Digital Radio Mondiale (DRM); Minimum Receiver Requirements

Version 1.0

Contents

1 SCOPE 6

2 REFERENCES 6

2.1 Normative References 6

2.2 Informative References 6

3 TERMS AND DEFINITIONS 7

4 BASIC IMPLEMENTATION AND FUNCTIONAL PERFORMANCE REQUIREMENTS 8

4.1 Audio decoder 8
 4.1.1 Introduction 8
 4.1.2 Requirements 8

4.2 Channel decoder and demodulator 8
 4.2.1 Introduction 8
 4.2.2 Requirements 8

4.3 Service selection 9
 4.3.1 Introduction 9
 4.3.2 Requirements 9

4.4 Receiver reactions to multiplex-reconfiguration 9
 4.4.1 Introduction 9
 4.4.2 Requirements 10

4.5 Handling of optional features 11
 4.5.1 Introduction 11
 4.5.2 Requirements 11

4.6 Backwards compatibility 12
 4.6.1 Introduction 12
 4.6.2 Requirements 12

4.7 Service following 12
 4.7.1 Introduction 12
 4.7.2 Requirements 12

4.8 Analogue AM 12
 4.8.1 Introduction 12
 4.8.2 Requirements 12

4.9 Response to conditional access (CA) services 13
 4.9.1 Introduction 13
 4.9.2 Requirements 13

4.10 Response to system delay 13
 4.10.1 Introduction 13

4.10.2 Requirements 13

4.11 Signal integrity 13
4.11.1 Introduction 13
4.11.2 Requirements 13

4.12 Frequency bands 14
4.12.1 Introduction 14
4.12.2 Requirements 14

4.13 Frequency grid 14
4.13.1 Introduction 14
4.13.2 Requirements 14

4.14 Frequency Offset 14
4.14.1 Introduction 14
4.14.2 Requirements 15

4.15 Receiver display 15
4.15.1 Introduction 15
4.15.2 Requirements 15

4.16 Text messages 15
4.16.1 Introduction 15
4.16.2 Requirements 15

4.17 DRM service labels 15
4.17.1 Introduction 15
4.17.2 Requirements 16

5 INTERFACES 16

5.1 General 16

5.2 RF input 16

5.3 Data interface 16

6 OPTIONS 17

6.1 General 17

6.2 Multiplex features 17

6.3 DRM packet mode 17

6.4 Additional multiplex reconfigurations 17

6.5 Spectrum occupancy 18

7 MINIMUM PERFORMANCE LEVELS AND MEASURING METHODS 18

7.1 Introduction 18

7.2 General conditions 18
7.2.1 Power supply 18

7.2.2 Atmospheric conditions 18
7.2.3 BER and audio signal measurement conditions 18
7.2.4 DRM signal 19
7.2.5 Analogue AM signal 19

7.3 Antenna system 19
7.3.1 General 19
7.3.2 50 Ω antenna system 20
7.3.3 Emulation network for measurements 20
7.3.4 Emulation network for high level measurements 21
7.3.5 Emulation network for car receivers 21

7.4 Sensitivity 22
7.4.1 Introduction 22
7.4.2 Method of measurement at RF-input 23
7.4.3 Method of measurement for receivers with built-in antenna 23
7.4.4 Presentation of results 25
7.4.5 Requirements 25

7.5 Dynamic Range 25
7.5.1 Introduction 25
7.5.2 Method of measurement 26
7.5.3 Presentation of results 26
7.5.4 Requirements 26

7.6 Adjacent channel selectivity 26
7.6.1 Introduction 26
7.6.2 Method of measurement 26
7.6.3 Presentation of results 27
7.6.4 Requirements 27

7.7 Far-off selectivity 28
7.7.1 Introduction 28
7.7.2 Method of measurement 28
7.7.3 Presentation of results 28
7.7.4 Requirements 28

7.8 Blocking 28
7.8.1 Introduction 28
7.8.2 Method of measurement 28
7.8.3 Presentation of results 29
7.8.4 Requirements 29

7.9 Co-channel selectivity (co-channel rejection) 29
7.9.1 Introduction 29
7.9.2 Method of measurement 29
7.9.3 Presentation of results 30
7.9.4 Requirements 30

7.10 Receiver linearity 30
7.10.1 Introduction 30
7.10.2 Method of measurement 30
7.10.3 Presentation of results 31
7.10.4 Requirements 31

7.11 Performance in Rayleigh channels. 31
7.11.1 Introduction 31
7.11.2 Method of measurement 32

7.11.3 Measurement combinations 32
7.11.4 Presentation of results 33
7.11.5 Requirements 33

7.12 Acquisition time after tuning 34
7.12.1 Introduction 34
7.12.2 Method of measurement 34
7.12.3 Presentation of results 35
7.12.4 Requirements 35

ANNEX A 36

ANNEX B 39

ANNEX C 54

1 Scope

This document describes the DRM (Digital Radio Mondiale) receiver characteristics for consumer equipment intended for terrestrial reception operating in the frequency bands below 30 MHz (i.e. DRM robustness modes A—D). Receiver characteristics for DRM robustness mode E for higher frequencies will be added to a later revision of this document. Dedicated receivers for specific applications like data service decoders without audio representation are not within the scope of this document.

The goals of the document are to:

- Provide guidelines to receiver manufacturers for minimum receiver performance and technical features
- Provide confidence for broadcasters that their DRM transmission can be received by all receivers in the market
- Provide assistance for broadcasters to plan their network
- Provide confidence for consumers when buying a receiver that all important DRM features are supported by receivers and all DRM transmissions can be received

2 References

Normative and informative references are listed in this chapter.

2.1 Normative References

[1] ITU Radio Regulations.

[2] ETSI EN 201 980 Digital Radio Mondiale (DRM); System Specification

[3] ETSI TS 102 386 Digital Radio Mondiale (DRM); AM signalling system (AMSS)

[4] ETSI TS 102 349 Digital Radio Mondiale (DRM); Receiver status and Control Interface (RSCI)

[5] ETSI TS 102 821 Digital Radio Mondiale (DRM); Distribution & Communications Protocol (DCP)

[6] ETSI TS 102 820 Digital Radio Mondiale (DRM); Multiplex Distribution Interface (MDI)

[7] IEC 315-1 Methods of measurements on radio receivers for various classes of emission

2.2 Informative References

[8] Digitale Radio Mondiale: A ‘pseudo TEM-cell’ for receiver testing’, BBC, R.H.M. Poole, available under: http://www.bbc.co.uk/rd/pubs/whp/whp140.shtml

[9] Digital Radio Mondiale: Name for BBC report about audio criterion, BBC, O.Haffenden, available under: http://www.bbc.co.uk/rd/pubs/whp/whpxxx.shtml

[10] Evaluation tool about audio criterion: http://sourceforge.net/projects/drm, to be published soon

3 Terms and definitions

DRM Receiver
receiver which is intended to receive and decode programmes transmitted according to the DRM system specification ETSI EN 201 980

DRM Audio Receiver
receiver which is intended to receive and decode audio programmes transmitted according to the DRM system specification ETSI EN 201 980

Minimum Requirements
specify the lowest performance that a DRM receiver should achieve in order to be called a DRM receiver. It takes into account low cost receivers

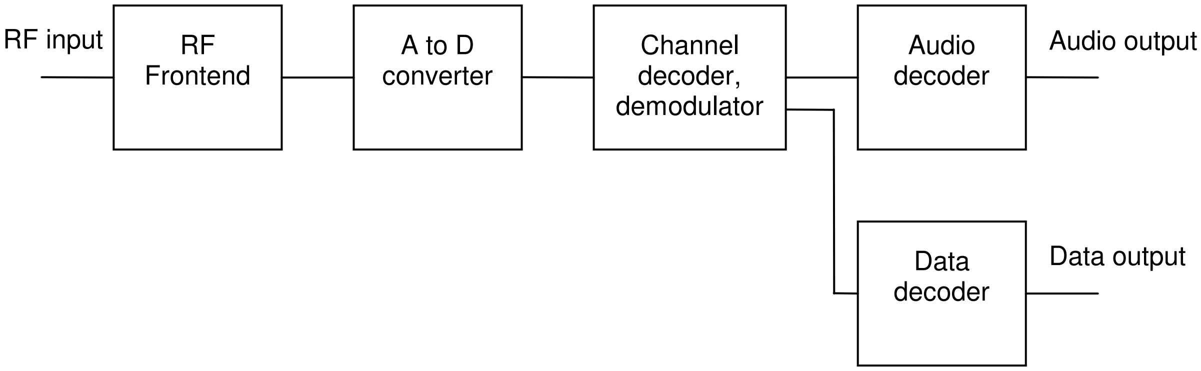

Figure 1 Example of functional block diagram of a DRM Receiver

4 Basic implementation and functional performance requirements

4.1 Audio decoder

4.1.1 Introduction

The audio decoder is shown in Figure 1 and comprises HVXC and CELP speech decoders and an AAC audio decoder including pre- and post-processing.

4.1.2 Requirements

The audio decoder function of a DRM Audio Receiver shall conform to the DRM system specification. The following features shall be supported:

- all three audio coding systems: CELP, HVXC and AAC
- the high frequency reconstruction method SBR
- all sampling rates according to the coding system: These are 8 kHz for HVXC, 8 kHz and 16 kHz for CELP, 12 kHz and 24 kHz for AAC.
- At least those data rates listed below according to the coding system:
    - For HVXC: 2000 bps without SBR to 14360 bps with SBR
    - For CELP: 3850 bps without SBR to 34300 bps with SBR
    - For AAC: up to 34760 bps.
- all AAC audio modes: stereo, mono and parametric stereo. Mono receivers shall be compatible with stereo and parametric stereo transmissions, e.g. a valid mono signal shall be output.

The audio decoder shall include an error concealment method. If for any reason the data stream cannot be decoded, the receiver shall avoid annoying sounds for example by muting.

4.2 Channel decoder and demodulator

4.2.1 Introduction

The channel decoder and demodulator is shown in Figure 1 and comprises the OFDM processing, QAM-demodulation, de-interleaving and channel decoding.

4.2.2 Requirements

The channel decoder and demodulator function of a DRM Receiver shall conform to the DRM system specification. The following features shall be supported:

- all robustness modes: A, B, C, D
- all signal constellations: 4-QAM and 16-QAM for the SDC and 16-QAM and 64-QAM for the MSC

- all protection levels: 0, 1, 2, 3 (64-QAM) and 0, 1 (16-QAM)
- hierarchical modulation: the standard protected part (SPP) and the very strongly protected part (VSPP) of the 3 different mappings: standard mapping (SP), symmetrical hierarchical mapping (HMsym) and the mixture of the previous two mappings (HMmix).
- equal error protection (EEP) and unequal error protection (UEP) in all possible combinations of protection levels with every allowed partitioning of data lengths for part A and part B of the MSC frame.
- both interleaver depths: long and short
- all transmission rates: data rates before channel decoding of up to 44385 bps

Different spectrum occupancies are defined in the DRM system specification. The spectrum occupancies 0 to 3, with bandwidths of 4,5 kHz, 5 kHz, 9 kHz and 10 kHz respectively shall be supported. Additional requirements for the decoding of the spectrum occupancies 4 and 5, with respective bandwidths 18 kHz and 20 kHz, are listed in section 6.5.

4.3 Service selection

4.3.1 Introduction

The DRM multiplex consists of the MSC (Main Service Channel), FAC (Fast Access Channel) and the SDC (Service Description Channel). The multiplex may contain up to 4 services and each service may be either of type audio or data. An audio service carries one audio service component (with or without text message information) and optionally one data service component, while a data service only carries one data service component.

See DRM system standard annex M “MSC configuration examples” for details.

4.3.2 Requirements

To gain access to the desired service, the receiver must decode the FAC service parameters and the SDC data entities 0 (MSC structure) and 5 (data service component) and/or 9 (audio service component) and in addition data entity 1 (service label) and make the information available to the MMI (Man Machine Interface) for selection. DRM Audio Receivers shall allow the user to select any individual audio service and data service (if the data application type is supported) within reception range that does not use CA (Conditional Access).

4.4 Receiver reactions to multiplex-reconfiguration

4.4.1 Introduction

There are two types of reconfiguration: a service reconfiguration and a channel reconfiguration. A service reconfiguration is one in which the data capacity of the MSC is reallocated between services. This happens when the number of services in the multiplex is changed, the parameters of the service components, or the size of data streams is changed. A channel reconfiguration is one in which the following FAC channel parameters are altered: spectrum occupancy, interleaver depth, MSC mode and when the robustness mode is changed. All reconfigurations are signalled in advance. Some reconfigurations can be handled without audio interruption, others cannot.

4.4.2 Requirements

The DRM Receiver shall handle all reconfigurations. Table 1 lists the requirements. The SDC data entity 10 and the following SDC data entities shall be decoded to make the receiver aware of the type of reconfiguration. The FAC reconfiguration index shall be evaluated to determine the time of the reconfiguration.

Table 1 Overview of reconfigurations

Case	Type	Reconfiguration	Comment	Requirement
1	Channel reconfiguration	Spectrum occupancy	Not possible without audio interruption. Time and frequency synchronisation should be very accurate in the transmitter. Also channel estimation not available in the receiver. The number of samples in the interleaver changes.	Audio interruption shall not exceed acquisition time in Table 9.
2	Channel reconfiguration	Robustness mode	Not possible without audio interruption. Difficult to achieve channel estimation without interruption. The number of samples in the interleaver changes.	Audio interruption shall not exceed acquisition time in Table 9.
3	Channel reconfiguration	Interleaver depth	When changing from long to short interleaving bits in the encoder will normally be missing. When changing from short to long interleaving bits will be needed to fill the interleaver before any output is possible.	Receiver should proceed with decoding without the need for new synchronisation. Audio interruption shall not exceed acquisition time in Table 9.
4	Channel reconfiguration	MSC mode	Possible on transmission super frame basis	No audio interruption
5	Channel reconfiguration	SDC mode	Possible on transmission super frame basis	No audio interruption
6	Service reconfiguration	SDC type 0 Protection level	Possible on transmission super frame basis	No audio interruption
7	Service reconfiguration	SDC type 0 Data length	Possible on transmission super frame basis	No audio interruption

8	Service reconfiguration	SDC type 9 Audio coding	Possible on transmission super frame without audio interruption, but receiver implications expected. Broadcaster should reconfigure during silence.	Audio interruption shall be less than 400 ms
9	Service reconfiguration	SDC type 9 SBR flag	Possible on transmission super frame basis	No audio interruption
10	Service reconfiguration	SDC type 9 Audio mode	Possible on transmission super frame basis	No audio interruption
11	Service reconfiguration	SDC type 9 Audio sampling rate	Possible on transmission super frame basis	No audio interruption
12	Service reconfiguration	Audio data rate	Possible on transmission super frame basis	No audio interruption

In the case where a reconfiguration event combines more than one reconfiguration type, the least stringent requirement shall apply. For example, if a reconfiguration consists of case 1 and case 4 the requirement will be as for case 1.

SDC data entities 1 (Label), 3, 4, 7, 11, 13 (AFS information), 12 (Language and country), 6 (Announcement support) and 8 (Time and date information including the local time offset) may change at any time. Changes limited to these parameters will not be signalled as a reconfiguration. Changes limited to the FAC service parameters ‘language’ and/or ‘programme type’ (only present for audio services) will not be signalled as a reconfiguration. All these changes shall be supported without audio interruption.

Note: More information on conditions for seamless reconfigurations is listed in Annex Q of the DRM system specification.

4.5 Handling of optional features

4.5.1 Introduction

The DRM system specification includes many features signalled in the FAC and SDC; some of which are optional for implementation in receivers. Different Broadcasters use different subsets of features.

