.3	-48.6	-52.3	-54.3	9	15.9
DRM_B3	DRM_B3	-52.7	-50.7	-47	-37.7	-11.1	-3.1	0	-3.1	-11.1	-37.7	-47	-50.7	-52.7	10	15.9

Table A2.6: S/I correction values to be used in Tables A2.3 and A2.4 for other combinations of modulation scheme and protection level No

Modulation scheme	Protection level No.	Average code rate	Correction values (dB) for DRM robustness / spectrum occupancy type	
			A/0 (4.5 kHz) A/1 (5 kHz)	A/2 (9 kHz) A/3 (10 kHz)
16-QAM	0	0.5	-7.0	-6.7
	1	0.62	-4.9	-4.6
64-QAM	0	0.5	-1.5	-1.2
	1	0.6	0.0	0.0
	2	0.71	1.7	1.8
	3	0.78	3.4	3.4

Table A2.7: S/I correction values to be used in Tables A2.3, A2.4 and A2.5 for other combinations of modulation scheme and protection level No.

Modulation scheme	Protection level No.	Average code rate	Correction values (dB) for DRM robustness / spectrum occupancy type	
			B/0 (4.5 kHz) B/1 (5 kHz)	B/2 (9 kHz) B/3 (10 kHz)
16-QAM	0	0.5	-6.7	-6.6
	1	0.62	-4.7	-4.6
64-QAM	0	0.5	-1.3	-1.2
	1	0.6	0.0	0.0
	2	0.71	1.7	1.8
	3	0.78	3.3	3.4

Table A2.8: S/I correction values to be used in Tables A2.3 and A2.4 for other combinations of modulation scheme and protection level No.

Modulation scheme	Protection level No.	Average code rate	Correction values (dB) for DRM robustness / spectrum occupancy type	
			C/3 (10 kHz)	D/3 (10 kHz)
16-QAM	0	0.5	-6.7	-7.0
	1	0.62	-4.7	-5.1
64-QAM	0	0.5	-1.2	-1.3
	1	0.6	0.0	0.0
	2	0.71	1.8	1.9
	3	0.78	3.4	4.2



The values in Tables A2.2 to A2.5 represent relative RF protection ratios,  $A_{RF\_relative}$ . For the pure AM case, the relative protection ratio is the difference (dB) between the protection ratio when the carriers of the wanted and unwanted transmitters have a frequency difference of  $\Delta f$  Hz, and the protection ratio when the carriers of these transmitters have the same frequency (Recommendation ITU R BS.560), i.e. the co-channel RF protection ratio,  $A_{RF}$ , which corresponds to the AF protection ratio,  $A_{AF}$ . In the case of a digital signal, its nominal frequency instead of the carrier frequency is the relevant value for the determination of the frequency difference.

For spectrum occupancy types 2 and 3, the nominal frequency corresponds to the centre frequency of the OFDM block; for the types 0 and 1, the centre frequency is shifted about 2.2 and 2.4 kHz, respectively, above the nominal frequency. Due to the fact that the spectrum of the interference signal is different from the AF spectrum of analogue AM, the values for relative AF protection ratio in the case of co-channel interference are not equal to zero.

To adjust Table A2.2 to a given AM planning scenario, the relevant AF protection ratio has to be added to the values in the Table to get the required RF protection ratio. Relevant values may be determined taking into account:

- for HF, the AF protection ratio of 17dB, which was adopted for HFBC planning by WARC HFBC-87 for AM interfered with by AM;
- for LF/MF, the AF protection ratio of 30dB, which was adopted by the Regional Administrative LF/MF Broadcasting Conference for Regions 1 and 3 (Geneva, 1975) for AM interfered with by AM.

With DRM as the wanted signal the AF protection ratio as a parameter for the quality of service has to be replaced by the  $S/I$  required to achieve a certain BER. A BER threshold of  $1 \times 10^{-4}$  is supposed for the calculations.

The protection ratio values in Tables A2.3 and A2.4 are based on 64-QAM modulation and protection level No. 1. For other combinations, the correction values in Tables A2.6 to A2.8 have to be added to the  $S/I$  values given in the Tables.



