

# **Report ITU-R BS.2502-1**

**(09/2023)**

BS Series: Broadcasting service (sound)

## **Measuring techniques for digital audio broadcast coverage performance**

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(2022-2023)

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## Abstract

The topics covered in this Report pertain to digital audio broadcast (DAB) coverage measurement. The reasons why such measurements may be necessary are discussed in depth, along with the technical prerequisites required before these measurements are made. Various use cases for measuring DAB network coverage are presented; for each use case the techniques, measuring parameters and requirements are described. Further, the requirements for the measuring equipment and its operation are discussed.

Some details about the relevant parameters for DAB are given, along with the results of some measurements that have been made, with a view to identifying a possible method for objective network and reception quality assessment for the DAB system.

The use of the term ‘DAB’ in this Report applies to both DAB and DAB+ systems. Where there is a difference in the impact on network planning and coverage performance between the two systems, this is explained.

## List of abbreviations

AU	Access unit
BER	Bit error rate
$C/N$	Carrier-to-noise
$C/(N+I)$	Carrier-to-noise plus interferer
CIR	Channel impulse response
COSNF	Conceptual overall system noise figure
CRC	Cyclic redundancy checksum
DAB	Digital audio broadcast
EEP	Equal error protection
FEC	Forward error correction
FIC	Fast information channel
FS	Field strength
ID	Identifier
IIP3	Input third order intercept point
MER	Modulation error ratio
MSC	Main service channel
QEF	Quasi error free
QoS	Quality of service

RS	Reed-Solomon
SAT	Site acceptance test
SFN	Single frequency network
TII	Transmitter identification information
UEP	Unequal error protection

## 1 DAB coverage measurement goals

There are several reasons why a measurement of a DAB network and coverage is to be planned. The key target for a broadcaster is to ensure the quality of coverage while maintaining the cost efficiency of the network as well as fulfilling regulatory requirements (i.e. licence obligations). The following points are just a few examples in order to indicate potential cases and how the background may influence the way the measurements have to be performed, i.e. to what extent and with which depth of detail:

- Check regulatory requirements – e.g. fulfilment of coverage obligations.
  - Such a check might be carried out nationwide, in different regions (e.g. in areas with difficult topography or in areas which serve as “examples”).
- Check business arrangements/contracts – e.g. agreement on QoS between a network operator and a platform owner/content provider.
  - Often areas which serve as ‘examples’ are enough but might be also nationwide or with higher intensity in certain areas/regions.
- Check broadcaster’s requirements – e.g. fulfilment of coverage goals.
  - Such a check might be carried out nationwide, in regions (e.g. in areas at the border of the network or for overlapping adjacent allotments).
- Check real/actual coverage in a certain area – e.g. following complaints by customers or in order to check necessity of further network deployment (to fill “coverage holes”). These measurements are performed within a limited area.
- Check the correct implementation of network and sites – e.g. antenna diagrams, transmitted power, transmitting delay, self-interferences and other key parameters.
- Check the frequency spectrum – e.g. co-channel interferers from other transmitters/networks on the same frequency.
- Check between prediction and reality – e.g. in order to validate a wave propagation model, to confirm/check planning parameters or to verify data bases used for coverage prediction (especially clutter data).
  - Often these measurements are carried out over a larger area but might be also lab-based. A typical example of the latter is the verification of parameters for real equipment on the market, e.g.  $C/N$  of receivers or antenna gain of cars or attached antennas.
- Check for long term aspects – e.g. variation of key parameters due to changed wave propagation of wanted signal or interferers.

In general, the targets can be classified into use cases as follows:

- 1 to verify service quality:
  - a) to survey the minimum outdoor coverage and quality for mobile reception:
    - i) this measurement use case aims at verifying the coverage for a defined mobile reception quality in cars as defined in Tech 3391 Guidelines for DAB network planning [1], within a defined area;

- b) to survey the minimum outdoor coverage and quality to determine indoor reception:
    - i) this measurement use case aims at verifying the coverage for a defined reception quality for indoor reception as defined in [1] measured outside of the buildings, within a defined area;
  - c) to survey the minimum indoor coverage and quality for indoor reception:
    - i) this measurement use case aims at ensuring a defined reception quality for indoor reception measured indoors in defined rooms or at the place of the receiver. This use case might be useful in specific cases of customers complaints.
- 2 to verify network quality:
- a) to verify the network deployment:
    - i) this measurement use case aims at verifying the “as built” network against the planning (e.g. radiated power, antenna radiation-pattern, network timing etc.);
  - b) to verify planning results and field strength predictions:
    - i) this measurement use case aims at verifying planning predictions with reality by measurements for defined planning situations;
  - c) to redo measurements to assess long term stability of coverage:
    - i) this measurement use case aims at verifying the network deployment and quality periodically for long term stability and for the reason of changes within the network or externally of the network.
- 3 to define or verify the minimum coverage criteria and link budget:
- a) this measurement use case aims at predicting and verifying parameters of the link budget as depicted in Recommendation ITU-R BS.1660 [2] and in the EBU DAB planning guideline [1] (e.g. receiver sensitivity, antenna-gain or man-made noise). These measurements are mainly lab-based and specific per each parameter.

### 1.1 Major Prerequisites

Prior to measurements of above-mentioned use cases, the proper implementation of the DAB data stream (e.g. ID's), transmitted parameters (e.g. spectrum-mask, delay) as well as the desired radiation of transmitting sites (e.g. antenna diagram) shall be ensured. Some of the above-mentioned use cases are dedicated to this verification of the network:

- Transmitter frequency accuracy, phase stability, spectrum mask (e.g. spurious emissions, attenuation of shoulders), transmitter power, geographical coordinates.
- Transmitter-delay, transmitter-ID, SFN-ID, network-ID/sub-ID, ensemble-ID<sup>1</sup>, country-ID.
- SFN-synchronization, constellation-diagram, modulation error ratio of transmitter, crest factor, I/Q-unbalance, frequency response and group delay.
- Antenna height, antenna diagram, attenuation of cable, standing-wave-ratio and return loss of antennas.

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<sup>1</sup> Compared with analogue broadcast radio systems, a DAB transmission is relatively wideband, this extra bandwidth allowing several services to be carried on the transmission. Such a transmission carrying more than one service is known as an ensemble [3], [1].

## 2 Measuring techniques

### 2.1 General

Considering measuring techniques, different approaches are to be applied for the above-mentioned targets, resulting in different methods and criteria for the measuring equipment.

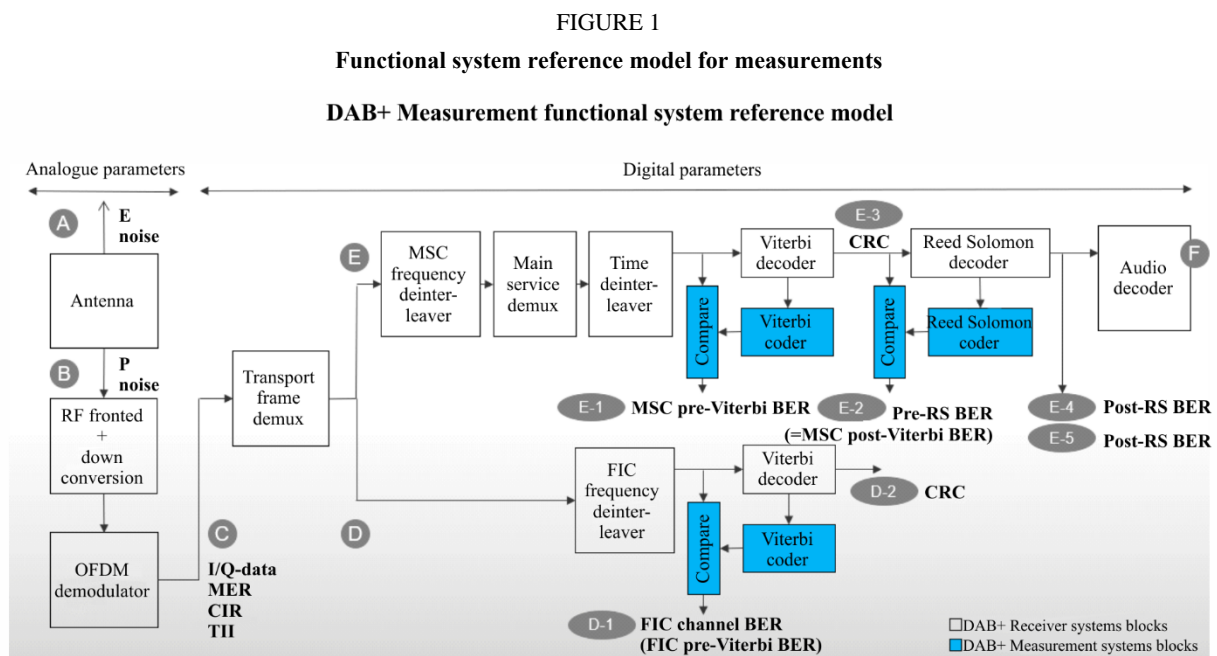
A measurement campaign and measuring techniques shall be universal for any foreseen analysis as far as possible. Distinctions between use cases and criteria shall be possible during the post processing of measured data.