4.5.2 Requirements

The DRM Receiver shall have a deterministic response to all states of control data and shall ensure proper function independent of whether optional features are in use or not.

4.6 Backwards compatibility

4.6.1 Introduction

The DRM system specification includes several possibilities to expand the system with new features. Therefore some bits in the FAC and SDC are reserved for future use and future addition. The receivers shall ignore bits “reserved for addition”. The receiver shall check explicitly bits “reserved for future use”. If such a bit is unequal to "0", then the parameter(s) to which this rfu bit refers to shall be ignored.

4.6.2 Requirements

The DRM Receiver shall support backwards compatibility. All information in the multiplex reserved for future use or future addition shall be handled as described in the DRM system specification to assure proper function after system extensions. This includes the signalling of the ‘Enhancement Layer’ of the DRM multiplex structure wherever available.

4.7 Service following

4.7.1 Introduction

The DRM system is able to signal alternative frequencies for services in the SDC in a comprehensive manner. Because of mobile reception or varying channel characteristics various transmission frequencies could be used for reception. Different strategies for switching between frequencies in the receiver exist. Implementations with manual switching or automatic switching are possible.

4.7.2 Requirements

The DRM receiver shall support switching between alternative frequencies of DRM transmissions and analogue AM transmissions with AMSS for the same service. The service could be broadcast at the same time on different frequencies or consecutively on different frequencies. SDC data entities type 3 and 11 shall be decoded, and SDC data entities 4, 7 and 13 should be decoded to improve the switching process in the receiver. Therefore the receiver shall support the switching process so that the user is not required to have any knowledge of the alternative frequency values.

4.8 Analogue AM

4.8.1 Introduction

The analogue AM system is widely used all over the world. The transition from the analogue to the digital world requires careful planning by broadcasters. The AM signalling system (AMSS) defines a system for adding a limited amount of service information to analogue broadcasts in the frequency bands below 30MHz in a complementary way to the DRM system.

4.8.2 Requirements

The DRM receiver shall support analogue AM reception and decoding of AMSS.

4.9 Response to conditional access (CA) services

4.9.1 Introduction

In DRM some service components may be individually scrambled to make these components incomprehensible for unauthorised users.

4.9.2 Requirements

DRM Receivers without CA capabilities shall either make scrambled services unavailable for selection or indicate their presence together with the fact that they are scrambled and thus not accessible. If a service consists of two service components and only one of them is scrambled, the receiver shall still present the non-scrambled service component.

Special care has to be taken in the transition from "unscrambled" to "scrambled". When this occurs on one of the selected services, the receiver shall mute the audio and give an appropriate indication.

4.10 Response to system delay

4.10.1 Introduction

After selecting a DRM reception frequency the DRM receiver needs some time until the audio signal will be available. This delay depends on the processing time in the receiver for synchronisation and channel estimation and also on the interleaver depth. For the user the reason for the delay will not be obvious, and it is therefore necessary to provide some feedback to the user.

4.10.2 Requirements

The DRM Receiver shall indicate if reception on the chosen frequency is possible after tuning or switch-on.

4.11 Signal integrity

4.11.1 Introduction

The position and orientation of the DRM receiver and its antenna will influence the reception quality. Because of the inherent delay in the receiver between signal reception and audio output it is difficult for the user to find the optimum position for the receiver while listening to a program. Information from the receiver about signal integrity is therefore helpful.

4.11.2 Requirements

The DRM receiver shall indicate the signal integrity by evaluation of the signal-to-noise ratio, the bit error rate, the field strength or some other meaningful method. This indication shall help the user to optimise the radio position.

Note: This requirement is only valid for portable receivers or receivers with external antennas. Other types of receivers like car receivers are not affected.

4.12 Frequency bands

4.12.1 Introduction

DRM with robustness modes A—D provides a system for digital transmission in the broadcasting bands below 30 MHz. These frequencies are split into LF, MF and HF bands. The usage of these bands depends on the ITU Region.

4.12.2 Requirements

The DRM Receiver shall support at minimum the category MF or LF or HF1 and HF2 of Table 2. It is strongly recommended to support all.

Table 2 Frequency bands

Receiver category	Frequency range	ITU Region
Category LF	148,5 kHz to 283,5 kHz (Region 1)	Region 1
Category MF	525 kHz to 1710 kHz	worldwide
Category HF 1	2,3 MHz to 6200 kHz	worldwide
Category HF 2	6200 kHz to 27 MHz	worldwide

Note: The frequencies around 455 kHz and 10,7 MHz are often used as intermediate frequencies in the receivers and are not useful for reception.

4.13 Frequency grid

4.13.1 Introduction

The frequency grid is dependent on the band and the ITU Region. The reception of all regulated transmissions should be possible.

4.13.2 Requirements

The DRM receiver shall allow reception of DRM transmissions in 3 kHz steps in the LF band, in 1 kHz steps in the MF band and 5 kHz steps in the HF bands.

4.14 Frequency Offset

4.14.1 Introduction

Different transmission configurations especially some simulcast options can induce frequency offsets from the nominal frequency grid.

4.14.2 Requirements

The DRM receiver shall support the reception of DRM transmissions with offsets up to +/- 600 Hz from the nominal frequency grid.

4.15 Receiver display

4.15.1 Introduction

The display is useful to inform the user about the current broadcast. Different receiver categories have different requirements with regard to user feedback. The general receiver is the typical in-home, portable or handheld receiver. The car receiver is applicable to the automotive environment. The specialist receiver is a tuner box which may be connected to an external controller, and may not have its own display.

4.15.2 Requirements

General DRM receivers shall have a display with a minimum of 2 lines of 16 characters. Car receivers shall have a display size appropriate to the automotive environment, preferably with a minimum of 1 line of 16 characters. Specialist receivers shall have an appropriate interface to allow feedback to the user.

4.16 Text messages

4.16.1 Introduction

Text messages can provide valuable additional information to the user. The implementation effort at the receiver is low.

4.16.2 Requirements

General DRM receivers with a display according to section 4.15.2 shall support text messages. The implementation shall conform to the DRM system specification including UTF-8 character coding explicit checking of provided CRC values, and support for additional codes

The receiver shall display all Unicode characters supported by the used display type and font set. For characters that cannot be displayed, the rules described in the DRM system specification, annex G (Guidelines for receiver implementation), clause G.4 (character sets) shall apply. Individual characters not supported by the receiver character set may for example be replaced by spaces.

UTF-8 may use multiple bytes per character. The receiver shall assure that a replacement character (if needed) shall be output once per unknown character, not per byte of a multi byte sequence!

4.17 DRM service labels

4.17.1 Introduction

DRM service labels are transmitted per service in the SDC data entity type 1.

4.17.2 Requirements

All DRM receivers with a display according to section 4.15.2 shall support displaying the service label. Whenever possible, the full service label (up to 16 characters) should be shown without scrolling.

The receiver shall display all Unicode characters supported by the used display type and font set. For characters that cannot be displayed, the rules described in the DRM system specification, annex G (Guidelines for receiver implementation), clause G.4 (character sets) shall apply. Individual characters not supported by the receiver character set may for example be replaced by spaces.

UTF-8 may use multiple bytes per character. The receiver shall assure that a replacement character (if needed) shall be output once per unknown character, not per byte of a multi byte sequence!

5 Interfaces

5.1 General

If any of the following interfaces are implemented, the described standardised versions should be used. Dedicated solutions, which do not require connections to other standard products, may use special interfaces.

5.2 RF input

An internationally recognised antenna connector should be used.

5.3 Data interface

It is recommended for DRM Receivers with a data interface to use the Receiver Status & Control Interface (RSCI) based on the Distribution & Communication Protocol (DCP) for providing the full received digital DRM Multiplex information (FAC, SDC, MSC) and reception statistics data to external decoder/monitoring/visualisation units. Optionally the receiver may accept control commands via RSCI (to for example allow remote re-tuning of the reception frequency). The digital DRM Multiplex may in addition be output using the Multiplex Distribution Interface (MDI over DCP), a sub-set of the RSCI information.

The receiver may also provide an input for digital DRM Multiplex information via MDI or RSCI for further decoding, internally bypassing the receiver’s HF and demodulation stages.

The combination of an MDI/RSCI output and an MDI/RSCI input can for example be used for external on-the-fly conditional access decoding, for temporary storage of received data (‘delayed playback’), or for general recording and playback of DRM transmissions.

6 Options

6.1 General

The following features are not mandatory for a basic receiver, but are recommended. When any of these optional features are supported they shall be implemented in accordance with the DRM system specification.

6.2 Multiplex features

It is recommended to use multiplex features such as program type, language and announcements to simplify the operation of a receiver for the user. The features shall be implemented in accordance with the DRM system specification.

6.3 DRM packet mode

An MSC stream can use the DRM packet mode mechanism to distinguish up to 4 sub-streams, each carrying an individual data service component. The DRM packet mode allows to carrying a continuous data stream per service component, or a sequence of DRM data units (i.e. blocks of bytes of well-defined length). If a DRM receiver supports decoding the DRM packet mode, the SDC data entity 5 shall be supported. In addition the Forward Error Correction (FEC) for packet mode streams should be supported, which is signalled in SDC data entity type 14.

6.4 Additional multiplex reconfigurations

Receivers supporting CA shall support also reconfiguration case 13 for currently decoding CA protected services or if CA is newly enabled for a service (signalled in the FAC service parameters).

Receivers with data decoders shall support also reconfiguration case 14. Packet mode parameters like packet length or packet Id may be changed without reception interruption; behaviour after changes in application data is application dependent.

Table 3 Additional multiplex reconfigurations

Case	Type	Reconfiguration	Comment	Requirement
13	Service reconfiguration	SDC type 2 Conditional Access	Possible on transmission super frame basis	No long interruption
14	Service reconfiguration	SDC type 5 Application information	Possible on transmission super frame.	No long interruption

Note: SDC data entity type 5 data entities only need to be monitored by the receiver in case of data service components being currently presented to the user

6.5 Spectrum occupancy

It is recommended to support spectrum occupancies 4 and 5 according with bandwidths of 18 kHz and 20 kHz respectively. DRM Receivers shall support data rates for audio decoding of up to 71960 bps for AAC and/or data application decoders and transmission data rates for the MSC of 91770 bps. Requirements for the other spectrum occupancies are explained in section 4.2.2.

7 Minimum performance levels and measuring methods

7.1 Introduction

Receivers with an external antenna input have to be tested excluding antenna, receivers with built-in antenna have also to be tested including antenna.

A comprehensive specification shall contain all the performance values in accordance with this chapter. Abbreviated specifications may be published in addition. In both cases, the published values of all the characteristics shall be measured by the methods specified here. There should be a statement to that effect in the text or footnotes of the measurement results. For example, this might read: "measured in accordance with DRM document: Minimum Receiver requirements for DRM". All measurement results shall be published for all frequency bands covered.

7.2 General conditions

7.2.1 Power supply

The power supply shall be in accordance with IEC 60315-1.

7.2.2 Atmospheric conditions

The atmospheric conditions for measurement shall be within the ranges:

Ambient temperature:	15°C to 35°C
Relative humidity:	25 % to 75 %
Atmospheric pressure:	86 kPa to 106 kPa

For further information, see EN 60068-1, EN 60721 and IEC Guide 106.

7.2.3 BER and audio signal measurement conditions

The bit error ratio (BER) shall be measured at the receiver's multilevel decoder output. During the measurement, the receiver should remain synchronised. Unless otherwise noted, BER measurements shall be performed in the MSC, using equal error protection (EEP), protection level 1, MSC mode 0, interleaver depth 1 and robustness mode B. The spectrum occupancy shall be 2 (9 kHz) for the frequency categories LF and MF and 3 (10 kHz) for the frequency category HF.

The test sequence should comprise the whole multiplex to reduce the measurement time. The number of bits in the measurement time shall be at minimum 10^6 if not otherwise stated.

Any known digital pattern with a length of more than 1 symbol can be used as the test sequence. For example, either all zeros or a test pattern confirming to ETSI TS 102 349 “Receiver status and Control Interface” would be suitable.

In the case the BER is not available at the receiver, the audio signal can be used to judge the receiving quality. For the evaluation a distinction between Gaussian-like disturbances and Rayleigh channels has to be done. The procedure is described in Annex C.

7.2.4 DRM signal

The generated DRM signal shall be in accordance with ETSI ES 201 980.

7.2.5 Analogue AM signal

As it is difficult to generate a signal modulated with ITU colored noise or with a de-emphasis filtered white noise signal with standard laboratory measurement equipment the following set up shown in Figure 2 shall be used. The modulated AM signal is generated with a sine sweep of 100 Hz to 4.1 kHz and a sweep time of 20 ms. This sine shall be modulated with a factor of 30 %. For measurement purpose the signal power is defined as the power of the AM carrier neglecting the sidebands.

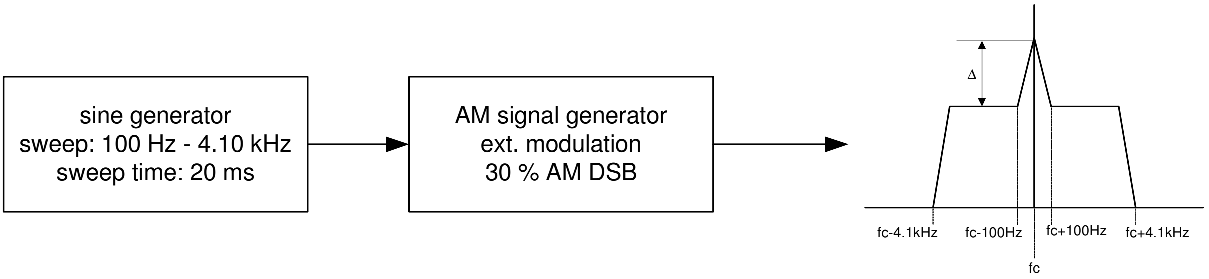

Figure 2 AM signal generation

The spectrum is shown with a peak hold after one complete modulation signal sweep (20 ms). Details of the signal generation are explained in Annex A. The analogue AM signal is needed for co-channel selectivity measurements.

7.3 Antenna system

7.3.1 General

Different kinds of antennas are suitable for different applications. Portable receivers are usually provided with high-impedance, electrically-short whip antennas. The receiver must present such an antenna with a high-impedance load to prevent excessive signal loss. Car radios generally also have high-impedance inputs, although a typical antenna arrangement has a low-impedance output. Professional receivers would normally be provided with 50 ohm inputs.

When testing the sensitivity of a portable receiver, it is recommended that the normal antenna is connected and the complete receiver placed within a TEM-cell. In addition, an emulation network can be used, as detailed in 7.3.3. An emulation network for car radios is given in 7.3.5. The emulation network shall always be connected directly to the receivers RF input to prevent impedance change originating from additional cables.

7.3.2 50 Ω antenna system

DRM Receivers developed with 50 Ω RF-input impedance can be connected directly to signal generators. The defined voltage values can be set directly at the signal generator.

7.3.3 Emulation network for measurements

The antenna emulation network is necessary to provide a convenient way of measuring the receiver performance under realistic conditions of source impedance and EMF. The network is designed such that at a given input power level, the output is equivalent to that of a standard antenna in a field strength of 0dBµV/m.

A suitable emulation network is provided for a short (0.7m) whip antenna of average diameter 5mm, attached to a receiver of a reasonable size (250 x150x 100mm). This arrangement is considered to be typical of what might be used in a typical portable ("kitchen") receiver. The circuit values are derived from a combination of theoretical analysis and practical measurement. The effective length is assumed, from theory, to be 0.35m. However, due to the small dimensions of the ground plane, this may not be strictly accurate.