## Annex 3 Results of some DRM trials

### A3.1 DRM test in the MF band in Madrid

**Source: document ITU-WP6E-0175 [22]**

An extensive measurement campaign was carried out during 2004 in order to evaluate and study DRM's daytime performance. This campaign was based on a 4 kW DRM transmitter installed near Madrid. The study analysed several aspects of both fixed and mobile DRM reception in different environments.

Regarding the static reception, several estimated field-strength thresholds for rural and suburban environments have been calculated based on a restrictive audio quality criterion (98% of correctly received audio frames). The results lead to similar values to the ones proposed by the ITU-R in Recommendation ITU-R BS.1615 for DRM mode A/64/16/0.6/S and to slightly higher values for modes B/64/16/0.5/L and A/16/4/0.5/S. These results are not definitive but give a good indication of the performance of the DRM system.

The audio quality was very good all over the measurement area with audio qualities near 100% in all areas. Actually, all the suburban and rural locations within a radius of 100 km from the transmitter received 100% of the transmitted audio frames correctly for all the tested DRM modes, whereas the percentage of locations where the audio quality was higher than 98% ranged from 83% to 100%, depending on the selected DRM mode.

The critical factor for perfect audio decoding in urban environments has been the high level of man-made noise typically found in large cities like Madrid. Measurement of this noise is needed to obtain realistic values. In such noisy environments, broadcasters will have to maintain higher field strengths in order to ensure perfect coverage in large cities.

This document has also presented a detailed comparison study between measured field strength values in rural and suburban environments and the predicted values given by Recommendation ITU-R P.368-7. The main result of this analysis has led to a very good matching between data predicted using Millington method and the actual measured field strength values. Simulations in 50% of the locations led to a prediction error  $\leq 3$ dB and almost all the locations have errors  $\leq 9$ dB. The overall results indicate that the Millington method underestimates the received field strength when dealing with irregular terrain.

The accuracy of conductivity data has been proven to be critical for good prediction and the maximum error caused by a wrong estimation of the permittivity has been calculated to be 1.5dB. A simpler method than the Millington mixed paths method has been also proposed, leading to worse but still acceptable prediction results in areas where the terrain conductivity is not known in detail.

Regarding mobile reception, several routes were measured along radials from the transmitter using three DRM modes. For distances up to 35 km from the transmitter, a perfect audio quality could be observed in rural and suburban environments. In the range of 35 to 70 km, very few audio dropouts were present. Audio dropouts were due to power lines, power plants and tunnels.

The possible effect of vehicle speed seemed not to be significant for the reception; thus, the wider carrier separation of mode B did not provide any benefit during these MW tests.

The use of a long interleaver slightly improved the DRM service availability against low-intensity isolated impairments such as small field-strength variations, due mainly to bridges, but it did not show an improved performance against high man-made noise level spots. Besides, as was expected,

impairments present when receiving low field-strength signals caused longer dropouts to modes using a long interleaver than those observed for the modes with short interleaving.

### A3.2 DRM test in the MF band in Mexico City

**Source: document ITU-WP6E-0403 [23]**

As with digital audio signals in general, the DRM signal was either audible if the signal-to-noise ratio was high enough, or muted if it was so low that the error correction mechanism failed, giving noticeable “audio dropouts”.

For the 10 kHz channel the DRM audio quality was similar to that of a FM broadcast, although with a simulated stereo effect (“parametric stereo”) rather than true stereo. Listeners were pleasantly surprised by the lack of noise in the audio.

This result can be applied to the use of the DRM system in all bands because the audio quality that it can provide depends on the available bitrate and, therefore, the DRM mode but not the frequency band.

It was found that no audio dropouts detectable by non-professional listeners occurred if the signal-to-noise ratio is greater than 17dB. This value is approximately 19dB less than the signal to- noise ratio necessary for the reception of an intelligible AM signal. It was found that the system presents a very high reliability of reception with values near to 100% in the different types of environment in Mexico City There were reception problems in only 4 out of 36 locations; these are extremely difficult locations as they are located in places where there is a high electrical noise.

A “perfect reception area” can be defined as the contour where there are few or no perceptible audio dropouts. A little farther away, annoying dropouts were to be expected and even a bit farther away, audio mute was probable.