- radio parameters e.g. measured field strengths shall be post-processed for specific criteria (e.g. 50% median values);
- quality criterion including e.g. demodulation, demultiplexing, bit error measuring would be beneficially postprocessed from sampled radio data by a software defined receiver.

### 2.2 Functional system reference model

The functional system reference model provides a general insight into the signal-processing of a consumer receiver and of a measurement receiver. It defines the reference points where radio- and quality-parameters could be measured. The functional system reference model is neutral to any signal processing architecture.

The reference model helps to understand the quality criterion measured at specific points. DAB network quality and received DAB service quality can be assessed with the measurement results.



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The reference model is comprised of the following building blocks and reference points for measurements:

#### A. Antenna Interface:

- Field strength of wanted signal

- SFN self-interferers
- Co-channel and adjacent channel interfering power
- Man-made noise.

B. Radio Interface:

- Radio frequency parameters, Power,  $C/(N+I)$
- Power of wanted signal
- receiver parameters signal level, MER, CIR,  $C/N$
- receiver performance noise figure,  $C/N$ .

C. OFDM Demodulator Interface:

- I/Q-Data
- MER
- CIR
- TII Signal.

D. Fast Information Channel, FIC:

- 1 FIC Pre-Viterbi BER
- 2 FIC Post-Viterbi CRC.

E. Main Service Channel, MSC:

- 1 MSC Pre-Viterbi-BER
- 2 MSC Post-Viterbi-BER (or number of corrected bits at RS decoder)
- 3 MSC Post-Viterbi-CRC
- 4 MSC Post-RS-BER (applicable for DAB+ only)
- 5 MSC Post-RS-CRC (applicable for DAB+ only).

F. Audio Service:

- Audio Service
- QEF criteria.

### 2.3 Relevant parameters

DAB measuring receivers may give the option of measuring, FIC BER, MSC BER or MER or a combination of these.

As can be seen from Fig. 2, the DAB system has three symbols within the FIC. These are not time interleaved and are encoded at a standard 1/3 coding rate. The MSC has 72 symbols where, for DAB, each service can be encoded at one of the five available encoding rates, the audio/data is encoded with Unequal Error Protection (not all bits are protected equally hence audible break up before failure) and is time interleaved. As the services can be encoded with less robust encoding rates than the FIC and the FIC data is repeated regularly, it is better to record the MSC BER data if this option is available.

Errors in MPEG 1 layer 2, bit allocation and high bits of scale factors are extremely damaging to the service. Therefore, Cyclic Redundancy Check (CRC) words are included in the bit stream and if these are wrong the audio is muted.

For DAB+, a more efficient coding method is used which adds an extra layer of correction based on Reed-Solomon encoding placed around the byte interleaved audio frame but inside the convolutional coding of the DAB system, increasing its ruggedness. However, due to its high efficiency encoding



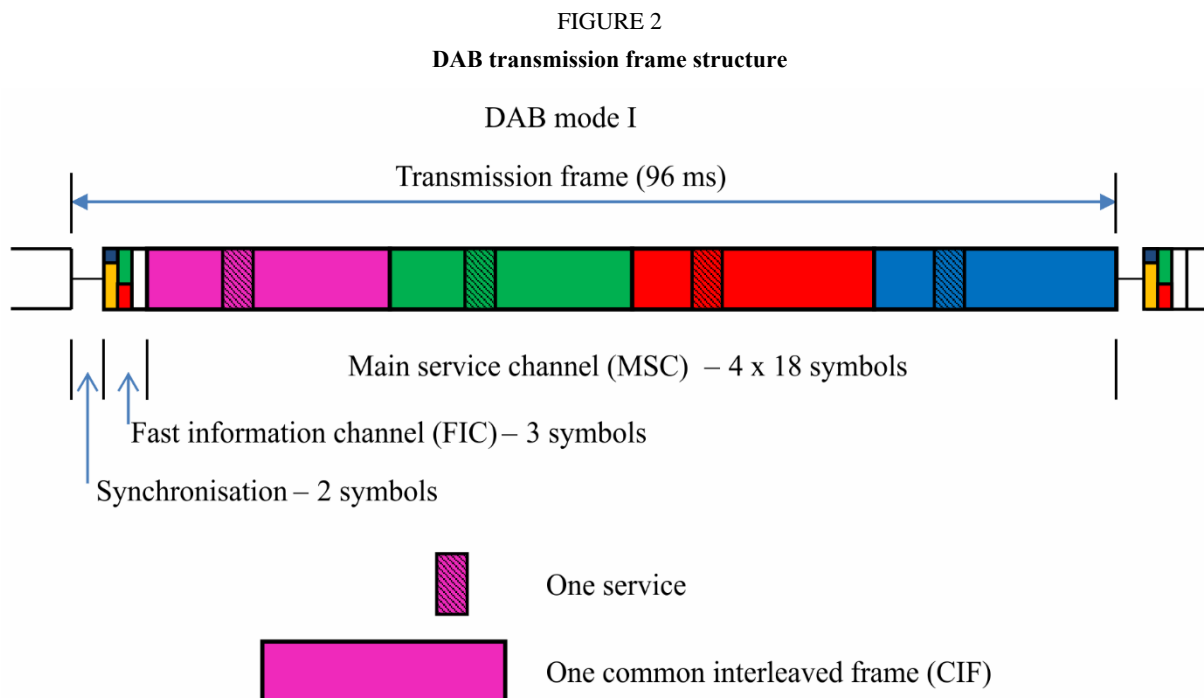
(AAC version 2 compared to MPEG 1 layer 2 for DAB) the impact of lost bits would be greater, so all bits are protected equally (Equal Error Protection). This means that when the signal gets too weak, audio frames are lost and the audio mutes. This is indicated by CRC errors only, as the failure point is much sharper than for DAB.

Modulation Error Ratio (MER) provides an indication on how well each symbol was received. It defines the total of all interferences on a digital quadrature modulated signal calculated by averaging the error of all OFDM subcarriers. MER is the ratio of average symbol power to average error power, for example, a small spread on the symbol points gives a high MER and good reception. The occasional stray symbol phase and amplitude will have little effect on MER and in the presence of bursty or intermittent interference the MER will often be fine while the Bit Error Rate (BER) will not. The MER is often used for transmitter testing, and values are, generally, higher than 20 dB. At the received signal, MER is mainly influenced by the radio channel and propagation of the signal, resulting in lower values (minimum MER should be around 10 dB).

Channel Impulse Response (CIR) is one of the key criteria for reviewing network performance, network planning and timing of the SFN. MER and CIR are, combined with the  $C/(N+I)$ , key criteria for assessing the network quality on radio interference level.

Noise and co-channel interferers are measured every 2nd null-symbol, when for a short moment the wanted signal is muted. In every 2<sup>nd</sup> null-symbol, no TII-symbol is transmitted according to [4] Chapter 5.4.2.2. The  $C/(N+I)$  ratio is calculated then from the wanted signal, the noise component and the interferers.