It will be clear that the performance of the antenna will be critically dependent on the dimensions of the ground plane and the presence of any external cabling such as power supply leads etc. Manufacturers should measure the sensitivity and other parameters assuming the worst case, i.e. for a battery/mains receiver, the unit should be measured while running on its internal batteries and placed on a non-conductive surface.

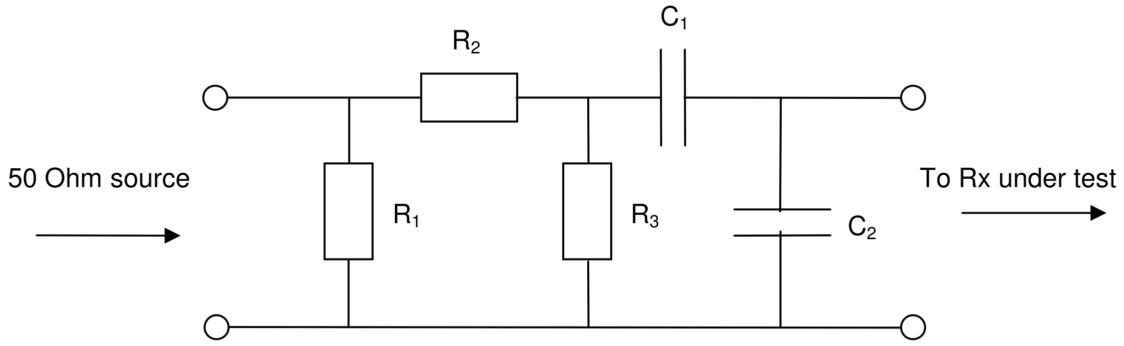

Figure 3 Diagram of antenna network

The network is shown in Figure 3 and the derivation of the component values is given in Annex B. It is up to the receiver manufacturer to determine whether the values used are representative for their particular receiver. Emulation networks for magnetic (H-field, or loop) antennas are not provided. This is because firstly, it will be very difficult to make a connection to a receiver which uses an H-field antenna without disturbing the circuit conditions (as such antennas usually form part of a high Q tuned circuit), and secondly, that generation of a known field strength for measurement purposes is relatively straightforward.

For the aforementioned antenna, the following values are suggested:

R1 = 180Ω

R2 = 68Ω

R3 = 5.1Ω

C1 = 6.8pF

C2 = 3.9pF

For these values, an input level of –85dBm (22dBμV) is equivalent to a field strength of 0dBμV/m. This level is chosen as a compromise between convenience and output level requirement of the signal source. It is found from both theory and measurement that a single emulation network may be used for the entire frequency range, assuming that the antenna is electrically short compared with the shortest wavelength used (11m). In practice, this will be true of most antennas that are supplied with DRM receivers, so this network is a reasonable one to use for test purposes. If any larger antenna is used, for instance by a radio enthusiast, the effective sensitivity will be improved.

Unless there is good reason, in any specific situation, to do otherwise, it is suggested that receiver manufacturers assume that an electrically-short whip will be used as an antenna.

If another emulation network is used the receiver manufacturer shall give reasons for it. The network circuit and the conversion factor between field strength and input level shall be provided.

Details about the derivation of the antenna network are provided in Annex B.

7.3.4 Emulation network for high level measurements

The emulation network described above has too much attenuation to allow it to be used for dynamic range measurements, where very high signal levels are required. For this reason, a different network is proposed. Whilst this is a slightly less accurate emulation of the antenna, the difference will not be significant as far as the receiver is concerned. The values required are:

R1 – Not fitted

R2 = 0Ω

R3 = 50Ω

C1 = 6.8pF

C2=3.9pF

For the 0.7m antenna, the effective height is 0.35m. Therefore the voltage required at the input is 0.35 x the desired field strength on V/m.

For instance, to emulate a field of 10V/m, 3.5V (+24dBm) must be supplied by the signal generator.

7.3.5 Emulation network for car receivers

The emulation network described is applicable for receivers with high impedance designed for active antennas with 50 Ω. This is a typical case for car receivers. The network is derived from a description in IEC 315-1.

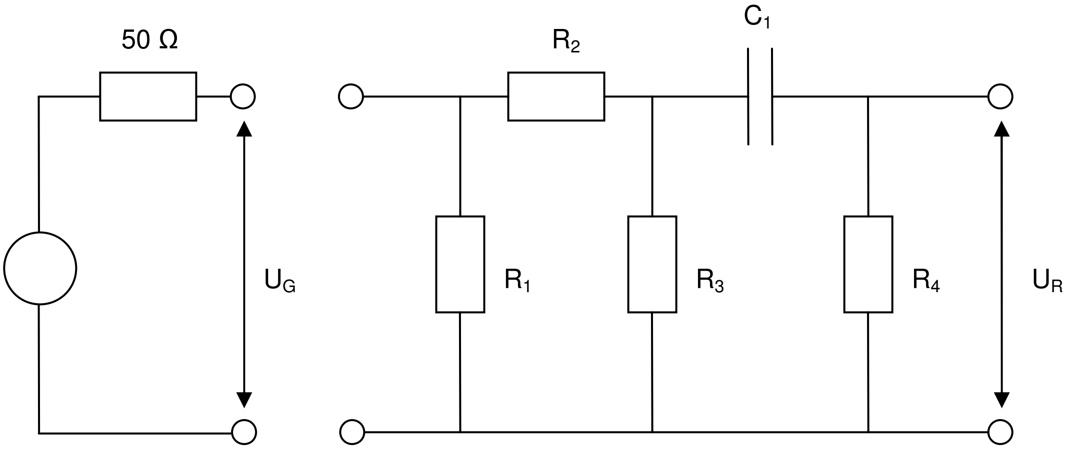

Figure 4 Diagram of antenna network for car receivers

The following values are given:

R_1 = 150 Ω

R_2 = 37,5 Ω

R_3 = 470 Ω

R_4 = 220 Ω (load for remote power supply)

C_1 = 470 nF (blocking of DC components of the receiver)

$U_G = U_R$ is valid.

This assumption is valid if the signal generator has an 50 Ω impedance output and the receiver has a high impedance input. The loss of the network is compensated by the mismatching between signal generator and antenna network. The reason for it is that the signal generator sees a higher impedance when connected to the network and delivers a higher voltage.

All in the following sections defined voltage values shall be set at the signal generator when using this antenna network. The attenuation of the network is independent of the used frequency and the input impedance of the receiver (for an impedance higher than 300 Ω).

7.4 Sensitivity

7.4.1 Introduction

The sensitivity value gives an indication of the lowest RF-input level and field strength of the DRM receiver for a given reception quality, in other words it measures the ability of the receiver to decode weak signals. The measurement shall be arranged for all receivers according to section 7.4.2 and in addition according to section 7.4.3 for receivers with built-in antenna.

7.4.2 Method of measurement at RF-input

The measurement setup is given in Figure 5 below. The signal generator shall be connected to the RF-input of the receiver under test. The BER shall be measured at the output. The input level is reduced until the BER reaches 10^{-4}.

The measurement shall be done for each supported type of power supply. Thus battery/mains receivers shall be tested while running on internal batteries as well as while mains operated.

Note: The operation with a mains adaptor could improve the sensitivity or decrease the sensitivity because of additional interferences.

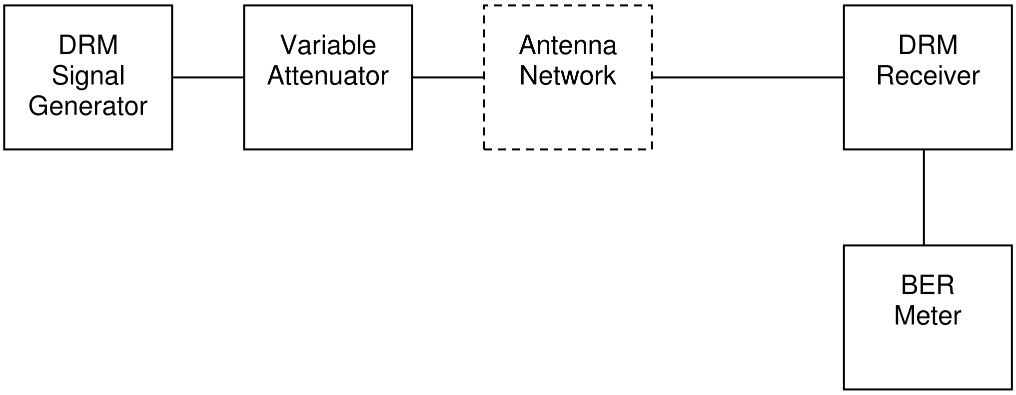

Figure 5 Block diagram for the measurement of sensitivity and maximum input power

7.4.3 Method of measurement for receivers with built-in antenna

The measurements are split for E-field antennas as rod antennas and H-field antennas as ferrite rod and magnetic loop antennas. According the used antenna types in the receiver the appropriate measurement setup for the relevant frequency ranges have to be chosen. The measurements shall be executed on a number of selected frequencies per frequency category to ensure the performance. The measurement shall be done for each supported type of power supply. Thus battery/mains receivers shall be tested while running on internal batteries as well as while mains operated according to Figure 6 and Figure 7.

The sensitivity of the receiver should be measured by means of a TEM-cell, GTEM-cell or pseudo TEM (PTEM) -cell. In that way, the receiver will be subjected to uniform E- and H-fields in the correct proportion. To get accurate results the minimum height for the cell should be at least 1.5 m and the maximum variation in field-strength over the volume occupied by the receiver-under-test including antenna should be less than +/- 3 dB.

An appropriate design of PTEM-cell is described in document [8]. The measurements should be carried out at intervals of no greater than 1 MHz on HF, and no greater than 100 kHz on LF and MF: this is necessary to show up any problems with self-interference.

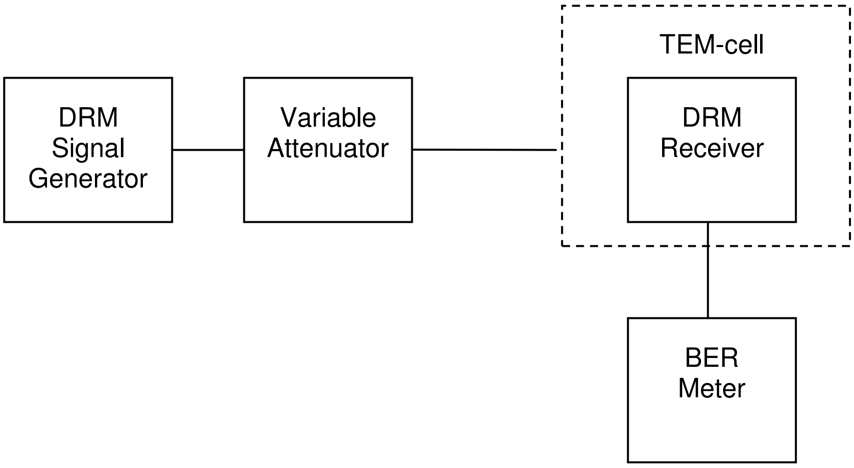

Figure 6 Block diagram for the measurement of sensitivity in a TEM-cell

Where the receiver is to be tested while running on internal batteries, it should be placed midway between the floor and septum of the TEM-cell, or midway between the lower and upper transmission lines of the PTEM-cell. Before testing starts, the E-field at the midpoint should be checked using a calibrated probe. The calibration has to take potential differences of the detector between CW-signals and DRM-signals into account. The probe should also be used to ensure that the field variation does not exceed ±3 dB, relative to its midpoint value, over the height occupied by the receiver and antenna. The receiver and antenna should occupy no more than half the distance between the floor and septum, or between the two transmission lines of the PTEM-cell.

Where the receiver is to be powered by mains adapter, the receiver and power cable should be placed on the floor of the TEM-cell, or, in the case of the PTEM-cell, on a wooden surface at approximately mid-way between the transmission lines. The E-field needs to be checked appropriately, as indicated in the diagram below.

No connections other than the power supply should be made to the receiver.

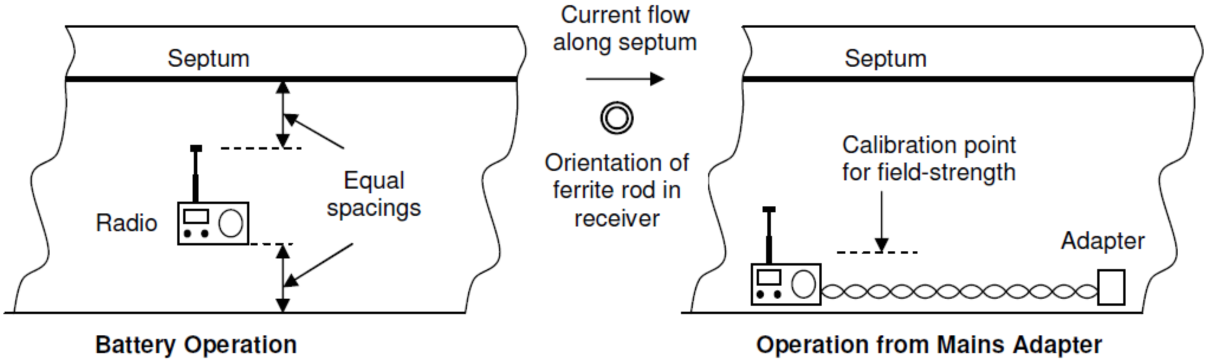

Figure 7 Diagram to show the positioning of receiver in TEM-cell

7.4.4 Presentation of results

The sensitivity is the input level expressed in dBµV at which the BER reaches 10^{-4}. It shall be given for all covered frequency bands. For receivers with built-in antennas in addition the sensitivity is expressed in dBµV/m at which the BER reaches 10^{-4}.

7.4.5 Requirements

Table 4 gives the required values for the different broadcasting bands.

Table 4 Minimum requirements for sensitivity

Min. requirement	LF	MF	HF 1	HF 2
Field strength (TEM cell measurement)	46 dBµV/m	40 dBµV/m	32 dBµV/m	28 dBµV/m
Voltage at signal generator output (Portable receiver network)	68 dBµV	62 dBµV	54 dBµV	50 dBµV
Voltage at signal generator output (Portable receiver high level network))	37 dBµV	31 dBµV	23 dBµV	19 dBµV
Voltage at signal generator output (Car receiver network or without network)	8 dBµV	8 dBµV	8 dBµV	8 dBµV

Note: The requirements from Table 4 are defined for the receiver including casing. Hence modules need better values to compensate for losses of the casing.

Note: It has to be taken into account that the sensitivity of the receiver measured with a cable to the RF-input should be better than stated in Table 4 to compensate for additional receiver internal interferences when measuring the sensitivity with built-in antenna according to section 7.4.3.

When stating the sensitivity performance of a receiver with built-in antenna a precise description of the measurement set-up including TEM-cell type, size and calibration method has to be given.

7.5 Dynamic Range

7.5.1 Introduction

The dynamic range is the difference between the weakest and strongest signal a receiver can demodulate. It depends mainly on the automatic gain control of the receiver. The relevant measurement is the difference in level between the required minimum sensitivity and the strongest signal the receiver can handle at a given quality level.

7.5.2 Method of measurement

The same measurement set up as given in Figure 5 shall be used. The input level is increased until the BER reaches 10^{-4} or just before synchronisation is lost.

The measurements have to de done with the emulation network for high level measurements for portable receivers or the car radio network for car radios.

7.5.3 Presentation of results

The dynamic range is expressed in dB relative to the required minimum sensitivity. It shall be given for all frequency bands covered.