It was found, however, that due to other factors that influence the coverage, such as the topography, the type of buildings or the type of human activity present, the relationship between the transmission power and the coverage area is not so easy to calculate. The measurements carried out in these tests demonstrated that with a power of 1.25 kW for DRM signals, correct reception was achieved in 32 out of 36 locations at distances from about 4 to 20 km from the transmitter.

Because the received signal-to-noise ratio heavily depends on the local position of the receiver, there are small areas even within the coverage contour where the power level dropped (e.g. when passing under a bridge) or where the noise level was high enough to force the receiver to mute the corrupted signal. In the same or even far better conditions, an AM signal would also be degraded because it requires a higher signal-to-noise ratio than the DRM signal.

It can be emphasized that the overall noise encountered in the Medium Wave band has been very significant. Extensive measurements of electrical noise were taken at 1720 kHz and it was found that levels were quite a lot higher (40dB) than the published references in the reports and ITU recommendations.

The results of the measurements provide a means of estimating the coverage radius as a function of average DRM power, taking into account increases of 3 and 6dB above the 1.25 kW used in this test.

To estimate the coverage in environments similar to Mexico City, the calculation is not based on a simple power-distance relation, but in fixed points and mobile measurements.

### A3.3 DRM / AM simulcast tests at MW in Mexico

**Sources:** *DRM: MW simulcast tests in Mexico City [23], DRM developments: Experimental and Regular Transmissions [20]*

Simulcast transmissions with DRM and AM in adjacent channels were tested in Mexico with the following configuration (see Figure A3.1):

AM transmission: Frequency 1060 kHz, Power (AM carrier): 50 kW

DRM: Mode A/64/16/0.5/L<sup>1</sup>

Bandwidth: 10 kHz

Frequency 1070 kHz

Power (rms): 1.25 kW.

Bitrate: 22.1 kbit/s, AAC+Parametric Stereo, providing near FM quality

AM/DRM power ratio: 16dB (see Figure A3.2)

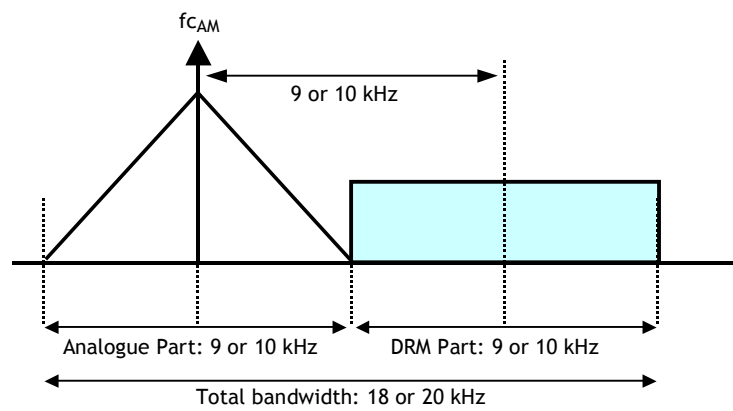


Figure A3.1: The multichannel simulcast as tested in Mexico.

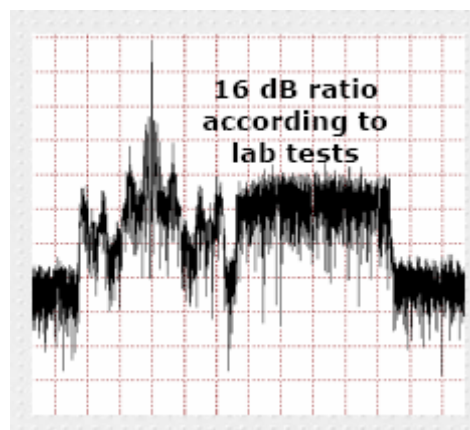


Figure A3.2: AM/DRM spectrum plot and power ratio

<sup>1</sup> A/64/16/0.5/L means:

DRM mode A, Modulation used for the MSC channel: 64-QAM, Modulation used for the SDC channel: 16-QAM  
Code rate: 0.5, Interleaver: Long.

Static (more than 30 locations) and Mobile (500 km) measurements were performed to assess:

- AM static/mobile measurements (subjective quality assessment by experts)
- DRM static/mobile measurements
- Man-made noise levels

The results may be summarized as follows:

DRM does not degrade the AM subjective quality<sup>1</sup> with the tested configuration.