A BER can be measured as a so called ‘pseudo BER’ only because the reference bitstream is not available for the measurement equipment. For this purpose, the blue building blocks in Fig. 2 provide the alternative bitstream reference.



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As a first measure to reduce bit errors, frequency interleaving and time interleaving are applied on the bitstream. The goal is to reduce the effect of burst errors due to fast fading, velocity and other effects based on time or location variation in the radio channel. The Viterbi decoder acts on service

level. It can decode a bitstream that has been encoded using convolutional coding. This coding scheme provides a further reduction of the impact of burst errors.

For DAB+, an additional Reed-Solomon Forward Error Correction (FEC) can reduce remaining bit errors further down. However, it is not able to cope with bursts as well as with higher BER. The input BER of the Reed-Solomon FEC has to stay below a specific value for proper operation otherwise the Reed-Solomon algorithm will lose its correction gain.

The resulting maximum tolerable BER is dependent from the velocity, the received  $C/(N+I)$  and the characteristics of the radio channel at any stage of the functional reference model. However, the later the reference point the less pronounced the influence of the channel is. The difference between pre- and post-Viterbi BER is dependent from the radio channel.

A pseudo-BER measurement is accurate for low post-Viterbi values only ( $QEF 2 \times 10^{-4}$ ). For higher pre- and post-Viterbi BER values which a DAB receiver is able to decode at its failure point, the BER measurements are less representative.

MSC pre-Viterbi BER is highly sensitive for any quality impact on the receiving path, long before any interruption on the audio service occurs. Pre-Viterbi BER is therefore well suited for quality measurements of the network, while post-Viterbi and post-RS measurements are more suited to assess the resulting quality on service level.

However, MSC pre-Viterbi BER measurements are not representing an individual service quality given by the protection level. To assess the gain of protection levels, MSC post-Viterbi BER measurements shall be performed, and this parameter is the favourite for the assessment of the quality of service.

FIC pre-Viterbi BER is not time interleaved. It is fast, sensitive to quality impacts and accurate. Therefore, it is the favourite for verifying planning results.

For DAB+, Reed-Solomon (RS) -Decoding a time interleaving over 120 ms (5 CIF frames with 24 ms) is applied. The DAB+ audio super frames are comprised of 110 bytes payload and 10 bytes code for the Reed-Solomon FEC. Five of these 120 bytes can be corrected. So, to say a BER of  $5 / (120 \times 8) = 5.208 \times 10^{-3}$  is the maximum allowed post-Viterbi BER for a lossless audio service.

Furthermore, the correction activity of the Reed-Solomon decoder could be an indication for the incoming BER, which is equivalent to the post Viterbi BER.

### 3 Measurement equipment

#### 3.1 Sampling

For the minimal collected samples per second, Recommendation ITU-R SM.1708 “Field-strength measurements along a route with geographical coordinate registrations” [5] and CEPT [6] recommend considering the Lee Method. This method assures that one gathers enough data for statistical analysis by measuring with constant speed. This means that the measurement system should collect 50 samples within 40 wavelengths. For some common vehicle speeds, the minimal collected samples per second are calculated in Table 1.

TABLE 1  
The minimal collected samples per second

Measurement vehicle speed (km/h)	Frequency		
	174 MHz	200 MHz	230 MHz
	Minimal samples per second (1/s)		
25	5	5.8	6.7
50	10.1	11.6	13.3
80	16.1	18.5	21.3
100	20.1	23.1	26.6
120	24.2	27.8	31.9

For individual calculations the following equation can be used:

$$\text{minimal samples per second} = \frac{v}{\lambda * (\frac{40}{50})} \text{ in 1/s}$$

where:

v: measurement vehicle speed (m/s)

$\lambda$ : wavelength of measured frequency (m).

In reality, a constant speed is often not feasible. In this case the post processing has to ensure an equal spread of the results relative to the distance.

## 3.2 Requirements for measuring equipment

### 3.2.1 Requirements for BER measurements

A DAB measurement receiver shall provide capability for BER measurements. When BER is the target of measurements, it is important to specify how often the measurement receiver shall provide updated BER values and how these values are determined. The receiver shall be capable to provide enough BER measurement data. It is key to understand, that the minimal measurement time needed for BER is depending on the desired BER to be measured and from the channel bit rate.

The measurement interval shall be long enough to provide a reasonable confidence. To provide a reasonable confidence, the amount of measured data shall be averaged up to 30 times the reciprocal value of the BER to be measured. However, it shall be avoided to average measurement samples over a longer or even an infinite period. Such a result might be not representative.

To provide a fast update rate for mobile measurement campaigns, all services in the MSC of a DAB ensemble shall be encountered for the calculation of BER. This is feasible for MSC pre-Viterbi BER measurement or for post-Viterbi BER for services with the same protection level.

For a BER of e.g.  $5 \times 10^{-2}$  (the threshold for EEP-3A at MSC pre-Viterbi), 600 bits have to be analysed with respecting the confidence interval. Measuring this BER for a service with e.g. 64 kbit/s will need 10 milliseconds.

Example: Encountering all services in an ensemble, the usable bitstream, which is available for both pre-Viterbi and post-Viterbi, will be 1.152 Mbit/s. For a desired BER of  $1 \times 10^{-3}$ , the update rate will be 26 ms, for a BER of  $1 \times 10^{-4}$  it will be 260 ms. For mobile measurements these BER are sampled 40 times and 4 times per second or with a speed of e.g. 100 km/h all 0.7 m and 7 m.

When the impact of different protection levels within a DAB ensemble shall be assessed on reception quality, the use of post-Viterbi BER measurement is mandatory. Post-Viterbi BER takes roughly 10 times longer than pre-Viterbi, thus measurement speed lower than 20 km/h or stationary measurements shall be considered.

As a conclusion for mobile quality measurement campaigns, the measurement of the pre-Viterbi BER is recommended as this needs less time to provide the result. Pre-Viterbi BER provides a short measurement interval and therefore the highest possible rate of samples.

As a result, BER measurement of mobile campaigns can only serve as an indication for the assessment of stationary indoor services. With performing mobile measurements, impacts (e.g. doppler-shift) are influencing the measurement results.

Suppliers of measurement equipment shall ensure the whole MSC-bit stream is considered in order to allow the shortest possible measurement time.

For quality measurements (BER, Audio Service), a referenced measuring setup is mandatory as described in § 7.3.2. It is assumed the parameters of this reference receiver have been defined prior to planning of the network. Quality measurements are feasible with such a reference measuring receiver only.

Parameters relevant to be set according to the reference measuring receiver are:

- receiver's sensitivity;
- receiver's time synchronisation method;
- receiver's implementation of BER measurements.

### **3.2.2 Requirements for field strength measurements**

For measuring field strengths in mobile measurement campaigns, the equipment shall provide measurements as accurate as possible, with a sampling rate of minimum 40/s according to § 3.1. For accurate field strength measurements, the receiver might be operated in a configuration with best noise performance.

### **3.2.3 Requirements for receiver performance**

The requirement for receiver performance depends on the type of measurement being made.

For quantitative measurements, to allow both low and high signal levels to be evaluated, the receiver should perform as well as possible, i.e. low noise floor and high overload margins. In general, most high-end measuring receivers achieve such performance.

For representative quality measurements, it is most important that the performance of the receiver equals that of the receiver with the parameters as defined in [1]. In this Report it will be referred to as 'the reference receiver' as defined in [1]. It should be noted that commercially available measurement equipment may not be in-line with [1], in which case, quality measurements cannot be representative without some adjustment. If the equipment performs better than [1], its performance may be aligned by e.g. introducing a switchable attenuator at the receiver input. Receiver noise performance depends not only on the performance of the measurement equipment but on the overall setup including e.g. antenna, preamplifier, cabling and connectors, so the choice of attenuation should be made accordingly.

To achieve a receiver's reference noise performance according to Table 8 in [2] or any broadcaster specific criteria, the measurement receiver shall be configurable according to the overall noise performance as described in § 7.3.2.

To avoid any spurious interferers and avoid broadband noise from measurement equipment, any man-made noise from switching power supplies shall be avoided.