7.5.4 Requirements

Table 5 gives the required values for the different broadcasting bands.

Table 5 Minimum requirements for dynamic range

Min. requirement	LF	MF	HF 1	HF 2
Dynamic range	84 dB	90 dB	80 dB	80 dB

7.6 Adjacent channel selectivity

7.6.1 Introduction

The selectivity of a receiver is a measure of its ability to discriminate between a wanted signal to which the receiver is tuned and unwanted signals entering the RF-Input. In case of adjacent channel selectivity the unwanted signal or interferer is in the neighbouring channels to the wanted signal.

7.6.2 Method of measurement

The measurement set up is depicted in Figure 8. Both wanted signal and interferer shall be DRM signals according to 7.2.4.

The distance between the centre frequencies of the DRM signals depends on the selected neighbouring channel (see table Table 6). Upper and lower adjacent channels shall be tested. The spectrum occupancy for both DRM signals shall be 2 (9 kHz) or 3 (10 kHz) dependent on the frequency category. The spectrum of the signal generator shall have an intermodulation shoulder (measured at 4.5 kHz from centre frequency) of more than 45 dB and a sufficient low noise floor.

The level of the wanted signal P_{wanted} at the DRM receiver input shall be adjusted to 10 dB above the minimum required sensitivity (Table 4) using the attenuator 1 when signal generator 2 is switched off. The signal level P_{unwanted} of the interfering signal shall then be increased until a BER of 10^{-4} is reached.

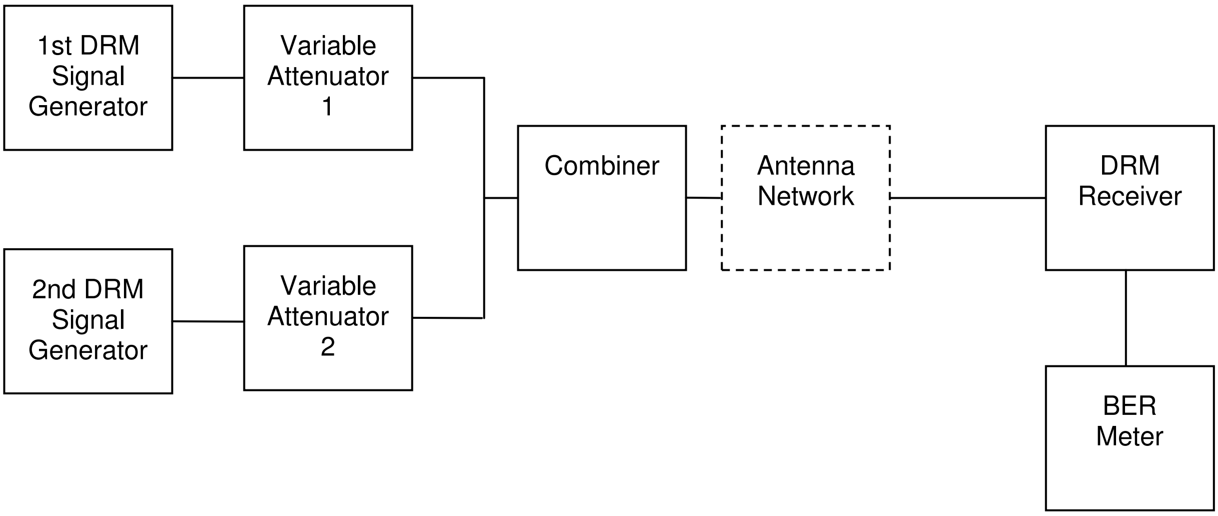

Figure 8 Block diagram for selectivity measurements

7.6.3 Presentation of results

The adjacent channel selectivity A_{CS} of a DRM receiver is expressed in dB. The value shall be calculated from the adjusted signal levels by the following equation:

$A_{CS} = P_{unwanted}$ [dB] $-P_{wanted}$ [dB]

The unwanted signal can be on either side of the wanted signal in frequency representation. The worse A_{CS} value for each frequency spacing shall be noted.

7.6.4 Requirements

The adjacent channel selectivity shall be greater than the values listed in Table 6 for all bands.

Table 6 Adjacent channel suppression

Adjacent channel	Frequency spacing	A_{CS}
1st adjacent channel	9/10 kHz	25 dB
2nd adjacent channel	18/20 kHz	35 dB
3rd adjacent channel	27/30 kHz	45 dB
Further	≥ 36/40 kHz and < 400 kHz	50 dB

7.7 Far-off selectivity

7.7.1 Introduction

The far-off selectivity of a receiver is a measure of its ability to discriminate between a wanted signal to which the receiver is tuned and unwanted signals which are separated in frequency by several channel spacings.

7.7.2 Method of measurement

The measurement set up is depicted in Figure 8. Both wanted signal and interferer shall be DRM signals according to 7.2.4.

The frequency of the unwanted signal should be ≥ 400 kHz from the centre frequency of the wanted DRM signal and can be on either side of the wanted signal in frequency representation. The level of the wanted signal P_{wanted} at the DRM receiver input shall be adjusted to 20 dB above the minimum required sensitivity (Table 4) using the attenuator 1 when signal generator 2 is switched off. The signal level P_{unwanted} of the interfering signal shall then be increased until a BER of 10^{-4} is reached.

7.7.3 Presentation of results

The far-off selectivity or rejection ratio R_r of a DRM receiver is expressed in dB. The value shall be calculated from the adjusted signal levels by the following equation:

$$R_r = P_{\text{unwanted}}\,[\text{dB}] - P_{\text{wanted}}\,[\text{dB}]$$

The worst R_r value shall be noted.

7.7.4 Requirements

The far-off selectivity shall be greater than 60 dB.

Within three reception channels which can be chosen by the receiver manufacturer the far-off selectivity can be relaxed. At these frequencies the far-off selectivity shall be 40 dB. The frequencies shall be stated in the measurement report of a receiver.

7.8 Blocking

7.8.1 Introduction

The blocking of a receiver is a measure of its ability to discriminate between a wanted signal to which the receiver is tuned and unwanted signals where the wanted signal level is near the sensitivity level.

7.8.2 Method of measurement

The measurement set up is depicted in Figure 8. Both wanted signal and interferer shall be DRM signals according to 7.2.4.

The frequency of the unwanted signal should be ≥ 400 kHz from the centre frequency of the wanted DRM signal and can be on either side of the wanted signal in frequency representation. The level of the wanted signal P_{wanted} at the DRM receiver input shall be adjusted to 3 dB above the minimum required sensitivity (Table 4) using the attenuator 1 when signal generator 2 is switched off. The signal level P_{unwanted} of the interfering signal shall then be increased until a BER of 10^{-4} is reached.

7.8.3 Presentation of results

The blocking or rejection ratio B_r of a DRM receiver is expressed in dB. The value shall be calculated from the adjusted signal levels by the following equation:

$$B_r = P_{\text{unwanted}}\,[\text{dB}] - P_{\text{wanted}}\,[\text{dB}]$$

The worst B_r value shall be noted.

7.8.4 Requirements

The blocking ratio shall be greater than 60 dB.

At three reception frequencies which can be chosen by the receiver manufacturer the blocking can be relaxed. At these frequencies the blocking shall be 40 dB. The frequencies have to be stated in the measurement report of a receiver.

7.9 Co-channel selectivity (co-channel rejection)

7.9.1 Introduction

The co-channel selectivity considers the impact of an unwanted analogue AM signal on the same channel as the wanted DRM signal. Since the frequency bands are crowded and analogue AM transmitters are used with high power this test was added.

7.9.2 Method of measurement

The measurement set up is depicted in Figure 9. The DRM signal shall be according to 7.2.4, the AM signal shall be according to 7.2.5.

The frequency offset between the centre frequency of the DRM signal and the centre frequency of the interferer for measurements shall be 70 Hz. It has to be guaranteed that the performance for other frequency offsets in the range +/- 5 kHz is not worse. The level of the wanted signal P_{wanted} at the DRM receiver input shall be adjusted to 20 dB above the minimum required sensitivity (Table 4) using the attenuator 1 when signal generator 2 is switched off. The signal level P_{unwanted} of the interfering signal shall then be increased until a BER of 10^{-4} is reached.

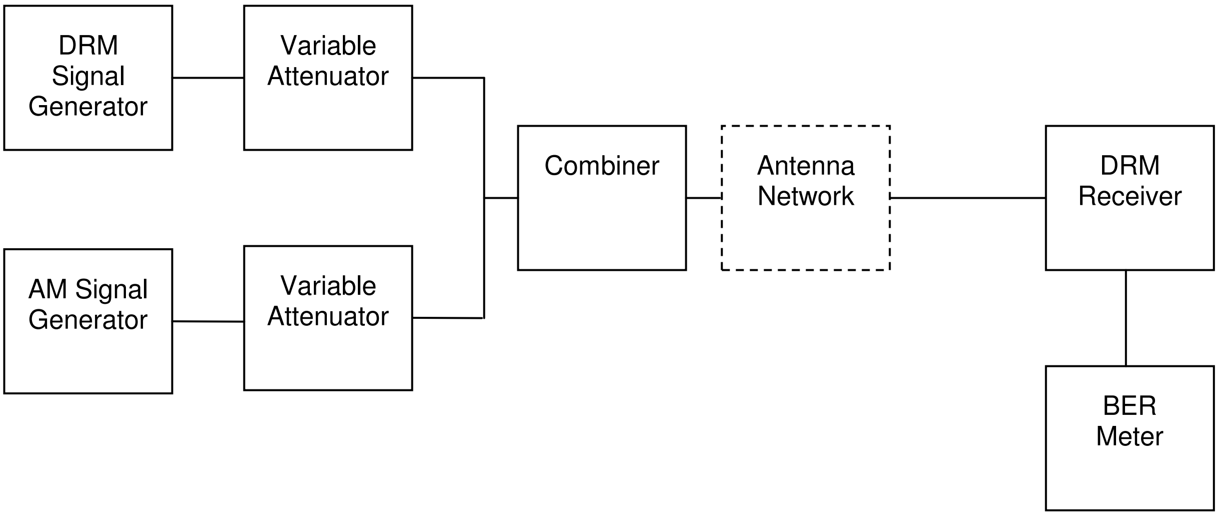

Figure 9 Block diagram for co-channel selectivity measurements

7.9.3 Presentation of results

The co-channel selectivity or co-channel rejection C_r of a DRM receiver is expressed in dB. The value shall be calculated from the adjusted signal levels by the following equation:

$C_r = P_{\text{unwanted}}\ [\text{dB}] - P_{\text{wanted}}\ [\text{dB}]$

7.9.4 Requirements

The co-channel selectivity shall be greater than -5 dB.

7.10 Receiver linearity

7.10.1 Introduction

Intermodulation is caused by the effect of receiver non-linearity on two or more applied signals. The measurements characterise the ability of a receiver to present a given quality in the presence of two strong interferers at chosen frequency separations.

7.10.2 Method of measurement

The measurement set up is depicted in Figure 10. The DRM signals shall be according to 7.2.4. The CW signal shall be 200 kHz, the unwanted DRM signal shall be 400 kHz away from the frequency of the wanted DRM signal. Both unwanted signals shall be on the same side of the wanted signal.

The level of the wanted signal P_{wanted} at the DRM receiver input shall be adjusted to 20 dB above the minimum required sensitivity (Table 4) using the attenuator 1 when signal generator 2 and 3 is switched off. The signal levels P_{unwanted} of each of the interfering signals both with the same power shall then simultaneously be increased until a BER of 10^{-4} is reached.

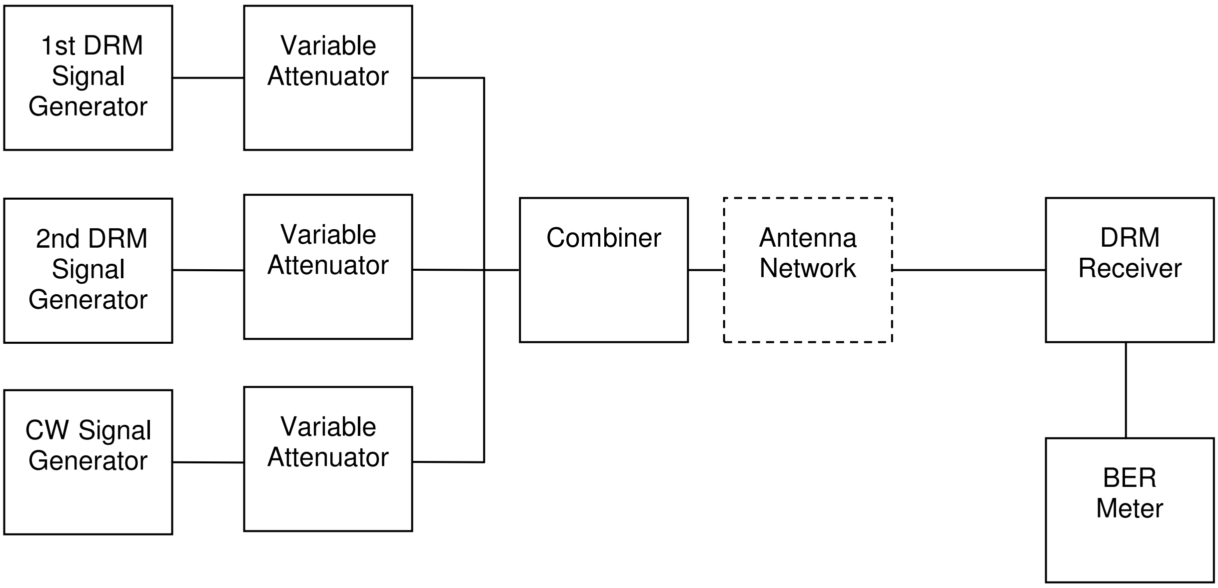

Figure 10 Block diagram for linearity measurements

7.10.3 Presentation of results

The intermodulation distance I_r of a DRM receiver is expressed in dB. The value shall be calculated from the adjusted signal levels by the following equation:

$I_r = P_{\text{unwanted}}\,[\text{dB}] - P_{\text{wanted}}\,[\text{dB}]$

7.10.4 Requirements

Intermodulation distance shall be greater than 40 dB.

7.11 Performance in Rayleigh channels.

7.11.1 Introduction

It is recognised that the behaviour under various channel conditions is one of the strong features of the DRM system. The objective of this chapter is to provide a reference for the performance of a DRM receiver in a dynamically changing environment. The different effects can be described by a channel model with different channel profiles which include the Doppler-effect as well as multipath reception. In ES 201 980 Annex B six channel profiles for LF, MF and HF broadcast radio transmission are used. Since the receiver performance is also dependent on the chosen configuration of robustness mode, protection level, modulation scheme and interleaver type, several combinations are defined. These combinations represent a small subset of the various possibilities. The purpose of this test is to explore the performance of the receiver demodulation algorithms.

7.11.2 Method of measurement

The block diagram of a basic set-up for measurements in Rayleigh channels is shown in Figure 11.

The DRM signal generator is set to one DRM centre frequency and is modulated by a DRM encoder. A channel simulator and a noise generator are inserted between the DRM signal generator and the DRM receiver. The channel simulator must be programmed through its controller with parameters corresponding to the channel profiles mentioned. The noise generator at the output of the channel simulator adds white Gaussian noise with a specified level to reach the defined signal-to-noise ratios. With the variable attenuator the input level at the receiver shall be set to 40 dB above minimum required sensitivity (Table 4).

The S/N should be set to the value given in Table 7, and the BER checked to ensure that it is below 10^{-4}. In addition lower S/N can be tested. As an alternative to BER, the audio frame error rate may be used instead; see section Annex C.