Of 31 tested locations, twenty-eight showed an AM subjective quality of 5 or 4 and three showed an AM subjective quality of 3 or less. It should be noted that expert subjective evaluation invariably leads to pessimistic results compared to the standard ITU evaluation method.

Moreover, it was noted that the results did not change with the type of analogue receiver tested (four receivers were tested from different manufacturers and with different prices and qualities) and that the AM reception problems were related to external man-made electrical noise.

The DRM reception quality results were excellent:

The total number of tested locations was 36. The audio quality was better than 98% at thirty-two of these locations. Correct reception was obtained at 88.88% of locations and the measured SNR threshold was 17dB.

It was also noted that the DRM reception quality was independent of the environment (five types were identified: Industrial, Typical Mexican dense, Typical Mexican (not dense), Open residential and Urban).

Further tests were carried out at an AM/DRM power ratio of 13dB, and the AM subjective quality was still rated at 5 - 4 even with this 13dB power ratio.

Measurements were also conducted in ‘special’ locations such as in the proximity of high power electrical towers. The results showed that DRM was perfectly received while the AM subjective quality was rated 1.

Finally, man-made noise measurements conducted in Mexico City showed that the measured median values were around 40dB higher than the ITU-R reference for the MF band. Other measurements made in Madrid have shown man-made noise levels that were 10dB higher than the ITU-R reference. This leads to the conclusion that reception environmental factors must be taken into account for planning purposes.

In summary of the results of the AM/DRM simulcast tests at MW in Mexico:

- AM-DRM recommended power ratio: 16dB
- No degradation of the subjective AM quality

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<sup>1</sup> AM Subjective quality is defined in recommendation ITU-R BS.1284:

	Quality		Degradation
5	Excellent	5	Unnoticeable
4	Good	4	Perceptible, but not annoying
3	Enough	3	Slightly annoying
2	Not enough	2	Annoying
1	Bad	1	Very annoying

- Excellent DRM mode A/64/16/0.5/L quality with 9 or 10 kHz bandwidth
- DRM is very robust in "special" situation with regard to AM
- Noise levels in Mexico City are 40dB higher than the reference values of ITU-R.

### A3.4 DRM test in the MF band in Italy

**Source: document ITU-SG06-0353 [24]**

Global results

The whole north-west part of Italy is completely covered with a DRM signal whose level is greater than the minimum indicated in the relevant ITU-R Recommendation for the adopted transmission parameters (38.6dBµV/m). Moreover, a minimum SNR of 14.1dB was exceeded at each measurement point, even in deep valleys.

The extent of the coverage area can be identified with the national border (Sestriere, Ceresole Reale, Domodossola and Bormio). To the east, the DRM signal is available up to Trieste, where at the coast the field strength is 48.5dBµV/m with a SNR of 21.7dB. Due to particularly mountainous and bad terrain conductivity the Brennero valley is covered up to the town of Trento, only. In a southeastern direction, DRM is available to just before Ancona. In the south, DRM reaches the entire Liguria coast and a part of the Tuscany coast up to Grosseto town. The cities of Genova, Savona, La Spezia and Livorno are also covered.



- Reception by professional receivers only
- Reception by professional & commercial receivers

Figure A3.3: Measured coverage area

The contours on Figure A3.3 show where commercial receivers and professional receivers were able to successfully decode the DRM signal.

The service area shown in Figure A3.4 is computed on the basis of 45dB $\mu$ V/m for towns with a population below 1000 and of 53dB $\mu$ V/m for towns with a population of more than 1000.

At the moment, about 150 static measurement points have been verified.