### 3.2.4 Requirements for large signal capability

Large signal handling is key when high power DAB sites, high power FM sites, non-co-located DAB sites or further radio service are operated in the vicinity of the measurement route. The degradation of the noise performance of the receiver by intermodulation has to be avoided. Therefore, preamplifiers and receivers have to be designed with a high third order intercept point at the output (IIP3).

### 3.2.5 Requirements for time synchronisation

The receiver time synchronisation (see Chapter 2.3 in [1]) shall be configurable for the measurement receiver to provide the desired reference as there is no common rule out of [1]. Consumer receivers follow their own strategy for time synchronization. When it comes to quality measurements, the specific time synchronization method shall be deemed to be the reference, as it was applied during the planning of the DAB network.

As a conclusion, the measurement receiver shall be flexible for this parameter. Ideally the receiver time synchronisation shall be selectable for the measurement receiver to provide the desired reference.

Measuring service quality with different methods of time synchronisation might be beneficial to assess network quality for different receiver implementations.

### 3.2.6 Summary of requirements

Suppliers of measurement equipment shall provide following features:

- BER measurement at FIC pre-Viterbi, MSC pre-Viterbi, MSC post-Viterbi and MSC post RS for DAB+ are provided and described in the user manual and in the menu.
- All services of an MSC shall be considered for the calculation of any BER in order to allow the shortest possible measurement time.

Receiver performance shall be equal to the reference receiver as defined in [2] Table 8 for this use case or any broadcaster's criteria.

- For indicating indoor reception quality by outdoor BER measurements through a mobile measurement campaign, it would be beneficial to have the receiver reference to the use case as described in § 7.3.2 (e.g. a concept of step-attenuation at the input of the measuring receiver for the simulation of the allowance of building entry loss used in the planning process (see Chapter 7 in [2])).
- The absolute accuracy of the entire setup, including measurement device, calibration and correction factors, must be able to derive a field strength value with  $\pm 3$  dB. The relative accuracy shall be even higher.
- The minimum sampling rate shall be 40/s.
- It is recommended that the entire setup, including measurement device, calibration and correction factors, shall be able to derive a field strength value with an accuracy of  $\pm 2$  dB at a minimum sampling rate of 40/s.
- Overload margins shall allow reception of 120 dB( $\mu$ V/m) in the VHF III band, while still ensuring the desired receiver performance.
- Time synchronisation according to [1] Chapter 2.3.
- Any man-made noise in the measurement setup or around it e.g. from displays influencing the performance of the measurement receiver shall be avoided.
- Provision of a GPS reference for mobile measurements.

## **4 Definition of quality criteria**

### **4.1 General**

As criterion for quality, the BER of a service is chosen. A given BER on service level is not a synonym of good network alone as some variation of network performance shall be considered and some resilience to the breaking point shall be available. Respecting this, it is obvious to set a margin between the maximum BER criterion which produces not yet audio losses and the BER criterion chosen as the minimum criterion for quality measurements. Fading and long-term effects (e.g. variation of propagation over time) in a DAB network will need the above-mentioned margin for an acceptable service.

### **4.2 Quality criteria**

Based on the results of the study for quality criteria of Rai Way in § 7.3.1, the quality criteria for a DAB service protected with a protection level EEP-3A can be derived.

As shown in Table 5 of the study, a pre-Viterbi BER of  $5 \times 10^{-2}$  is near the failure point of the service. The failure point is more or less identical for all measured radio channels at a BER of  $6 \times 10^{-2}$  to  $7 \times 10^{-2}$ . Beyond that limit, the CRC value start to rise indicating a loss of service. Further, it should be taken into account that BER measured at the failure point includes some uncertainty due to the lack of a reference signal in a pseudo-BER measurement setup.

- Max BER MSC pre-Viterbi for an acceptable service quality:  $5 \times 10^{-2}$
- Max BER MSC pre-Viterbi for good service quality:  $2 \times 10^{-2}$
- Max BER MSC pre-Viterbi for a very good network quality:  $5 \times 10^{-3}$ .

‘Acceptable quality’ indicates the service is available during the measurement. However, long-term quality of the service at this given point in the network is not ensured with this service quality level, so close to the failure point.

‘Good quality’ indicates the service is available during the measurement. This quality level includes a reasonable margin with respect to the failure point.

‘Very good quality’ indicates the service is available during the measurement. This quality level includes enough margin to overcome long-term effects within the network.

The above-mentioned quality levels are generic. The criteria (BER) are valid for the most common protection level EEP-3A. Higher protection levels allow a higher robustness at pre-Viterbi, however, are less efficient in terms of capacity. Higher protection levels will lead to other MSC pre-Viterbi BER criteria needed for the above-mentioned service levels.

## **5 Measurements to verify service quality**

### **5.1 To survey the minimum outdoor coverage and quality for mobile reception**

#### **5.1.1 Introduction**

This measurement use case aims at ensuring a defined reception quality for mobile reception in cars as defined in [1] within a defined area.

#### **5.1.2 Description of the use case**

It is likely that large areas will need to be covered to assess the coverage performance of the network, a suitable car with a receive antenna height set for normal car reception would be required to make mobile measurements. Mobile measurements should be taken at a relatively constant speed to

maximize the number of measurements and provide an even spread. The speed should be adequate to the area under investigation. For example, in an urban environment a speed of maximum 50 km/h is considered suitable and on highway a speed of 100 km/h could be advisable (to be kept into consideration that the speed of the fading profile TU 6 and RA 4 is commonly 25 km/h and 120 km/h, respectively).

Regarding the number of samples to be collected, in the case of the assessment of the quality of service, a sampling of 3/4 measurements each meter is enough. In the case of a speed of 120 km/h, 10 measurements each second could be advisable if no statistical measurements are foreseen. The receiver should be able to treat each measurement and discard the values related to the Null Symbol when the DAB signal is locked. It is important also to know how much time the equipment needs to perform a measurement (integration time of the measurement circuit, acquisition time of digital parameters) in order to choose the appropriate measuring time.

The coverage is verified within a defined area, for example  $100\text{ m} \times 100\text{ m}$ , along a road or in a tunnel. For the area or the road, the value of the field strength in the 99% of case is calculate. This value should be above the required minimum threshold, i.e. 35 dB( $\mu\text{V/m}$ ) at 1.5 m a.g.l. in order to consider covered the area.

The survey equipment shall have the ability to measure the field strength fast and accurate.

If the survey equipment has the ability to decode DAB signals, then subjective listening of the services can be carried out while undertaking the survey. If it also provides error rate data, then this can be used to further classify the quality of the service where interferences or man-made noise may have affected reception of the wanted services. In this case, in order to better define the quality of service, a three-grade scale, where the average of all MSC BER values collected in the pixel is considered, could be used (see Chapter 3.2 and Chapter 7.1.3).

### 5.1.3 Relevant parameters

#### 5.1.3.1 Primary parameters

- Field Strength, FS.
- Fast Information Channel BER, FIC BER, pre-Viterbi.
- Main Service Channel BER, MSC BER, pre-Viterbi and post-Viterbi (pre-Viterbi is more feasible for mobile measurements due to its higher possible update rate, the MSC BER post-Viterbi is mandatory of assessing the influence of specific protection levels).
- Audio Service.
- Transmitter Identification Information, TII (identification of the main transmitter and the one of two or three others belonging to the SFN).

#### 5.1.3.2 Secondary parameters

- Channel Impulse Response, CIR.
- Modulation Error Ratio, MER.
- Carrier-to-noise,  $C/N$ .
- Main Service Channel BER, MSC BER, post Reed-Solomon.

To be noted that generally, CIR and  $C/N$  data are not collected during mobile measurements. It is preferable to measure  $C/N$  and get CIR in some specific points (static measurements) where specific situations have to be deeply investigated. In fact, the  $C/N$  could help in finding disturbing adjacent emissions and the CIR in evaluating self-interferences.