The minimum measurement times are given in Table 7. These times are designed to allow sufficient bit errors and to ensure that a statistically significant volume of data is sampled, especially for channels with low Doppler spread. For these measurement times the resulting error in S/N at a BER of 10^{-4} is less than 0,5 dB. The BER evaluation shall be performed on the whole MSC.

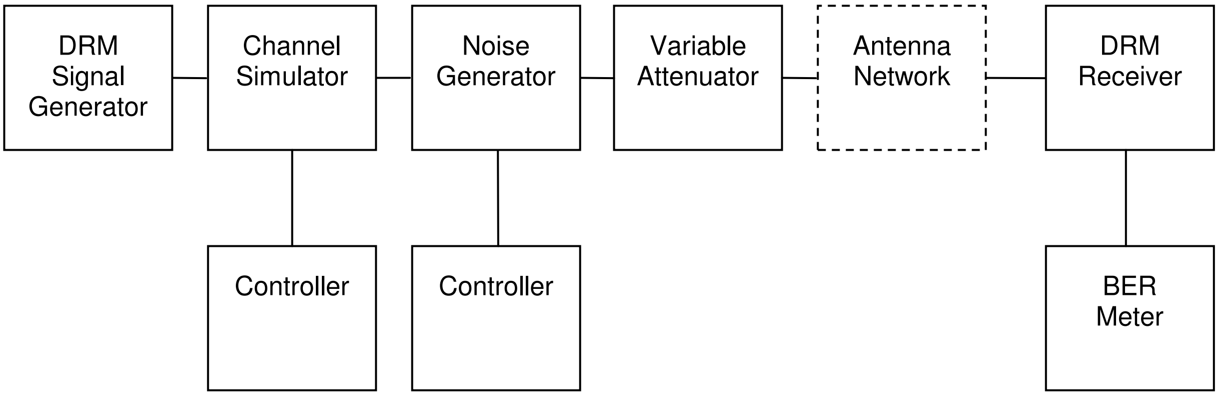

Figure 11 Block diagram for measuring the performance for different channel profiles

7.11.3 Measurement combinations

Measurements shall be done for as many as possible combinations, at minimum for the ones according to the Table 7 below.

Table 7 Different combinations for measurement of the performance for different channel profiles

Parameter	Combination					
Test No.	1	2	3	4	5	6
Channel model	1	2	3	4	5	6
Frequency range	Any convenient LF/MF channel			Any convenient HF channel		
Robustness mode	A	A	B	B	C	D
Spectrum occupancy type (bandwidth)	2 (9 kHz)	2 (9 kHz)	3 (10 kHz)	3 (10 kHz)	3 (10 kHz)	3 (10 kHz)
MSC mode (Modulation scheme)	00 (64-QAM)	00 (64-QAM)	00 (64-QAM)	00 (64-QAM)	11 (16-QAM)	00 (64-QAM)
Protection level (code rate)	3 (0.78)	2 (0.71)	2 (0.71)	1 (0.6)	1 (0.6)	0 (0.5)
Interleaver depth	0 (short)	0 (short)	1 (long)	1 (long)	1 (long)	1 (long)
Min. measurement time in seconds	200	2400	4000	4000	1200	1200

Note: Combination 3 will not be frequently used for transmissions, but helps to determine the receiver performance in situations where high signal-to-noise ratios are demanded.

7.11.4 Presentation of results

The result from this measurement is presented as the lowest signal-to-noise ratio in dB at which the receiver is still able to reach an average BER of less than 10^{-4} over the measurement time, and for each defined combination. If the measurements were done only for the defined signal-to-noise ratios from Table 7 it shall be mentioned if the receiver passed the test successfully. The used measurement time shall be given in seconds.

7.11.5 Requirements

It has to be guaranteed that in all spectrum occupancies, channels, robustness modes, MSC modes, interleaver depths and protection levels an appropriate performance will be achieved. Table 8 gives the maximum S/N values for the defined combinations.

Table 8 Required signal-to-noise values for the different channel profiles

Parameter	Combination					
	1	2	3	4	5	6
S/N from Simulation	18,7	19,5	28,3	23,5	17,9	22,2
Requirement: S/N	21	22	31	26	20	25

Note: The S/N from simulation values are only informative. They do not include receiver implementation losses.

7.12 Acquisition time after tuning

7.12.1 Introduction

Excessive delay between tuning to a frequency and audio output will be annoying to the user. The receiver manufacturer should spend effort to keep this time as short as possible, but also to provide a reliable synchronisation in the various transmission channels.

7.12.2 Method of measurement

The DRM signal generator shall provide a DRM signal with an offset of 220 Hz to the chosen nominal centre frequency for the measurements. It has to be guaranteed that the performance for other frequency offsets in the range +/- 300 Hz is not worse. It is recommended that the audio content is a sinusoid to simplify the measurement process. The receiver shall not have any advance information about the spectrum occupancy, the robustness mode or the information provided by the FAC and the SDC. The measurement setup is depicted in Figure 12. The configurations of the channel simulator and noise generator are the same as in section 7.11.2. The noise generator shall deliver a S/N according to Table 9. A switch and an oscilloscope are also needed. The first channel of the oscilloscope shall be connected to the RF-input of the receiver, the second channel to the audio output of the receiver.

The DRM receiver shall be tuned to the nominal reception frequency. The oscilloscope shall be started in single shot mode and trigger to the first channel. The switch shall then be used to make the RF-signal available at the receiver. The oscilloscope shall measure the time between RF-signal switching and a valid audio output at the receiver. “Valid audio signal” in this case means a continuous undisturbed audio signal.

The measurement shall be done 5 times for each combination.

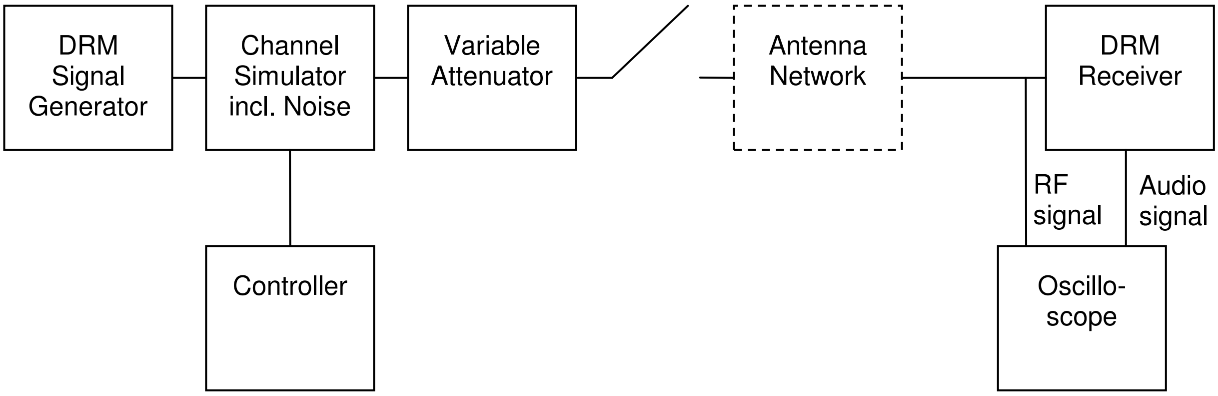

Figure 12 Block diagram for acquisition time measurement

7.12.3 Presentation of results

The averaged acquisition time for the 5 measurements shall be calculated for each combination and given in milliseconds (ms).

7.12.4 Requirements

The averaged acquisition time shall be less than or equal to the values in Table 9.

Table 9 Required acquisition time

Parameter	Combination					
	1	2	3	4	5	6
S/N	26	27	39	31	25	30
Max. Acquisition time	3200 ms		4000 ms			

Annex A

This Annex describes the derivation of the analogue interfering signal and shows measurement plots.

The signal can be built with everywhere available laboratory equipment. As sine generator an ordinary waveform generator can be used, e.g. a HP 33250A. As AM signal generator a ordinary signal generator can be used, e.g. HP 8647A.

The measurement bandwidth $B_{measure}$ of the spectrum analyser should be set to 50 Hz. Therefore the frequency range covered by the sweep signal equals 80 times the measurement bandwidth.

$$B_{sweep} = 80\ B_{measure} = (4100\text{Hz} - 100\ \text{Hz}) = 4000\ \text{Hz}$$

Taking into account that an AM-signal modulated by a sinusoid with a modulation index m and a carrier power P has the overall transmitted power $P_{transmit}$ of:

$$P_{transmit} = P(1+\frac{m^2}{2}) = P + P_{sidebands}$$

and taking into account that the energy of the modulating signal is equally spread between the two subbands for DSB modulation, we get a power ratio $\Delta_{sinusoid}$ between the power of a single sinusoid measured in one subband and the centre carrier of

$$\Delta_{\sin usoid} = 10\log_{10}\left(\frac{P_{sidebands}}{2P}\right)dB = 10\log_{10}\left(\frac{m^2}{4}\right)dB$$

Example values for $\Delta_{sinusoid}$ are calculated in Table 10 for different values of m. Figure 13 gives the screen shot from a spectrum analyser for m=0.5.

Assuming a sweep as modulating signal, we have to take into account $B_{measure}$. Therefore the relative power level Δ_{sweep} that should be visible at the spectrum analyser is:

$$\Delta_{sweep} = 10\log_{10}\left(\frac{P_{sideband}B_{measure}}{2PB_{sweep}}\right)dB = 10\log_{10}\left(\frac{m^2}{320}\right)dB$$

An example measured by the spectrum analyser for m=0.5 is shown in Figure 14 for the values m=0,5 and a sweep time of 20 ms. Table 10 summarizes the values for different values of m. Note that the measurement for a sweep is highly dependent on the equipment used, as there can easily be strong distortions in the measurement due to the relations of sweep steps of the modulator as well as sweep time with the measurement bandwidth and integration time of the spectrum analyser. It is therefore easier to measure the integrated energy for one side band from 100Hz to 4.1 kHz. The result becomes thereby independent from the measurement resolution bandwidth and is identical to the static sinusoidal case, as can be seen from Figure 14.

Table 10 Measured Power level separation

m	0.25	**0.3**	0.53	0.75
$\Delta_{sinusoid}$ [dB]	-18,1	**-16,5**	-11,5	-8,5
Δ_{sweep} [dB]	-37,1	**-35,6**	-30,6	-27,5