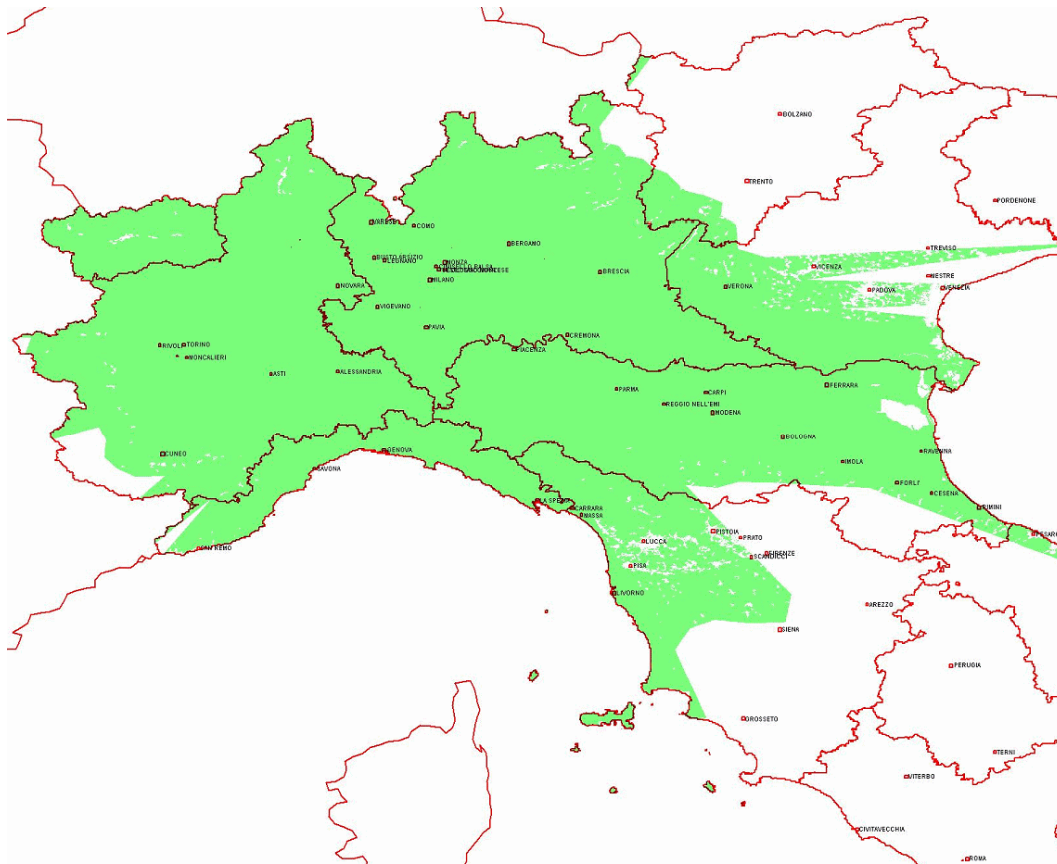


Figure A3.4: Predicted coverage area

Some data analysis was done in order to identify locations where reception was not available because of local difficulties:

- in the centre of Turin, 125 km from the transmitter, in 1 of 12 measurement points the performance of the DRM signal is degraded by an electric feeder for public transport. At this point a SNR of 13.4dB was measured with a signal strength of 52.1dB $\mu$ V/m and no audio was decoded;
- north from Milan, at the beginning of the Valtellina valley (93 km from the transmitter) some mountainous topography and bad terrain conductivity cause low signal strength (35.7dB $\mu$ V/m) and SNR (8.5dB). Travelling along the valley route, the signal and SNR increase up towards Bormio, 170 km from the transmitter.

During daytime, no significant broadcast interference was recorded in the whole predicted and measured coverage areas.

It should be noted that the measured and predicted areas are a good match.



### Annex 4 RMS Modulation Depth

Modulation depth is conventionally expressed in terms of peak sine wave excursion. A sine wave that doubles the carrier (voltage) on positive peaks and reduces it to zero on negative peaks is said to modulate the carrier by 100% (see fig A4.1).