### 5.1.4 Measurement equipment

To carry out DAB mobile outdoor coverage and quality surveys, a vehicle with the following equipment is recommended:

- A roof mounted antenna, positioned for best omni-directional performance (typically a centrally mounted  $\frac{1}{4} \lambda$  whip antenna for vertical polarisation, a horizontal polarisation might be used in some countries or cities).
- The omni-directional antenna shall be mounted between 1.5 m and 2.5 m above ground.
- The maximum degradation from the ideal horizontal diagram shall be less than 2 dB.
- The return loss shall be better than 10 dB.
- A GPS system for position information.
- Ideally a DAB receiver for subjective listening and BER or CRC results.
- A method of measuring Field Strength (preferably calibrated).
- For quality measurements receiver sensitivity and selectivity shall match the reference receiver defined for the coverage criteria.
- Suitable control and logging software.
- Any influence of man-made noise from the measuring vehicle shall be verified and avoided.
- The receiver shall be capable to perform up to 40 measurements per second.
- The performance of the receiver shall equal the reference receiver as defined in [1] for this use case. It is important that local interferences should not compromise receiver performance beyond those shown in the reference performance parameters in [1].

## 5.2 To survey the minimum outdoor coverage and quality to determine indoor reception

### 5.2.1 Introduction

This measurement use case aims at ensuring a defined reception quality within a defined area for indoor reception as defined in [1] based on measurements taken outside of the buildings.

### 5.2.2 Description of the use case

This use case is similar to the survey of the minimum outdoor coverage and quality for mobile reception as described in § 5.1. Although in this case, some allowance must be made to take account of the difference between the actual (outdoor) measurement location and the point of reception (indoor). Such an allowance would compensate for building attenuation and for the man-made noise within the building. For the survey of the quality criteria (digital parameters according to § 2) this could be e.g. facilitated by the introduction of an additional attenuator in the receiving path. In any case, the noise performance of the measurement receiver shall be referenced to the specific indoor use case with the broadcaster's criteria by adjusting the overall noise performance as described in § 7.3.2. Field strength criteria would not need any change to the receiving set-up and could be derived from a survey for the mobile reception.



### 5.2.3 Relevant parameters

#### 5.2.3.1 Primary parameters

- Field Strength, FS.
- Fast Information Channel BER, FIC BER.
- Main Service Channel BER, MSC BER, pre-Viterbi and post-Viterbi (the MSC BER post Viterbi is mandatory of assessing the influence of specific protection levels).
- Audio Service.

#### 5.2.3.2 Secondary parameters

- Channel Impulse Response, CIR.
- Modulation Error Ratio, MER.
- Carrier-to-Noise,  $C/N$ .
- Main Service Channel BER, MSC BER, post Reed-Solomon.

#### 5.2.3.3 Additional parameters

- Attenuation for building entry loss to be added.
- Level of man-made noise to be added.

### 5.2.4 Measurement equipment

To carry out the necessary outdoor measurements to determine DAB portable indoor coverage, a vehicle with the following equipment is recommended:

- A roof mounted antenna, positioned for best omni-directional performance (typically a centrally mounted  $\frac{1}{4} \lambda$  whip antenna for vertical polarisation, a horizontal polarisation might be used in some countries or cities).
- The omni-directional antenna shall be mounted between 1.5 m and 2.5 m above ground.
- The maximum degradation from the ideal horizontal diagram shall be less than 2 dB.
- The return loss shall be better than 10 dB.
- A GPS system for position information.
- Ideally a DAB receiver for subjective listening and BER or CRC results.
- A method of measuring field strength (preferably calibrated).
- For quality measurements receiver sensitivity and selectivity shall match the reference receiver defined for the coverage criteria.
- Suitable control and logging software.
- Any influence of man-made noise from the vehicle into the measurement receiver shall be verified and avoided. Man-made noise will influence the receiver noise performance and measurement results.
- The receiver shall be capable to perform up to 40 measurements per second.
- The performance of the receiver shall equal the reference receiver as defined in [1] for this use case.
- For survey of quality criteria, it shall be possible to introduce an additional attenuation into the receiving path representing the amount of the assumed median building entry loss.

It has to be understood that for quality measurements (BER) a reference receiver is mandatory. The parameters of the reference receiver shall match the ones chosen for the planning.

### **5.3 To survey the minimum indoor coverage and quality for indoor reception**

#### **5.3.1 Introduction**

This measurement use case aims at ensuring a defined reception quality for indoor reception measured indoors in defined rooms or at the place of the DAB receiver.

#### **5.3.2 Description of the use case**

This use case is useful in specific cases. Not only does it directly measure the reception quality at the point of reception, when the results are combined with those of use case in § 5.2, it represents a survey of the building entry loss. Measurements are performed at specific places, where receivers are intended to be operated, or measurements are performed overall in rooms with a defined set of measuring points.

Measurements might be performed upon listener's negative feedback or to verify the planning criteria for building entry loss. These measurements are beneficial for critical coverage situations to determine whether an additional transmitter shall be planned, adjacent channel situations where different building entry losses could influence the coverage reserve, or for 'last building' situations where the outer front of the building is not served by reflections of the signal.

#### **5.3.3 Relevant parameters**

##### **5.3.3.1 Primary parameters**

- Field Strength, FS.
- Fast Information Channel BER, FIC BER.
- Main Service Channel BER, MSC BER, pre-Viterbi and post-Viterbi (the MSC BER post Viterbi is mandatory of assessing the influence of specific protection levels).
- Audio Service.

##### **5.3.3.2 Secondary parameters**

- Channel Impulse Response, CIR.
- Modulation Error Ratio, MER.
- Carrier-to-noise,  $C/N$ .

#### **5.3.4 Measurement equipment**

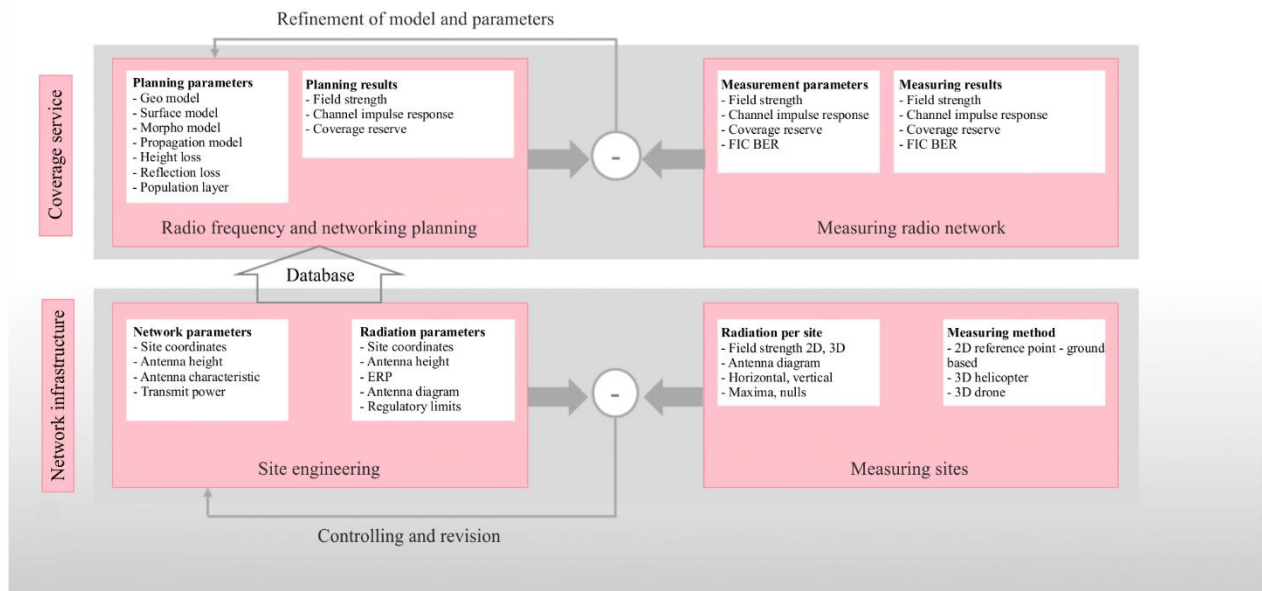
To carry out DAB indoor coverage surveys a handheld receiver with the following parameters is recommended:

- A handheld antenna, with omni-directional diagram (typically an active antenna with a switchable pre-amplifier. The antenna should be capable of operating with either vertical or horizontal polarisation.
- The omni-directional antenna shall be placed 1.5 m above ground.
- The maximum degradation from the ideal horizontal diagram shall be less than 2 dB.
- The return loss shall be better than 10 dB.
- Ideally a DAB receiver for subjective listening and BER or CRC results.
- A method of measuring field strength (preferably calibrated).
- Suitable control and logging software.
- For quality measurements receiver sensitivity and selectivity shall match the reference receiver defined for the coverage criteria in [1] for this use case.