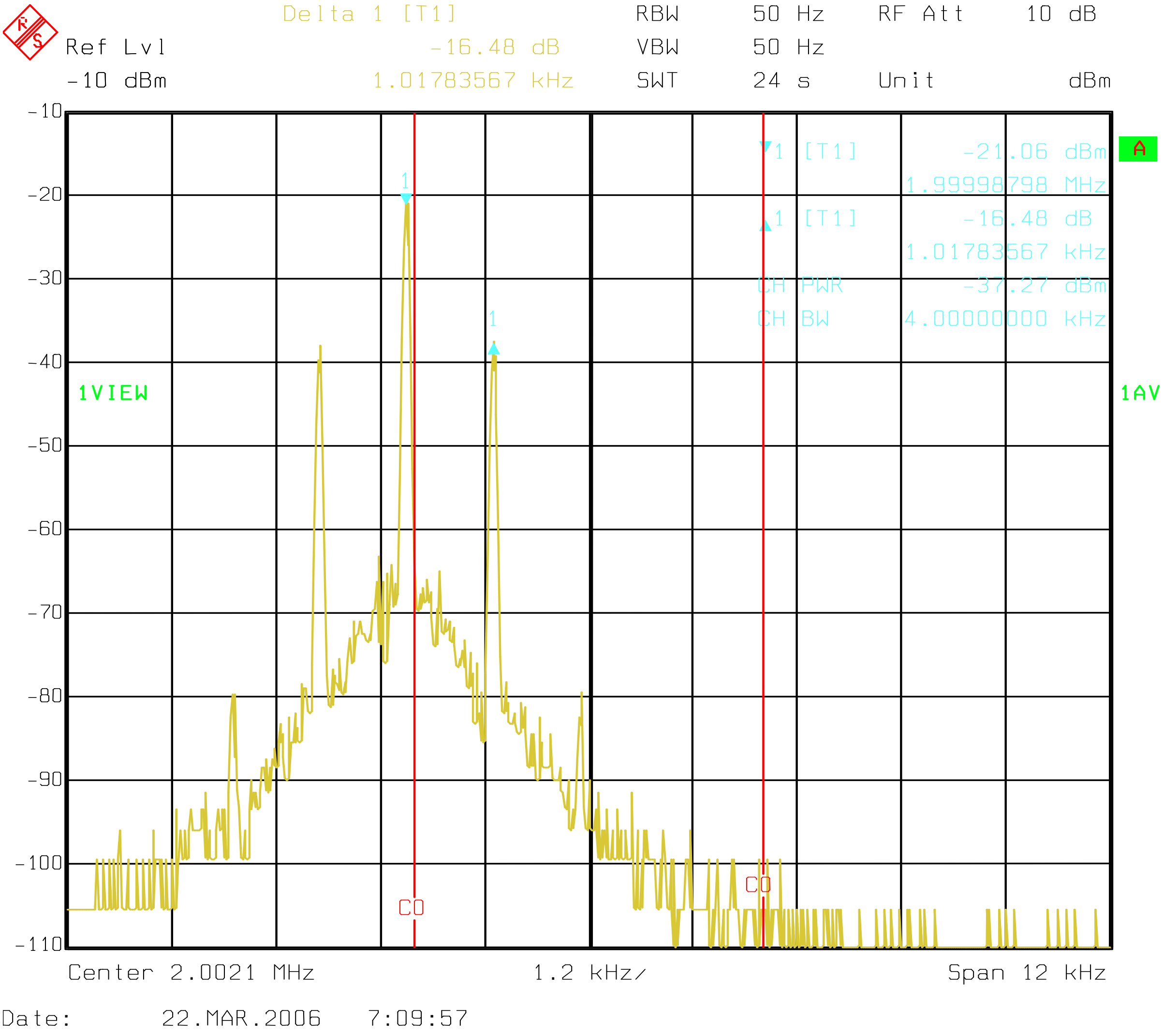

Figure 13 Snapshot of spectrum analyser for modulation with sinusoid

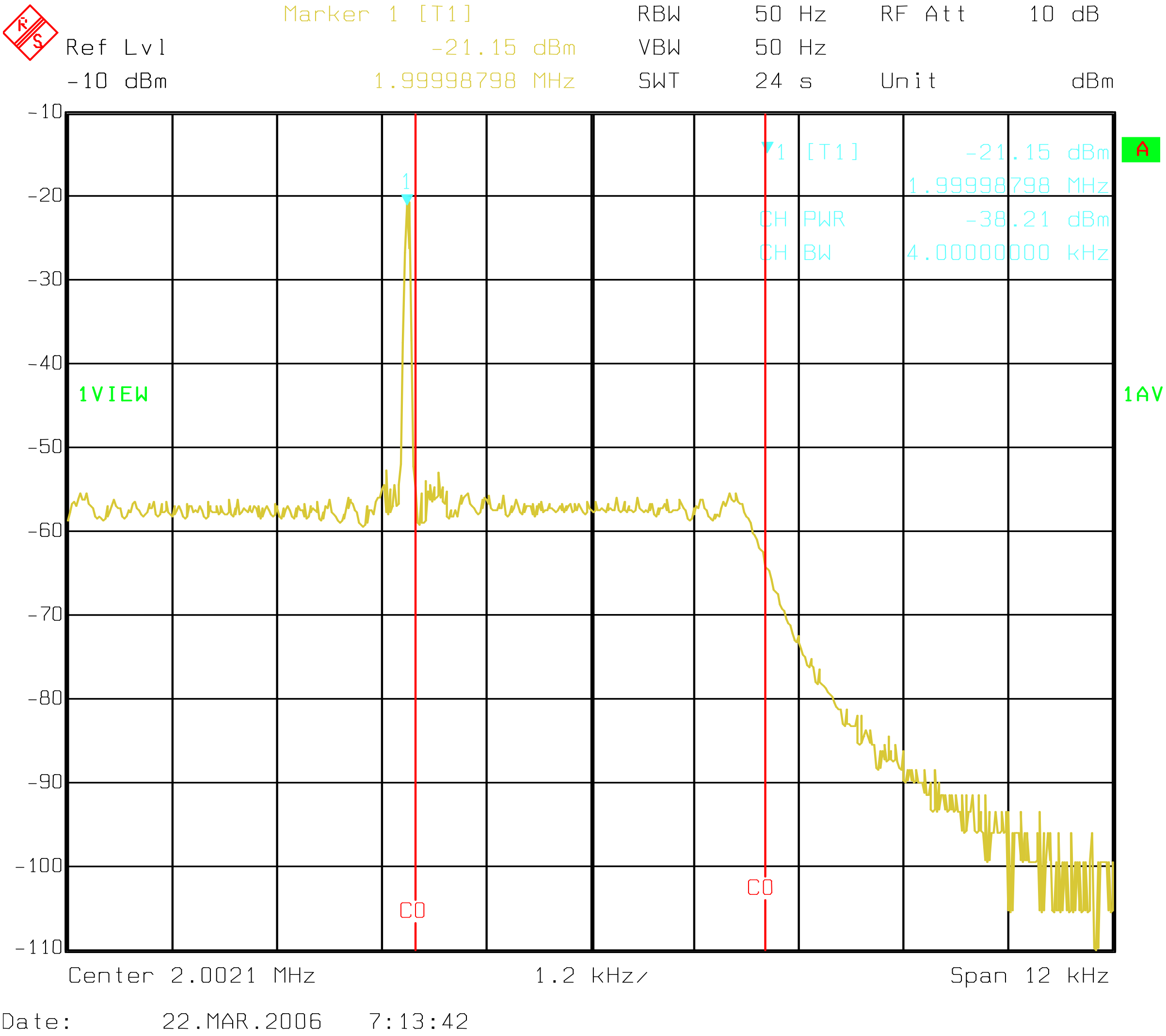

Figure 14 Snapshot of spectrum analyser for modulation with sweep

Annex B

Annex B: Antenna emulation networks

Abstract

The preferred basis for linking receiver performance to broadcast coverage is *field strength*. Nevertheless an antenna emulation network can be convenient. This Annex proposes a generic emulation network, which, with the appropriate choice of component values for a particular case, will model the behaviour of whip-style antennas used for car and portable receivers.

It also shows how to derive the component values, for the case of a theoretically ideal monopole antenna over an infinite ground plane. A worked example is presented. However, real antenna-receiver combinations are not ideal, and great caution should be exercised in applying these theoretical calculations. In particular, sensitivity measurements will be sensitive to over-estimations of the true effective length. Experimental verification of the model for each antenna-receiver design is therefore strongly recommended. A warning is also given concerning the risk of receiver self-interference going undetected when measuring sensitivity using an emulation network.

1 Introduction

In introducing a new broadcast system, it is necessary to ensure that broadcasts and receivers able to receive them are simultaneously available. The *minimum field strength required* is the meaningful common currency between broadcasters and receiver manufacturers.

However, it is also clear that receiver designers will sooner or later need to examine their circuitry and test it on the bench. So at some stage field strength has to be translated to voltage, current or power as appropriate and convenient. Unfortunately, this conversion requires knowledge of the fine detail of the antenna. For portables at least we expect the antenna to be attached or built-in, and thus under the sole control and responsibility of the radio manufacturer. Car radios form a special but important case where the radio manufacturer usually has to accept the antenna provided by the car manufacturer.

This Annex makes some observations about antenna emulation networks, based on a *theoretical approach*. It remains the responsibility of manufacturers to satisfy themselves that any antenna emulation network they use does adequately reflect the performance of the real antenna, taking account of its environment (e.g. a whip may be attached to a very small receiver assembly, and operated without any ground plane).

While the general principles apply to all antennas, most of the details in this Annex only apply to whip antennas. This should not be taken as any kind of endorsement of this type of antenna, indeed in many circumstances H-field antennas have a great deal to commend them. However, emulation networks are perhaps less useful in practice for H-field antennas (as they often form a key part of a tuned circuit, they would need to be modelled very accurately to avoid misleading results) but are also less necessary, since it is relatively easy to inject a known magnetic field strength using a test loop. This requires only a simple screened room, rather than an expensive test chamber.

Finer details of the mathematics are confined to the Appendix to this Annex.

2 Antenna Basics

Any antenna can be represented in a very simple way. In the presence of an electric field E (measured in units of V/m) the antenna delivers at its terminals an open-circuit e.m.f. V with an effective source impedance $Z = R + \jmath X$. There is an obvious simple equivalent circuit, Fig. 1.

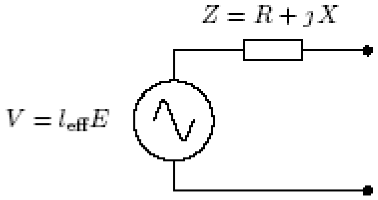

Figure 1: Equivalent circuit of *any* antenna

The open-circuit voltage V is proportional to the applied field E, implying a simple relationship:

$$V = l_{\text{eff}}\, E \tag{1}$$

where the constant of proportionality l_{eff} has the dimensions of length, and so is called the *effective length*. Note that it is very unlikely to be the same as any characteristic physical length of an antenna, although it will be related to it.

(*Note*: we assume in all this that the polarisation of the field matches that to which the antenna responds, and that the effective direction from which it arrives is on the antenna main beam[1].)

In general we may expect both l_{eff} and Z to vary with frequency for any particular antenna.

This representation is entirely general. For the rest of this Annex, however, we consider only specific antennas, those which are essentially short monopoles — the whip antenna common to both portable receivers and cars.

3 Theoretical behaviour of ideal monopole antenna

3.1 Warning

This section considers an antenna which is to a degree a figment of the imagination of theorists — a monopole over an infinite ground plane. Sometimes we shall consider it to be cylindrical, of specified radius, while we may also make use of an assumed current distribution (sinusoidal) which is probably only valid for an infinitely thin conductor.

3.2 Effective length

The effective length of a monopole over a ground is presented in the Appendix, § A.1. Although a general result is derived, for our purposes the standard approximate result for electrically-short monopoles is probably sufficient, namely $l_{\text{eff}} \approx h/2$, where h is the antenna length. For antennas whose length is more than say $\lambda/10$ then l_{eff} will begin to be noticeably larger, see Fig. 5. On the other hand, practical receivers with whip antennas will *not* have an infinite ground plane, and it seems reasonable that this will *reduce* the effective length, possibly more dramatically.

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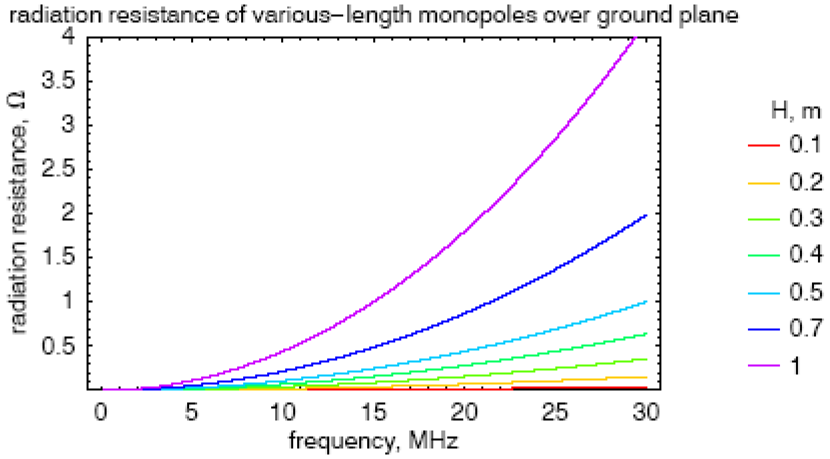
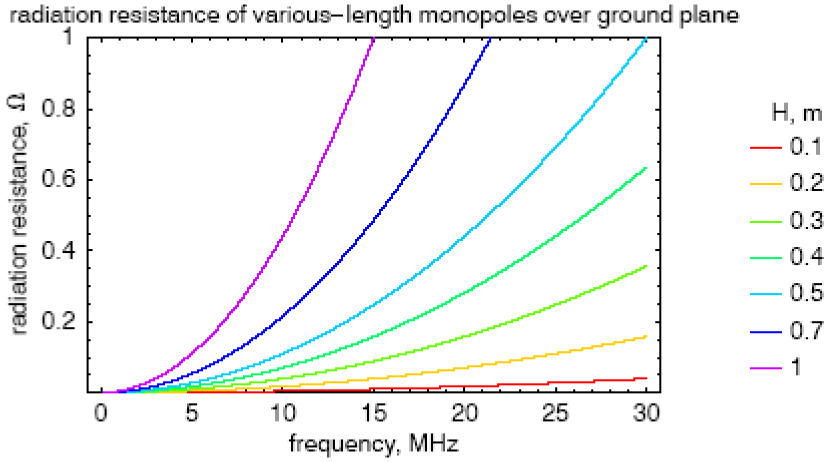
[1] It is perfectly correct to consider that for signals coming from off-beam directions — where we are happy to say that the gain varies with direction — then we can also say that the effective length varies correspondingly.



(a) overview plot



(b) detail for shorter antennas

Figure 2: Radiation resistance as a function of frequency for monopole antenna, of length H, over an infinite ground plane

3.3 Radiation resistance

The theoretical radiation resistance (seen from the terminals) of a monopole over an infinite ground plane is given in the Appendix, § A.2. The full version of the formula shown there, Eqn. (10), has been used to plot the graphs in Fig. 2.

For any given length of whip, the radiation resistance varies with frequency, so that the use of an emulation network which models a fixed resistance is not strictly correct. However, for the sizes of antenna we are concerned with, the radiation resistance is always very small. In practice it is likely to be dominated by the ohmic and skin-effect losses in the antenna and imperfect ground plane. We could do a lot worse than simply model the resistance of the antenna as simply "a few Ω".

3.4 Reactance (capacitance)

The theoretical reactance (seen from the terminals) of a cylindrical monopole over an infinite ground plane is given in the Appendix, § A.3. When the whip is *shorter* than resonant, the reactance is negative, i.e. *capacitative*. Provided the whip is always significantly shorter than resonant (something which will be the case for all whips we are likely to meet in DRM) it turns out that the effective capacitance varies very little with frequency. This is confirmed by the plot of Fig. 8 in § A.3.

Of course the effective capacitance still depends on the length of the monopole — and on its thickness. Fig. 3 illustrates this for the range of lengths and radii likely to be relevant for DRM receivers.

The capacitance is always small, but increases as either the length or radius increases.

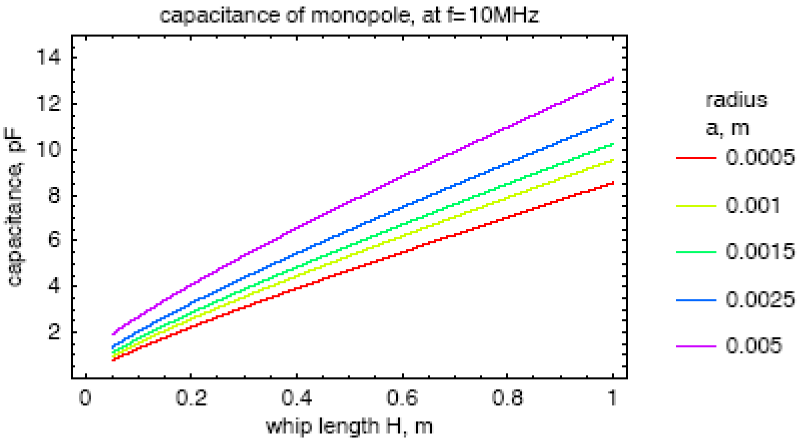


Figure 3: Capacitance (at 10 MHz) of a cylindrical monopole antenna over an infinite ground plane, as a function of its length H and radius a.

4 Possible emulation networks

4.1 Generic emulation network

Fig. 4 proposes a generic emulation network for whip antennas, and also illustrates its use: interposed between a test-signal generator and the receiver's input circuitry. The network is very similar in concept to that commonly used for car radio receivers. The tricky part is to specify the component values. It cannot be stressed enough that it would be quite wrong to use a single particular network (with fixed component values) for a range of receivers. Even the subset of receivers that we might describe as 'portable' will contain a range of receiver sizes, antenna sizes and methods of antenna mounting — all of which will vary the necessary component values for the network. Using a single network would lead to poorly optimised designs and to forming a misleading impression of receiver sensitivities.

One size *does not* fit all!

Now, for antennas which fit the assumptions under which the various plots and formulae of this Annex are described, it would be fairly simple to derive the values of the various emulation-network components. However, it must be remembered that practical antenna-receiver combinations will depart significantly from this ideal. So some form of practical, experimental qualification will be required before the network for a particular receiver design is taken too seriously.

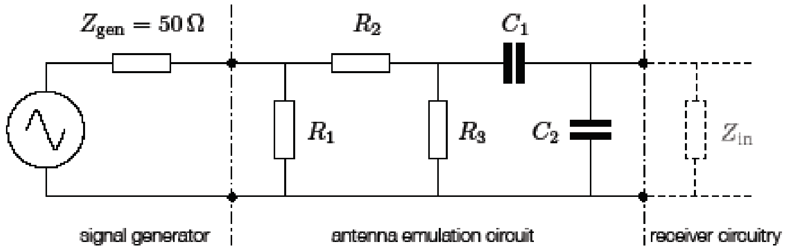


Figure 4: Proposed antenna emulation network and its use

4.2 The capacitors

C_1 is the most straightforward component. It models the equivalent capacitance of the antenna. Where there is a sufficient ground plane, the value for C_1 can be drawn from Fig. 3. We may reasonably guess that the appropriate value for any real-world antenna will be yet smaller — but how much so may be tricky to determine.

C_2 is introduced in order to model any *other* capacitance introduced in parallel with the antenna. Its appearance in the case of car radios is easy to understand: the cable connecting the car antenna to the radio has significant capacitance — rather more than the source capacitance of the antenna itself[2]. This means that there is a significant reduction in the open-circuit antenna e.m.f., as seen at the receiver input terminals.

Incidentally, while the use of C_2 to model the antenna cable in car radios is fine for LF/MF, where it has historically been applied, it may cause errors at HF. Once the antenna cable is long enough to form an appreciable fraction of a wavelength, then it is better modelled as a *transmission-line transformer* rather than as a simple capacitor. This suggests that the emulation

Reality is the best model of reality

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[2] This applies to 'conventional', passive car-radio antennas. Active antennas contain a preamplifier that buffers the antenna from the loading caused by the coaxial cable.

network for car radios used at HF should replace C_2 by an appropriate representative length of the appropriate representative type of coaxial cable.

The use of C_2 for portable radios has not previously been customary, but seems perhaps necessary. Where the antenna is short, C_1 will only be a few pF, so the incidental capacitance brought about by the antenna fixings and the wire joining the antenna to the input of the receiver circuitry is unlikely to be negligible.