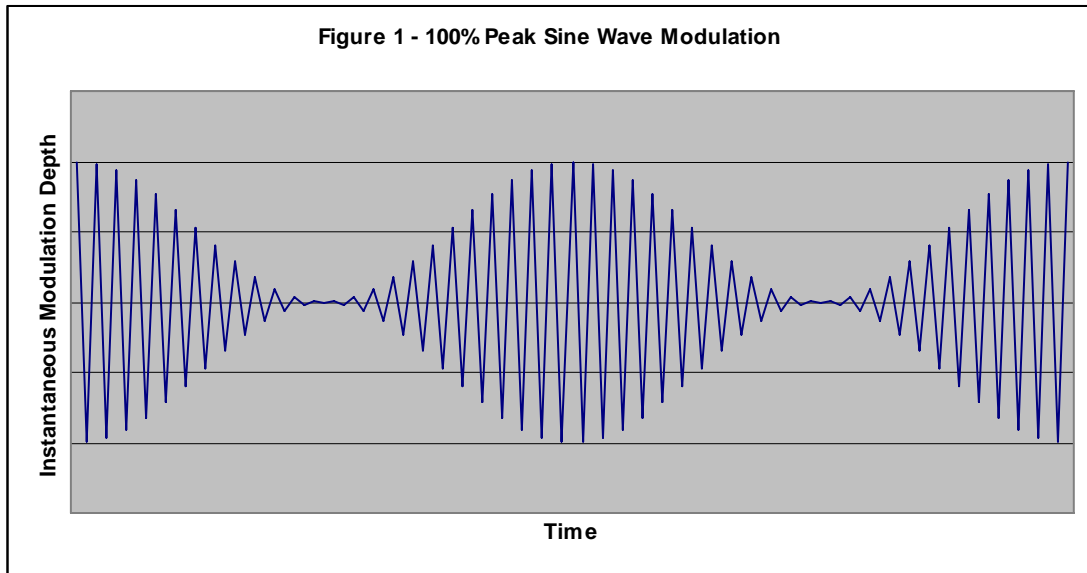


Figure A4.1: 100% (Peak) Sine Wave Modulation

(The maximum instantaneous modulation depth (outer horizontal lines) is +100%. The minimum instantaneous modulation depth (central horizontal line) is -100%)

For the signal in Figure A4.1, the instantaneous modulation depth  $\{M_{inst}(t)\}$  is:

$$M_{inst}(t) = 100 \text{ Sin} (\omega_m \cdot t) \quad (1)$$

Where  $\omega_m$  is the modulating (angular) frequency

For any (arbitrary) function  $\{F(t)\}$  the rms value of the function over a specific period of time  $\{T\}$  is given by:

$$F_{rms} = \sqrt{\left( \int_0^T \frac{1}{T} \cdot F^2(t) dt \right)} \quad (2)$$

In the case of the instantaneous modulation depth function shown in (1) above the rms value is:

$$M_{rms} = \sqrt{\left( 100 \cdot \int_0^{2\pi} \frac{1}{2\pi} \cdot \text{Sin}^2(\theta) d\theta \right)} \quad (3)$$

Where  $\theta$  is equal to  $\omega_m \cdot t$

Evaluating (3) yields the familiar result for a sine wave  $M_{rms} = 70.7\%$ . The rms modulation depth for a carrier fully modulated with a sine wave as shown in Figure A4.1 above is therefore 70.7%.

The rms value for any modulated waveform can be calculated by substituting the function describing the instantaneous modulation depth in equation 2 above.

$$M_{rms} = \sqrt{\left( \int_0^T \frac{1}{T} \cdot M_{inst}^2(t) dt \right)} \quad (4)$$

It can further be shown that the rms modulation depth can be expressed as;

$$M_{rms} = \sqrt{\frac{P_{SB}}{P_{CAR}}} \quad (5)$$

Where  $P_{SB}$  is the power in the sidebands and  $P_{CAR}$  the power in the carrier.

## Annex 5 DRM facilities and transmissions operated by European Broadcasters

Based on extracts from the DRM Web page [www.drm.org](http://www.drm.org), updated as per 19 November 2007.