## 6 Measurements to verify network quality

Quality assurance of the DAB transmitter network includes the following process steps. It includes the verification on system level, on infrastructure level as well as on planning level.

FIGURE 3  
Quality assurance of the DAB transmitter network  
Verification of radio frequency and network planning and radio infrastructure



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### 6.1 To verify planning results and field strength predictions

#### 6.1.1 Introduction

This measurement use case aims at verifying planning predictions by measurements for defined planning and normal tropospheric situations.

It should be noted that measurements can only record the state of the network at the time the measurement is taken. DAB planning and coverage prediction generally take account of enhanced interference due to long distance tropospheric propagation, which occurs for small percentages of time, but which can significantly change the coverage of the network during this time. For this reason, measurements taken at times of little or no tropospheric enhancement will tend to overestimate the coverage, and this should not be interpreted as a failure of the planning model.

#### 6.1.2 Description of the use case

The verification of the planning results is performed typically by mobile and ground-based measurements. Measurements can be performed at different places at the limit of the coverage area as well as in between or in the neighbourhood of a transmitter.

The prerequisite for this use case is the verification of the proper radiation of transmitter sites by ground-based measurements, helicopter- or drone-based measurements (see § 6.2).

Field strength predictions and simulations are performed for the 50% (median) location value. To verify field strength predictions, measuring results shall be documented for the same 50% location values. For the verification of the planning results the channel impulse response, CIR, is measured and compared with the simulation results. Some planning and measurement tools are able to calculate

or measure the CIR. The CIR of the FIC shall be measured. The FIC is not time interleaved and therefore suitable for the verification of the planning. The MSC is not applicable for this purpose. For this verification of field strengths, the accuracy of the measurement receiver is more relevant than its sensitivity.

If an area is simultaneously served by several transmitters in an SFN, there is expected to be a degree of spatial diversity, resulting in a further reduction in signal variation. In order to quantify the improvement, different measurement campaigns could be made with just a single transmitter in service and then the results compared with the one of the SFN. The spatial diversity is calculated for a pixel. The gain is generally evaluated for each single position of reception.

### **6.1.3 Relevant parameters**

- Planned Field Strength, FS, planned Channel Impulse Response, CIR.
- Measured Field Strength FS, Channel Impulse Response CIR, measured FIC BER.
- Field Strength FS over the height above ground.
- Transmitter delay, network tuning delay, transport delay.

### **6.1.4 Measurement equipment**

To verify planning results with field strength predictions, an equipment with the following criteria is recommended:

#### **For ground-based measurements**

- A rotatable fixed mounted antenna, positioned towards the transmitter with a directional diagram.
- A log-periodic antenna typically achieves best performance, and this could be used for either vertical or horizontal polarisation.
- The fixed antenna shall be positioned around 3.5 m and 10 m above ground.
- The return loss shall be better than 10 dB.
- A GPS system for position information.
- A method of measuring field strength (preferably calibrated for the foreseen antenna).
- Suitable control and logging software.
- The measurement receiver shall be capable to operate high field strengths without producing intermodulation. Any influence of man-made noise from the measuring vehicle shall be verified and avoided.
- For quality measurements receiver sensitivity and selectivity shall match the reference receiver defined for the coverage criteria. The performance of the receiver shall equal the reference receiver as defined in [1] for this use case.

#### **For air-based measurements**

It is not yet common to verify field strength predictions air based.

## **6.2 To verify the network deployment**

### **6.2.1 Introduction**

This measurement use case aims at verifying the network deployment and quality as built and periodically for long term stability and for the reason of changes within the network or externally of the network.

## 6.2.2 Description of the use case

The verification is performed at different levels of the network. This use case includes the verification of transmitting sites by ground based, helicopter or drone-based measurements.

### 6.2.2.1 Verifying the radiation of a transmitter site

The verification is performed for critical sites during site acceptance (SAT). To verify whether the radiation of a transmitter site fulfils regulatory limits, specific reference point measurements, either two dimensional (terrestrial, ground based) or three dimensional (air based) must be applied. For SAT the following cases have to be distinguished:

- New antenna: For critical sites it is crucial to be sure that the new antenna diagram fulfils the license and matches the coordinated values accurately. Therefore, a factory acceptance test (FAT) of the antenna or parts of the antenna is performed by the supplier prior the installation on-site. Any critical antenna shall be verified immediately after on-air date.
- Revision of antenna: A revision of the antenna (e.g. changing the vertical down tilt) is less critical by means of fulfilling license once an antenna is in operation and was verified. On the other hand, downtime of the site shall be avoided or limited.

FIGURE 4

**High tower high power transmitter Säntis, Switzerland, close to Germany and Austria with 2 502 metres height above sea level the DAB+ antenna is extremely critical. The antenna comprises 32 antenna panels with four directions and eight levels to fulfil regulatory requirements**



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The measurements are performed in the neighbourhood of a transmitter. The radiation of the transmitter and the antenna diagram is verified.

For the measurement of antenna diagrams, airborne systems are physically advantageous and more accurate over terrestrial systems. There are fewer interferences, such as ground reflections, shadows, damaged Fresnel zones, etc.

## 6.2.3 Relevant parameters

### 6.2.3.1 In the field

- Planned field strength, FS.
- Measured field strength, FS.
- Measured field strength over the height above ground.

### 6.2.3.2 On site

- Transmitter frequency accuracy, phase stability, spectrum mask, spurious emissions, attenuation of shoulder, transmitter power, geographical coordinates.
- Transmitter-delay, network-tuning-delay, transport-delay, transmitter-ID, SFN-ID, network-ID/sub-ID, ensemble-ID, country-ID.
- SFN-synchronization, constellation-diagram, MER of transmitter, crest factor, I/Q-unbalance, frequency response and group delay.
- Antenna height, attenuation of cable, standing-wave-ratio and return loss of antennas.

### 6.2.4 Measurement equipment

For verifying network deployment, equipment with the following criteria is recommended.

#### For ground-based measurements

- A rotatable fixed mounted antenna, positioned towards the transmitter with a directional diagram.
- A log-periodic antenna typically achieves best performance, and this could be used for either vertical or horizontal polarisation.
- The fixed antenna shall be positioned around 3.5 m and 10 m above ground.
- The return loss shall be better than 10 dB.
- A GPS system for position information.
- A method of measuring field strength (preferably calibrated for the foreseen antenna).
- Suitable control and logging software.
- The measurement receiver shall be capable to operate high field strengths without producing intermodulation.
- Any influence of man-made noise from the vehicle into the measurement receiver shall be verified and avoided. Man-made noise will influence the receiver noise performance and measurement results.
- For quality measurements receiver sensitivity and selectivity shall match the reference receiver defined for the coverage criteria. The performance of the receiver shall equal the reference receiver as defined in [1] for this use case.

#### For air-based measurements

- A helicopter or drone with a stability of  $\pm 2$  m. The system shall be operated safely and according to country rules with the influence of high field strengths radiated by the transmitter.
- If a helicopter is used, a rotatable mounted antenna, with a directional performance (typically a log-periodic) which could be used with vertical or horizontal polarisation. In some cases, a vertically polarised omni-directional whip antenna could be mounted on the body of the helicopter.
- The return loss shall be better than 10 dB.
- A GPS system for position information.
- A method of measuring Field Strength (preferably calibrated). For quality measurements receiver sensitivity and selectivity shall match the reference receiver defined for the coverage criteria.
- Suitable control and logging software.
- The receiver shall be capable to perform up to 50 measurements per second.