It follows of course that the emulation network must be connected *directly* to the receiver input during measurements. Using a typical laboratory BNC 'double-ender' cable between network and receiver will swamp C_1 and C_2 altogether! (Note: $50\,\Omega$ coaxial cable of the dimensions used in the laboratory has a typical capacity of 100 pF/m). So the construction of the network should take the form of a probe, directly connected to the receiver input circuitry, and any cabling required for practical convenience should be $50\,\Omega$ cable on the *input* side of the network. The exception would be for the car radio case, where as already discussed, it might be better to replace C_2 by actual representative cable, which could in this case serve double duty as the means of connection.

Note that any attempt to measure the capacitance of the antenna — which is a reasonable experiment to try to perform, given the suspicion we have about the extent to which any real portable-receiver antenna has a ground plane — will in effect measure $C_1 \| C_2$, and it may be difficult to deduce their individual values.

4.3 The resistors

The π-network of resistors $R_1 R_2 R_3$ serves several purposes:

Define input impedance If we are to get any calibrated results, the signal generator must see its intended termination, usually $50\,\Omega$.

Define attenuation We shall want to know the correspondence between the signal-generator output-power setting, and the field strength that is being modelled.

Define antenna resistance Looking 'through' C_1, the receiver should 'see' a resistance equal to the effective resistance of the antenna, which will be the sum of the very small radiation resistance R_{rad} and the perhaps not so small loss resistance, R_{loss}.

We could not in general do all of these things simultaneously and perfectly; however, provided that the antenna capacitance and resistance are both small, we can do well enough. We assume that we require significant attenuation through the network. This means that the input impedance seen by the signal generator is essentially resistive (i.e. we ignore the contribution of C_1). So we may say:

$$Z_{\mathrm{in}} \approx R_1 \| (R_2 + R_3) \approx \frac{R_1(R_2 + R_3)}{(R_1 + R_2 + R_3)} \ . \qquad (2)$$

R_2 and R_3 serve to divide down the voltage at the input terminals to represent the open-circuit e.m.f. of the antenna, in the ratio $R_3/(R_2 + R_3)$. (This e.m.f. is then further divided down by C_1 and C_2 before reaching the receiver input circuitry).

The antenna resistance (radiation resistance plus loss resistance) which is modelled by the network is the output resistance of the π-network, namely:

$$R_{\mathrm{antenna}} = \frac{R_3\big(R_1 R_2 + R_{\mathrm{gen}}(R_1 + R_2)\big)}{R_1(R_2 + R_3) + R_{\mathrm{gen}}(R_1 + R_2 + R_3)} \ . \qquad (3)$$

4.4 A worked example

We can illustrate how the network might be used, and how component values for a particular case would be arrived at, by means of a worked example.

We consider a portable radio with a whip antenna having height 0.7 m and radius 2.5 mm. We deduce its effective length to be 0.35 m. (This assumes for now that there is an effectively infinite ground plane). Thus the open-circuit output voltage of the antenna alone when receiving a field strength of 0 dBμV/m is $20\log_{10}(0.35) = -9.1$ dBμV.

Define reference levels

We choose an arbitrary but convenient relationship between the signal generator output and the field strength that is modelled. Suppose that reception of a field of 0 dBμV/m is to be modelled when the available power from the signal generator is -85 dBm. This allows plenty of headroom for the generator(s) when, in practice, more than one has to be combined and one of them has to generate a large signal, e.g. to perform blocking or image-response tests.

The terminated voltage across a matched 50 Ω load is 107 dBμV when the available power is 0 dBm, so the voltage across R_1 in our reference condition is $(107 - 85) = 22$ dBμV. So the voltage ratio of the potential divider formed by R_2 and R_3 must be $(-9.1 - 22) = -31.1$ dB.

Estimate losses

Applying Eqn. (10) (or using Fig. 2) we note that the radiation resistance is 0.2 Ω at 10 MHz, rising to 2 Ω at 30 MHz. There will be losses as well, and for want of any better information we take a guess at about 5 Ω for radiation and loss resistance combined[3].

Check results

An iterative design process may be needed, given that components come as members of the preferred-value series. We try a value for R_3 that is slightly greater than the antenna resistance we want to model. Say we take $R_3 = 5.6\,\Omega$. R_2 is then determined using the potential-divider ratio, and R_1 using Eqn (2). The nearest preferred values are $R_2 = 180\,\Omega$, $R_1 = 68\,\Omega$. Checking back using Eqn (2) shows that the load presented to the generator is 49.73 Ω (good enough) while the error in the voltage ratio is satisfactory at less than 0.1 dB. Finally, the antenna resistance that is modelled can be checked using Eqn. (3); it is 4.98 Ω.

Choose capacitors

So much for the resistors, what of the capacitors? Eqn. (11) and (12) (or Fig. 3) tell us that the intrinsic capacitance of the antenna itself[4] is 9 pF at 30 MHz (and very slightly less at lower frequencies). So we could take say $C_1 = 9.1$ or 10 pF as practical values. Finally we must estimate C_2. This will depend on the construction of the antenna mounting. Say $C_2 = 3.9$ pF?

Most of these values are of course based on a purely theoretical situation. We may suppose that all of l_{ref}, R_{ref}, and C_{equiv} will in practice be smaller, since there is *not* an infinite ground plane. The most important of these is probably the reduction in effective length, since it directly affects the modelling of the receiver sensitivity. The radio using its real antenna will be less sensitive than measurements made using the emulation network suggest.

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[3] You would have to do some very careful experiments to determine a more precise value. However, frankly it probably just doesn't matter very much. The reactance in series with it (as modelled by C_1) is sufficiently high that it seems unlikely that it will make any great difference to the receiver performance.

[4] Assuming an infinite ground plane, as always.

5 Discussion of limitations

The foregoing has shown that a generic network should be suitable to represent whip antennas. The network is made up of simple components whose values can be calculated for the *theoretical ideal* of a monopole antenna over an infinite ground plane, following the worked example presented in § 4.4. When this is done, it is possible to use the network to measure the performance of the receiver knowing that an output-power setting of a signal generator corresponds to a known field-strength being applied to the emulated receiving antenna.

Real radios are not ideal

Unfortunately, real antenna-receiver combinations are not ideal; they have no infinite ground plane, and so:

- The effective length l_{eff} for real receivers will depend on the environment, and may be assumed to be less than that calculated solely on the basis of the length of the whip. When a receiver is very small, without a metal case or other significant metalwork, and is used placed on e.g. a wooden table, it starts to be questionable whether the true antenna is the visible 'antenna' at all. Perhaps the size of the receiver circuitry itself is more representative of the true antenna, with the visible whip acting more like a counterpoise?
- We may also suppose that practical antenna-receiver combinations have different values of antenna impedance (resistive and capacitative components) from those predicted, although these may be less critical in their impact on the accuracy of measurements.

Verification is needed

Sensitivity measurements give rise to the greatest concern. Unfortunately, using a network based on the ideal monopole will always err on the same side, namely to give flattering results. Manufacturers would therefore be well advised to use an independent means to determine at least an indicative measure of true sensitivity in order to be able to apply a correction to the process. Once known it will be a simple matter to either modify the network values, or to correct for the use of an ideal one by following a rule that the signal generator should be set to provide an available power that is x dB below the nominal value for the field strength that is to be modelled in any particular test.

Obviously the ideal method for cross-calibration is to measure the receiver-antenna combination in a test chamber such as a TEM[5] cell which imposes a known field strength. But at least the largest (and therefore most important) discrepancies may perhaps be found with much simpler methods, e.g.: compare the performance of the receiver-antenna combination in an open space (a field, maybe even a car park) with that of the receiver connected via the emulation network to a calibrated active antenna[6] of $50\,\Omega$ source impedance, using off-air signals. Care would be needed in accounting for the effects of fading, especially if the reference active antenna is of a different type (e.g. a loop) from that used in the receiver under test.

Modelling of car-radio antennas is probably on a better footing, although for passive antennas it would be wise to replace C_2 (which in this case is intended to model the effects of the relatively long cable from antenna to radio) by a cable representative in both type and length. It is easy to imagine that the cable in a car could be 2.5 m long, and that is a $\lambda/4$ transformer at 30 MHz!

Beware of self-interference

Within the limitations just discussed, the antenna emulation network ensures that signal voltages representative of a particular field strength are injected into the receiver circuitry. However, while *necessary*, this is not *sufficient* to guarantee that sensitivity measurements are valid. Receiver sensitivity (especially for portable receivers with built-in or attached antennas) can also be limited by a *self-interference* mechanism whereby emissions from (usually) the digital circuitry of the receiver couple into the receiver antenna. The result of this coupling is that for satisfactory reception the wanted signal has to be of a greater strength than would otherwise be needed. This self-interference is less likely to occur when the radio is fed with signals via the

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[5] Transverse Electro-Magnetic

[6] It might be necessary to add an amplifier and attenuator to the output of the active antenna so as to produce a signal of the right available power at the input to the emulation network.

emulation network and so the worsening in sensitivity that it causes may not be detected. It follows that some radiated-field testing remains essential.

6 Conclusions

The 'common currency' between broadcasters and receiver manufacturers, when planning the simultaneous introduction of DRM receivers and broadcast services, is the planned *field strength* in the service area. However, manufacturers need to translate this into something more amenable to measurement on the laboratory bench, for both development and production testing. An *antenna emulation network* may be convenient for this purpose.

It is possible to define a single generic emulation network for whip antennas (as used by portable or car radios). However, the component values must be determined for each case, if use of the network in receiver testing is to give any meaningful indication of the real-world performance. The network must emulate the *particular receiver's antenna*.

The proposed emulation network (see Fig. 4) models four aspects of the antenna:

- its effective length l_{ref}
- its internal resistance, comprising R_{rad} and R_{loss}
- its reactance, modelled in this case as a series capacitance C_1
- the parallel capacitance of the antenna mounting, modelled by C_2

The values of the parameters l_{ref}, R_{rad} and C_1 can be derived on a theoretical basis for the ideal case of a monopole over an infinite ground plane, as a function of the antenna dimensions, using the formulae presented. R_{loss} and C_2 must always be determined empirically.

Real-world receiver-antenna combinations will depart from this ideal case. This may be especially significant where l_{ref} is concerned, since use of the ideal value will always lead to an over-flattering estimate of the receiver sensitivity. Manufacturers are therefore urged to perform some additional measurements of the receiver-antenna combination, and not to rely solely on theoretical values that are not applicable.

For car radios, it may be better to model the antenna-receiver cabling by a length of real cable instead of C_2. The use of a capacitor to model the cabling is reasonable at LF/MF, where it has historically been applied, but is very questionable at HF.

Over-optimistic results for receiver sensitivity will be obtained when using an emulation network if there is self-interference due to unwanted coupling between the receiving antenna and the receiver's internal circuitry. It is therefore recommended that receiver sensitivity is also checked at the prototype stage by a radiated-field method. The emulation network can be used for subsequent production testing provided nothing happens that might alter the degree of unwanted coupling[7].

References

[1] Jordan, E. C., and Balmain, K. G. *Electromagnetic waves and radiating systems*, 2nd ed. Prentice-Hall, Englewood Cliffs, New Jersey, 1968.

[2] Page, H. An introduction to the theory of aerials. BBC Research Department Report No. BBC RD 1963/27, 1963.

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[7] E.g. the physical layout, methods of screening etc. all remain unchanged.

A Appendix: more details of the theory

We use the hypothetical case of a *cylindrical monopole* over an *infinite ground plane* as a convenient model for the receiver antenna, since it is theoretically tractable.

This is analysed by Jordan and Balmain [1], from which most of the following formulae have been taken. Radiation resistance and reactance are derived separately, the first simply as a function of antenna length and the second involving the diameter of the cylindrical monopole as well. Corroboration can also be found in Page [2].

A.1 Effective length

The literature tends to contain more details about the effective length l_{eff} of an antenna when used for transmission than when used for reception. Thankfully, it can be shown (using the reciprocity theorem) that the effective length in transmission is the same as that for reception, see e.g. Jordan and Balmain [1, pp. 351–3]. J & B go on to derive l_{eff} by integrating the current distribution over the transmitting antenna, while Page [2, pp. 40–1] obtains the result for reception directly (but invoking reciprocity in the process). Fortunately they get the same answer! The effective length of a monopole length H over an infinite ground plane is:

$$l_{\text{eff}} = \frac{1-\cos(\beta H)}{\beta \sin(\beta H)} = \tan(\frac{\beta H}{2})/\beta \tag{4}$$

where $\beta = 2\pi/\lambda$.

Use of the small-angle approximation for $\tan x$ when x is small leads to the simplification that $l_{\text{eff}} \approx h/2$, for short monopole antennas with length[8] $h \ll \lambda$.

To avoid you agonising over the question "Is my antenna short?", we can rearrange the exact formula (4) as follows. We write $\rho = H/\lambda$ as a normalised antenna length, and obtain

$$\xi = \frac{l_{\text{eff}}}{H} = \frac{\tan(\pi\rho)}{2\pi\rho}. \tag{5}$$

ξ is a kind of effective-length factor relating l_{eff} to the physical length of the monopole antenna. For short antennas its value is $\frac{1}{2}$, as we have seen above, while the value rises as the antenna length increases[9] towards $\lambda/4$, for which $\xi = 2/\pi \approx 0.637$. This is shown in Fig. 5. Note that the shortest wavelength λ we are interested in is 10 m, corresponding to 30 MHz. (Strictly, a little longer than that, as there is no HF broadcasting band quite that high in frequency). It seems unlikely that a portable or car receiver will have a monopole longer than say a metre, so we need only consider up to say $\lambda/10$. We see that the error resulting from simply taking $l_{\text{eff}} \approx h/2$ is not worth worrying about, and we gain the great benefit of keeping the emulation circuit simple.

Remember that these results refer to a simple vertical monopole over a ground plane. If the (short) antenna were provided with a 'capacity hat', so that the current distribution in transmission tended towards uniform instead of approximately triangular, then the effective length would approach the physical length. On the other hand, with a whip over a reduced ground plane (as for a typical portable) we might expect the effective length to be *less* than $h/2$.

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[8] Note that we follow Jordan and Balmain in using h for the length of an electrically-short antenna, and H for the length more generally. In the context of this note there is probably little risk of confusing length H with magnetic field strength H, but you have been warned!

[9] Alternatively, we may say that for a fixed-length antenna, l_{eff} increases with frequency, implying that some frequency dependency would in principle be needed in the emulation circuit.

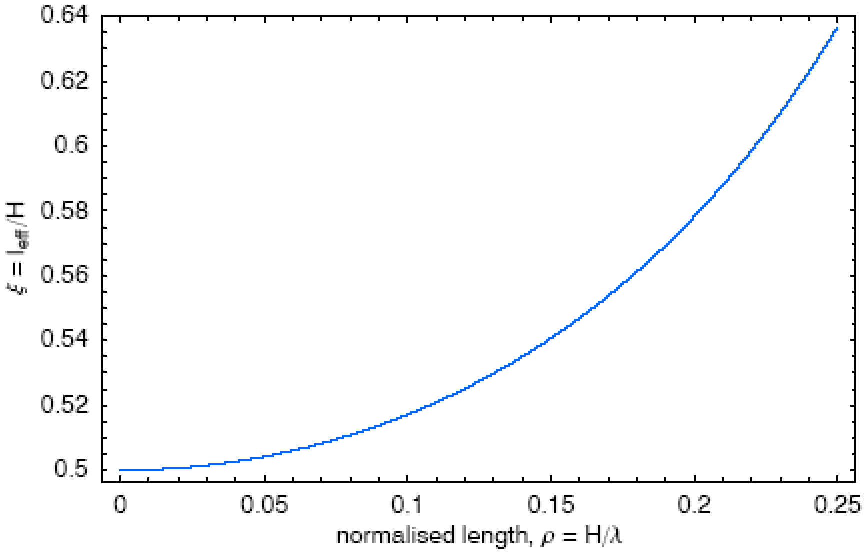

Figure 5: Effective-length factor $\xi = l_{\text{eff}}/H$ for a monopole antenna over a ground plane, as a function of its normalised length $\rho = H/\lambda$.