Programme*	Broadcaster/ Network Operator	Site	Power (kW)	Freq. (kHz)	Band	Target
OldieStar Radio	OldieStar Radio	<a href="#">Burg</a>	100	1575	MF	Europe
Radio Luxembourg	BCE (Broadcasting Centre Europe)	<a href="#">Dudelange</a>	0.15	25795	26 MHz	Luxembourg
	BCE (Broadcasting Centre Europe)	<a href="#">Junglinster</a>	50		HF	Europe
RTL Radio	BCE (Broadcasting Centre Europe)	<a href="#">Marnach</a>	120	1440	MF	Europe
RTL Radio	BCE (Broadcasting Centre Europe)	<a href="#">Marnach</a>	240	1440	MF	Europe
RTL Radio	BCE (Broadcasting Centre Europe)	<a href="#">Marnach</a>	120	1440	MF	Europe
	BCE (Broadcasting Centre Europe)	<a href="#">Junglinster</a>	50		HF	Europe
	Bayerscher Rundfunk	<a href="#">Ismaning</a>	10		HF	Europe
	CVC (Christian Vision)	<a href="#">Julich</a>	40		HF	Europe and other
	CVC (Christian Vision)	<a href="#">Julich</a>	40		HF	Europe and other
	CVC (Christian Vision)	<a href="#">Julich</a>	40		HF	Europe and other
	CVC (Christian Vision)	<a href="#">Julich</a>	40		HF	Europe and other
	CVC (Christian Vision)	<a href="#">Julich</a>	40		HF	Europe and other
	CVC (Christian Vision)	<a href="#">Julich</a>	40		HF	Europe and other
DLF	DLF (Deutschlandfunk)	<a href="#">Berlin-Britz</a>	10	855	MF	Berlin
	DW (Deutsche Welle)	<a href="#">Sines (Portugal)</a>	90		HF	Europe
	DW (Deutsche Welle)	<a href="#">Sines (Portugal)</a>	90		HF	Europe
	DW (Deutsche Welle)	<a href="#">Sines (Portugal)</a>	90		HF	Europe
	DW (Deutsche Welle)	<a href="#">Trincomalee (SRL)</a>	90		HF	Asia
	DW (Deutsche Welle)	<a href="#">Trincomalee (SRL)</a>	100		MF	South Asia

\* blank for HF because, usually, several programmes are transmitted at different hours

Programme*	Broadcaster/ Network Operator	Site	Power (kW)	Freq. (kHz)	Band	Target
Glas Hrvatske and HR1	HRT/OIV (Croatia)	<a href="#">Deanovec</a>	10	594	MF	NW Croatia
	KPN Broadcast (Netherlands)	<a href="#">Flevo</a>	40		HF	Europe
	MCR (Monte Carlo Radiodiffusion)	<a href="#">Fontbonne</a>	10		HF	Europe
BBC Radio Devon	NGW (National Grid Wireless)	<a href="#">Crownhill SFN</a>	0.25	855	MF	Devon
BBC Radio Devon	NGW (National Grid Wireless)	<a href="#">North Hessary Tor</a>	0.1	855	MF	Devon
	Norkring (or VT)	<a href="#">Sveio (Norway)</a>	200		HF	Europe and other
	ORS (Austria)	<a href="#">Moosbrunn</a>	50		HF	UK
	ORS for VT	<a href="#">Moosbrunn</a>	50		HF	UK
RAI tests	RAIWAY (Italy)	<a href="#">Milano</a>	30	693	MF	Italy
	RNW (Radio Netherlands Worldwide)	<a href="#">Bonaire (Dutch Caribbean)</a>	150		HF	Americas
	RNW (Radio Netherlands Worldwide)	<a href="#">Bonaire (Dutch Caribbean)</a>	150		HF	Americas
	RTBF (Radios et Télévisions Belges Francophones, Belgium)	<a href="#">Wavre</a>	100		HF	South Europe
EIRE	RTÉ (Ireland's National Television and Radio Broadcaster)	<a href="#">Summerhill</a>	100	252	LF	Ireland
SWR cont.ra	SWR (Südwestrundfunk Germany)	<a href="#">Mainz-Wolfsheim</a>	0.42	1485	MF	SW Germany
	TDF (Télédiffusion de France)	<a href="#">Montsinery-Guyane</a>	150		HF	Americas
	TDF (Télédiffusion de France)	<a href="#">Issoudun</a>	150		HF	Any
	TDF (Télédiffusion de France)	<a href="#">Issoudun</a>	1		HF (4 MHz)	France
	TDF (Télédiffusion de France)	<a href="#">Issoudun</a>	30		HF	Europe and other
TDF Radio	TDF (Télédiffusion de France)	<a href="#">Rennes</a>	0.1	25775	26 MHz	Rennes
	TSI (T-Systems International, Germany)	<a href="#">Nauen</a>	40		HF	Europe
	TSI (T-Systems International, Germany)	<a href="#">Nauen</a>	200		HF	Europe and other
DLR Kultur	TSI (T-Systems International, Germany)	<a href="#">Oranienburg</a>	150	177	LF	Germany
VoR (Simulcast)	TSI (T-Systems International, Germany)	<a href="#">Oranienburg</a>	250	693	MF	Berlin
	TSI (T-Systems International, Germany)	<a href="#">Putbus</a>	1	729	MF	NE Germany
	TSI (T-Systems International, Germany)	<a href="#">Wertachtal</a>	40		HF	Europe