**For on-site measurements**

- Spectrum Analyser, Signal Analyser, calibrated RF-measurement equipment.

**6.2.5 Measuring procedure****For ground-based measurements**

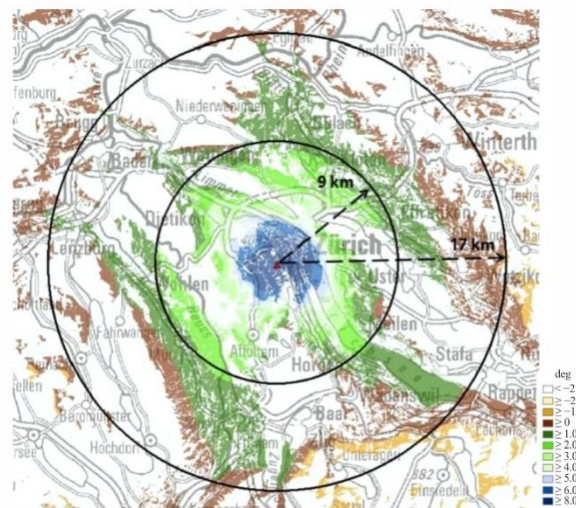
Before measuring, the relevant locations to be measured are determined. Following criteria need to be considered:

- knowing the wanted antenna pattern (vertical and horizontal) of the transmitter;
- line of sight from the location to the transmitter is mandatory.

For accurate measurement results, one should measure the transmitters field strength within the direction of the main beam of the vertical transmitter diagram with maximum  $-1$  dB attenuation. The angle between main beam and  $-1$  dB attenuation can be calculated upon the antenna design. This criterion limits the diameter around the transmitter for choosing the measurement location. Within this diameter, line of sight to the transmitter must be given.

FIGURE 5

**Example of a line-of-sight map and the ring around the transmitter, where the attenuation of the vertical antenna pattern is less than 1 dB**

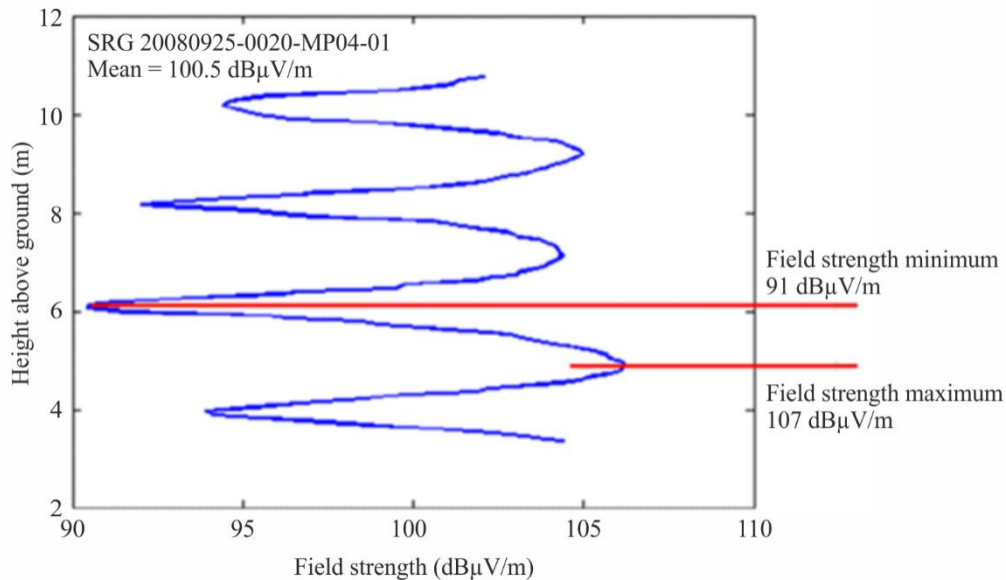


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Once the measurement location is set, the field strength between 3.5 m and 10 m above ground can be measured.

FIGURE 6

**Example of the field strength as a function of height above ground**  
**The mean value can then be compared with the theoretical calculated free space field strength**



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### 6.3 To redo measurements to assess long term stability of coverage

#### 6.3.1 Introduction

This measurement use case aims at verifying the network deployment and quality as built and periodically for long term stability and for the reason of changes within the network or externally of the network.

#### 6.3.2 Description of the use case

The verification is performed at different levels of the network. This use case includes the verification of the network performance by ground-based measurements. For long term measurements, the same measurement equipment and procedure as for ground-based measurements can be taken. Reasons for long term measurements can be many (e.g. influence of weather conditions like heavy rain and snow, influence of reflections of the ground, influence of oversea coverage, man-made noise, etc.).

Independent on the use case, some requirements have to be considered. For instance, that the long-term measurements need to be done at least at two different sites at the same time. Comparing the results of two measurement campaigns, it can be ensured that no site-specific factors (e.g. birds on the antenna, temporally man-made noise, etc.) are part of the result. The weather conditions at the measured site and operational issues like short interruptions need to be considered when evaluating the data. A common time reference like a GPS is needed to compare the data in function of time. The duration of the campaign depends on the use-case.

The data of the different locations are then evaluated individually and then analysed together. The field strength and the BER are displayed together for each site. A reception situation with channel impulse response (CIR) should be represented per site and compared to the expected situation.

#### 6.3.3 Relevant parameters

##### 6.3.3.1 In the field

- Planned Field Strength, FS
- Measured Field Strength, FS



- Field Strength, FS, over the height above ground
- Channel Impulse Response, CIR
- Measured FIC BER.

#### **6.3.4 Measurement equipment**

For verifying long-term network performance and stability, equipment with the following criteria is recommended:

- A rotatable fixed mounted antenna, with a directional diagram.
- A log-periodic antenna typically achieves best performance, and this could be used for either vertical or horizontal polarisation.
- The fixed antenna shall be positioned around 3.5 m and 10 m above ground.
- The return loss shall be better than 10 dB.
- A GPS system for position information.
- A method of measuring field strength (preferably calibrated for the foreseen antenna).
- Suitable control and logging software.
- The measurement receiver shall be capable to operate high field strengths without producing intermodulation.
- Any influence of man-made noise from the vehicle into the measurement receiver shall be verified and avoided. Man-made noise will influence the receiver noise performance and measurement results.

#### **6.3.5 Measuring procedure**

Before measuring, the relevant locations to be measured are determined. Following criteria need to be considered:

- knowing the wanted antenna pattern (vertical and horizontal) of the transmitter;
- line of sight from the location to the transmitter is mandatory.

For accurate measurement results, one should measure the transmitters field strength within the direction of the main beam of the vertical transmitter diagram with maximum  $-1$  dB attenuation. The angle between main beam and  $-1$  dB attenuation can be calculated upon the antenna design. This criterion limits the diameter around the transmitter for choosing the measurement location. Within this diameter, line of sight to the transmitter must be given.

Once the measurement location is set, the field strength between 3.5 m – 10 m above ground can be measured.

### **6.4 To define or verify the minimum coverage criteria and link budget**

#### **6.4.1 Introduction**

This measurement use case aims at predicting and verifying parameters of the link budget as depicted in [2] (e.g. receiver sensitivity, antenna-gain or man-made noise).

#### **6.4.2 Description of the use case**

These measurements of specific parameters are mainly lab-based or study-based with measurements in the lab and in the field. The measurement setup is specific for each parameter.

## **6.5 Measuring man-made noise**

### **6.5.1 Measuring man-made noise from the measuring vehicle**

Any man-made noise which is coupled into the measurement antenna, the cabling, couplers, preamplifiers or directly into the receiver shall be avoided. There are two approaches to identify man-made noise.

Man-made noise can be measured according CISPR standards. However, the distance of the antenna and the receiver to electrical devices (e.g. switched power supplies) will be much closer than the CISPR reference distance of 3 m. The method might help to find worst interferers. It might be not enough to ensure EMC compliance of in-vehicle electrical devices as the distance to the receiver is very close.