A.2 Radiation resistance

A.2.1 Simple approximation for short antennas

For a very short monopole of length[10] h over a ground plane, the radiation resistance is given approximately by:

$$R_{\text{rad}} = 40\,\pi^2\left(\frac{h}{\lambda}\right)^2 \approx 394.8\left(\frac{h}{\lambda}\right)^2. \tag{6}$$

It is assumed that $h \ll \lambda$, and that the current distribution (in transmission) is triangular. This result from Jordan and Balmain [1, p. 326] also appears in many other references.

Of course, requiring $h \ll \lambda$ begs the questions of "How short is sufficiently short?" and "What happens if it isn't?". Fortunately a more complete analysis is possible under certain assumptions, and the result is given in the next section.

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[10] h for a *short* antenna, as before.

A.2.2 More general result

For longer antennas it is possible to derive a more complicated formula under the assumption that the current distribution (in transmission) is now sinusoidal. Strictly this is believed to be correct for infinitely thin antennas and a good enough approximation for practical antennas of the 'whip' type that we are interested in, as long as we avoid cases where the antenna length H is a multiple of $\lambda/2$ (for which a sinusoidal distribution implies no feed current!).

Jordan and Balmain [1, pp. 542–4] evaluate the radiation resistance, *referred to the loop current* (the maximum of the sinusoidal distribution in transmission), as:

$$R_{\mathrm{rad(loop)}} = 15\left(\left(2 + 2\cos(b)\,\right) S_1(b) - \cos(b) S_1(2b) - 2\sin(b)\mathrm{Si}(b) + \sin(b)\mathrm{Si}(2b) \right) \tag{7}$$

$$\begin{aligned} \text{where:} \quad \beta &= 2\,\pi/\lambda, \\ b &= 2\,\beta\,H \\ \mathrm{Si}(x) &= \int_0^x \frac{\sin v}{v} dv, \text{(the so-called Sine Integral), and} \\ S_1(x) &= \int_0^x \frac{1-\cos v}{v} dv. \end{aligned}$$

Beware of confusing your Si's with your S_1's! Page [2, p 17] kindly avoids this by using $\mathrm{Ki}(x)$ instead of $S_1(x)$. Either way, this can in turn be expressed in terms of the Cosine Integral[11] $\mathrm{Ci}(x)$ as:

$$S_1(x) = \mathrm{Ki}(x) = \int_0^x \frac{1-\cos v}{v} dv = \gamma - \mathrm{Ci}(x) + \ln(x) \tag{8}$$

where $\gamma \approx 0.577216$ is Euler's constant.

We can plot this *loop* radiation resistance as a confirmation that all is correctly typed. Fig. 6 agrees with Fig. 14-5 of [1, p. 544] and gives the familiar result of 36.5 Ω for a $\lambda/4$ monopole.

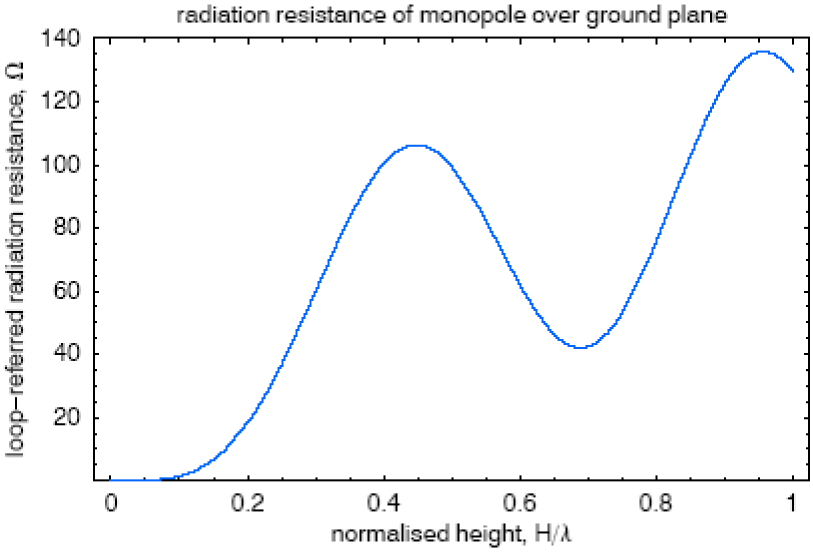

Figure 6: *Loop* radiation resistance of monopole as function of length

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[11] The Cosine Integral $\mathrm{Ci}(x)$ is itself defined as $\mathrm{Ci}(x) = -\int_x^\infty \frac{\cos v}{v} dv$.

We are more interested in the radiation resistance referred to the *feed point* (although as noted, this gives a nonsense result for $H = n\,\lambda/2$). This is given by:

$$R_{\mathrm{rad}} = \frac{R_{\mathrm{rad(loop)}}}{\sin[\beta\,H]^2}\ . \tag{9}$$

Combining (7), (8) and (9) we get the complicated result:

$$\begin{aligned} R_{rad} = {} & 15\csc(\beta\,H)^2\ \Big\{4\cos(\beta\,H)^2\ \left(\gamma - \mathrm{Ci}(2\,\beta\,H) + \ln(2\,\beta\,H)\,\right) \\ & -\cos(2\,\beta\,H)\ \left(\gamma - \mathrm{Ci}(4\,\beta\,H) + \ln(4\,\beta\,H)\,\right) \\ & -2\,\mathrm{Si}(2\,\beta\,H)\ \sin(2\,\beta\,H) + \mathrm{Si}(4\,\beta\,H)\ \sin(2\,\beta\,H)\,\Big\}. \end{aligned} \tag{10}$$

Fortunately it is easy to plot this using *Mathematica*, which has all the necessary built-in functions.

A.2.3 Example results

As noted already in § A.1, we need only consider lengths up to say $\lambda/10$. It is interesting to see how closely the simple approximation and full formula agree.

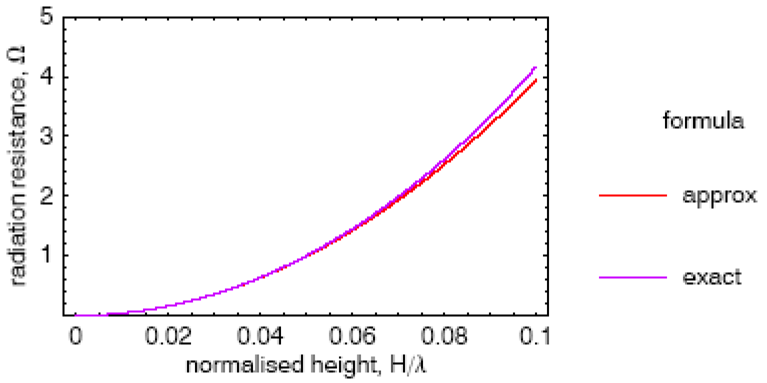

Figure 7: Radiation resistance of short monopole as function of length

Fig. 7 shows how the radiation resistance varies as the physical length of the monopole is varied in comparison to the wavelength — and shows that the simpler formula is a close approximation in the range of interest.

In practice we may be more interested in the behaviour of a particular antenna — which is of some fixed length, but has to work over a range of frequencies. This alternative presentation is given in the main text in § 3.3.

A.3 Reactance

Jordan and Balmain explain that in this case the diameter of the antenna must be finite, otherwise the reactance is infinite. This leads us again to uncertainty in that the sinusoidal current distribution that we assume is not strictly correct once the diameter is finite. However, allegedly, the method yields useful results.

Write a for the radius of the antenna, while H is its length as before. Combining equations from [1, pp. 545–7] we get the following long expression for the reactance *at the terminals*:

$$\begin{aligned} X_{\text{monopole}} = {} & -15\csc(\beta H)^2 \Big\{ 4\,\mathrm{Si}(u_0) - 2\,\mathrm{Si}(u_1) - 2\,\mathrm{Si}(v_1) \\ & - \cos(2\,\beta H)\ \big(-2\,\mathrm{Si}(u_0) + 2\,\mathrm{Si}(u_1) - \mathrm{Si}(u_2) + 2\,\mathrm{Si}(v_1) - \mathrm{Si}(v_2)\,\big) \\ & - 2\,\cos(\beta H)\,\sin(\beta H)\ \big(2\,\mathrm{Ci}(u_1) + \mathrm{Ci}(u_2) - 2\,\mathrm{Ci}(v_1) - \mathrm{Ci}(v_2)\,\big) \Big\}, \end{aligned}$$

where:

$$\begin{aligned} \beta &= 2\,\pi/\lambda, \\ u_0 &= \beta\,a, \\ u_1 &= \beta\left(\sqrt{H^2+a^2} - H\right), \\ u_2 &= \beta\left(\sqrt{(2H)^2+a^2} + 2H\right), \\ v_1 &= \beta\left(\sqrt{H^2+a^2} + H\right) \text{ and} \\ v_2 &= \beta\left(\sqrt{(2H)^2+a^2} - 2H\right). \end{aligned} \tag{11}$$

Jordan and Balmain go on to make simplifying approximations, relying on the antenna being relatively thin, but as *Mathematica* can easily handle the full expression we don't need them here.

A.4 Equivalent capacitance

For a simple capacitor we have impedance $Z = \jmath X = 1/(\jmath\,2\,\pi f C)$. So we can consider that any (negative) value of reactance X is equivalent (at some particular frequency f) to some equivalent capacitance C_{equiv} given by:

$$C_{\text{equiv}} = \frac{-1}{2\,\pi f X}\ . \tag{12}$$

We can simply apply (12) in conjunction with (11) to get the effective capacitance. There seems no need to spell out the messy formula here. We can then plot the effective capacitance of a representative example antenna as a function of frequency, see Fig. 8, where the antenna length H is taken as 0.5 m and its radius a as 2 mm.

We see that for all practical purposes, we could treat this antenna as having a constant effective capacitance of 6.2 pF over our frequency range. Nevertheless, the increase in capacitance at the highest frequency is plausible — as it gets towards resonance the inductive component is taking effect, reducing the numerical reactance, and thus *increasing* the effective capacity.

Further results are presented in the main text in § 3.4.

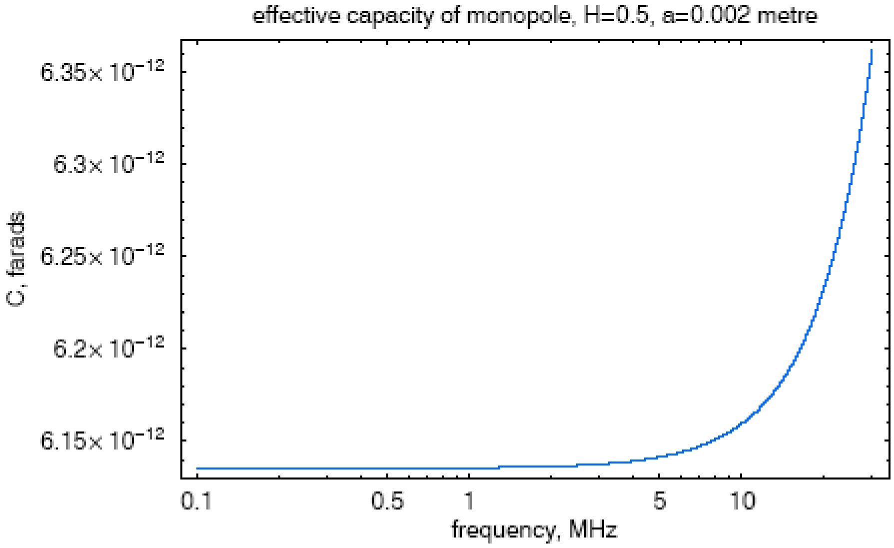

Figure 8: Capacitance of example short monopole as function of frequency. It is assumed to be cylindrical, of length 0.5 m and radius 2 mm, and to operate over an infinite ground plane.

Annex C

This Annex describes two methods based on the audio output signal to define the measurement thresholds for the case that the Bit error rate (BER) of the receiver is not available to the measuring institution. The measurement procedure is divided into set-ups for Gaussian-like disturbances and for Rayleigh channels.

Procedure for Gaussian-like disturbances

Simple listening to the audio signal of the receiver allows an acceptable determination of the BER threshold of 10^{-4} in many of the described tests. The digital cliff-edge behaviour makes the point of failure well defined. The sound quality varies with signal level as indicated in Figure 15.

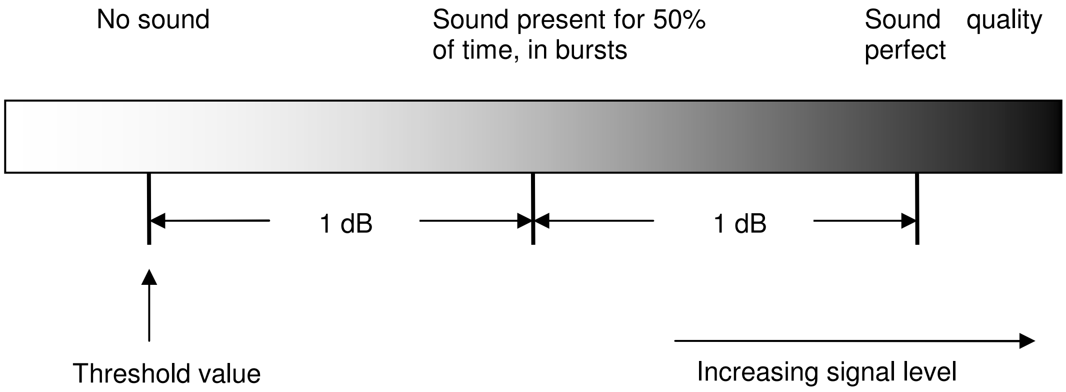

Figure 15 Relationship between signal level and audio quality

The BER=10^{-4} threshold is defined as the signal level point 1 dB below the signal level value with approximately 50% audio muting time. The audio signal at the threshold value point itself shall be verified for undisturbed sound quality.

This procedure can be used for all tests in chapter 7 except the ones in section 7.11 which are based on Rayleigh channels.

Procedure for Rayleigh channels

For receivers that do not offer BER measurement facility or raw bitstream output, the Audio Frame Error Rate (AFER) may be used instead. The Frame Error Rate is defined as the proportion of audio units in which a bit error or errors occur. An audio unit is as defined in [4], i.e. it corresponds to 40 ms of audio for all audio coders except MPEG-4 AAC at 12 kHz sampling rate where it contains one audio frame with 80 ms duration.

The AFER corresponding to a BER of 10^{-4} is different in different channels and the target AFER which shall be not exceeded for each channel is specified in Table 11.

Receivers may offer a display of audio frame errors, since these can be measured at the receiver using the error detection mechanisms in the audio encoding.

If such a display is not provided, the AFER can be measured using a test signal containing known audio and an automated process for detecting audio dropouts based on the audio output of the receiver. An implementation of such an automated process has already been developed, using an audio signal consisting of a repetitive sweep waveform; the audio is recorded to a WAV file and audio dropouts are detected using correlation in Matlab. It is described in [9] and is available as an open source project hosted at SourceForge [10].

Table 11 Required Audio Frame Error Rate (AFER) for the different channel profiles

Parameter	Combination					
	1	2	3	4	5	6
Requirement: S/N	21	22	31	26	20	25
AFER	10^{-2}	10^{-2}	10^{-3}	10^{-3}	10^{-3}	10^{-3}

This procedure can be used for the tests in section 7.11 which are based on Rayleigh channels.