Programme*	Broadcaster/ Network Operator	Site	Power (kW)	Freq. (kHz)	Band	Target
	TSI (T-Systems International, Germany)	<a href="#">Wertachtal</a>	60		HF	Europe
	TSI (T-Systems International, Germany)	<a href="#">Wertachtal</a>	60		HF	Europe
	TSI (T-Systems International, Germany)	<a href="#">Wertachtal</a>	60		HF	Europe
	TSI (T-Systems International, Germany)	<a href="#">Wertachtal</a>	200		HF	Europe
Oldiestar Radio	TSI (T-Systems International, Germany)	<a href="#">Berlin-Schaeferberg</a>	0.5	1485	MF	Berlin
Oldiestar Radio	TSI (T-Systems International, Germany)	<a href="#">Frohnou</a>	0.5	1485	MF	Berlin
Various	University of Hannover	<a href="#">Hannover</a>	0.04	26045	26 MHz	Hannover
Campus Radio	University of Nuremberg	<a href="#">Dillberg</a>	0.1	26000	26 MHz	Neumarkt
Campus Radio	University of Nuremberg	<a href="#">Nuernberg</a>	0.1	26012	26 MHz	Nuernberg
	VoR (Voice of Russia)	<a href="#">Komsomolsk Amur</a>	90		HF	Asia
	VoR (Voice of Russia)	<a href="#">Taldom</a>	40		HF	Europe
	VoR (Voice of Russia)	<a href="#">Taldom</a>	35		HF	Europe
	VoR (Voice of Russia)	<a href="#">Taldom</a>	35		HF	Europe
Vatican Radio	VR (Vatican Radio)	<a href="#">Santa Maria di Galeria</a>	70	1530	MF	Europe
Vatican Radio	VR (Vatican Radio)	<a href="#">Santa Maria di Galeria</a>	28	1611	MF	Europe
	VR (Vatican Radio)	<a href="#">Santa Maria di Galeria</a>	225		HF	America
	VR (Vatican Radio)	<a href="#">Santa Maria di Galeria</a>	120		HF	America
	VR (Vatican Radio)	<a href="#">Santa Maria di Galeria</a>	70		HF	Europe
	VR (Vatican Radio)	<a href="#">Santa Maria di Galeria</a>	125		HF	Europe
	VR (Vatican Radio)	<a href="#">Vatican + Santa Maria</a>	0.125		26MHz SNF	Vatican
Premier Radio	VT (VT Communications, UK)	<a href="#">Crystal Palace (London)</a>	0.1	25695	26 MHz	Greater London
Deutsche Welle (2nd audio service on Premier multiplex)	VT (VT Communications, UK)	<a href="#">Crystal Palace (London)</a>	0.1	25695	26 MHz	Greater London
	VT (VT Communications, UK)	<a href="#">Kvitsoy (Norway)</a>	50		HF	Europe
BBCWS	VT (VT Communications, UK)	<a href="#">Orfordness, UK</a>	70	1296	MF	Europe
	VT (VT Communications, UK)	<a href="#">Rampisham, UK</a>	35		HF	Europe
	VT (VT Communications, UK)	<a href="#">Rampisham, UK</a>	35		HF	Europe

Programme*	Broadcaster/ Network Operator	Site	Power (kW)	Freq. (kHz)	Band	Target
Deutsche Welle	VT (VT Communications, UK)	<a href="#">Skelton, UK</a>	100		HF	Europe
	VT (VT Communications, UK)	<a href="#">Woofferton, UK</a>	100		HF	Europe
	VT (VT Communications, UK)	<a href="#">Woofferton, UK</a>	100		HF	Europe
	VT (VT Communications, UK)	<a href="#">Woofferton, UK</a>	100		HF	Europe
	VT (VT Communications, UK)	<a href="#">Woofferton, UK</a>	100		HF	Europe
WDR 2 Klassik	WDR (Westdeutscher Rundfunk)	<a href="#">Langenberg</a>	10	1593	MF	W Germany