Man-made noise can be measured directly with the antenna, cable, preamplifier and receiver dedicated for the DAB measurements. When man-made noise is measured like this, the result is more representative. The DAB measurement receiver can be replaced by a sensitive spectrum analyser. In this case any direct coupling into the receiver is not verified.

First the whole spectrum in the VHF III band is observed. The noise floor shall be below  $-168$  dBm/Hz. Any higher value or spurious signals indicate interferers.

Second man-made noise in non-occupied channels is verified. Special care must be taken to understand if a channel is not occupied by any radio service and the results are showing man-made noise.

### **6.5.2 Measuring man-made noise from the environment**

For defining any needed allowance, it could be beneficial to identify man-made noise sources indoors or outdoors.

#### **6.5.2.1 Measuring man-made noise from the environment outdoors**

For measuring the man-made noise outdoors efficiently, RBT ARGE Rundfunk- Betriebstechnik, Germany has presented an appropriate approach. A variable DAB test signal is combined with the signal coming from the measurement antenna and feed into the test receiver. The DAB test signal is then levelled as low as possible by means of a defined service quality e.g. MSC BER or the audio service. When driving in an area with man-made noise, the DAB service will fail. By increasing the test signal the service can be regained and any margin needed to overcome this man-made noise can be identified.

#### **6.5.2.2 Measuring man-made noise from the environment indoors**

For measuring the man-made noise indoors, EBU / BNE members are working on possible measurement methods to estimate the level of indoor man-made noise interfering with DAB reception. The goal is to identify and measure the sources of interference in a household. A method has been developed and measurements have been initially carried out by the public Swiss broadcaster SRG SSR. Measurements by other members are ongoing. The outcome of the measures undertaken shall help in the understanding of how radio indoor reception is interfered with man-made noise.

## **7 Examples of measurement surveys**

### **7.1 DAB measurements of the antenna diagram**

The detailed knowledge of antenna diagrams implemented at the transmitting sites of a particular network is important for several reasons, e.g. in order to verify the fulfilment of the regulatory license and to make most reliable coverage predictions.

In general, there are three different ways to verify antenna diagrams:

- On the ground, by measuring field strength at several locations around the transmitter site.
- By helicopters, flying around the transmitting antenna (horizontal and vertical at certain locations) at a certain distance measuring field strength of those blocks/channels which are transmitted and of interest.
- By drones, similar as helicopters.

The latter is a relatively new technology which came up a few years ago. The main driver is an interest to be able to measure as soon as possible after having put a transmitter on air, to reduce costs and to make measurements simpler.

Measuring transmitted signals on the ground is very costly by means of manpower and often not accurate enough. Even though ground-based measurements are performed after having put a critical transmitter on-air in order to assure quality immediately and at least in a coarse manner, or if one suspects a particular fault of an antenna system. The following sections deals with air-based measurements, only.

To verify regulatory licence fulfilment and coverage of the population, SRG is monitoring its terrestrial transmitter network permanently. The antenna diagrams for large high power and high-altitude sites DAB sites are randomly verified.

#### **7.1.1 DAB antenna measurements by helicopter**

In 2008 Swisscom and SRG carried out measurements with a Super Puma. This helicopter is expensive to operate and requires a high initial effort as per measurement campaign.

In some countries, like Germany, helicopters are still in use for measurements in cities. In densely populated areas drones are not allowed to operate. Helicopters are beneficial for measurements in a larger distance of 1 to 1.5 km to reach the far field of the antenna. In larger countries the initial effort is affordable, when combining measurements of several sites.

FIGURE 7

Measurements of the antenna diagram with a helicopter by SRG SSR and Swisscom Broadcast AG



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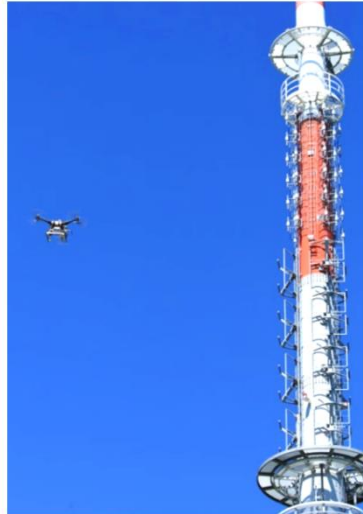
### 7.1.2 DAB antenna measurements by drone

In order to improve agility and cost efficiency, SRG, Swisscom Broadcast and Colibrex have investigated in measurements with a drone. The legislation to operate drones is different from country to country. Due to the cost efficiency a drone can be used even to measure smaller sites and Gap Fillers.

The default distance to the site is around 300 m due to the power limitations of the drones. The collected measurement data, the position and speed are transmitted online to the ground station as well as saved locally in the drone.

In 300 m distance to a high-power transmitter special care must be taken to avoid interfering the drone or overloading the measurement receiver.

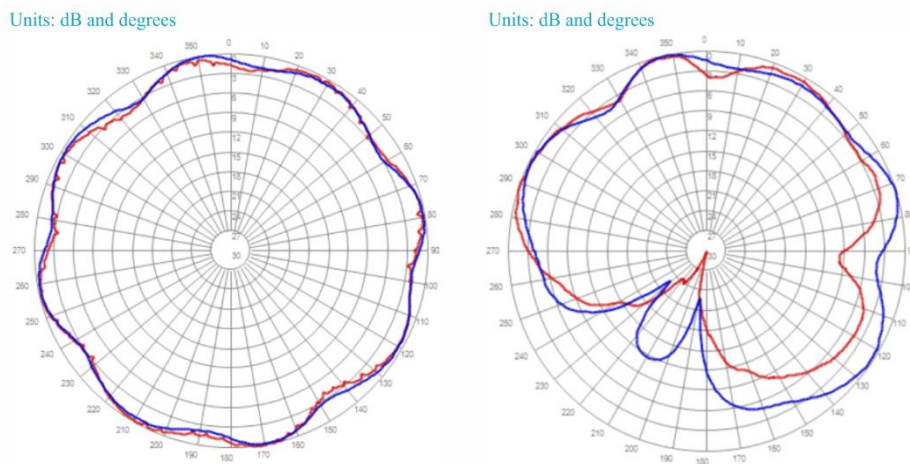
FIGURE 8  
Measurements of the antenna diagram with an unmanned aerial vehicle



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The measured antenna diagram is then compared with the wanted diagram.

FIGURE 9  
Example for a correct and a faulty antenna system



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#### Measurements by drones:

The appearance of small (unmanned) helicopters and later of drones led to the idea to use such devices also for antenna measurements and antenna inspection, in order to make both easier, cheaper and maybe even more reliable.

Since then, several companies worked on the development of drones for such a purpose. One of the major tasks was to develop a system which is 'RF resistant' enough (several kW, up to 100 kW in UHF band) and at the same time able to measure relatively small signals compared to total power.

Whilst correct location (in horizontal plane as well as concerning absolute height) is not an issue today anymore and data are normally transferred during the flight to the control centre (laptop/computer), there are other points which make the design and usage of drones substantially different from helicopters:

**Safety / License:**

- Safety rules and license conditions differ from country to country. In some countries e.g., it is strictly forbidden to fly over any building, ‘critical infrastructure’ like railways, factories or plants and other, specifically named terrain (e.g. within safety zones of airports).
- Furthermore, there are rules for the ‘pilot’ of such a device which differ from country to country as well (license, to be renewed every one or two years).

**Load:**

- The weight load of a drone is limited, at least if a relatively small (‘low-cost’) drone is considered. This limits on one hand its battery size, but also the measurement equipment which can be carried (antenna, receiver).

**Energy:**

- Battery size, load and flight time are strongly correlated. This is the reason why most drones used today for antenna measurements have a flight time of about 10 to 15 minutes, before they return (safely) to ground in order to get a new/full battery.
- Together with its maximum speed and flight height (i.e. antenna height), this limits the distance at which a drone can measure. While helicopters are typically flying at 1 to 1.5 km from the transmitter (horizontal and/or vertical flights), for drones this is limited to a few hundred metres.
- Developments in energy consumption, battery lifetime or weight load may improve this in the future.

**Flight stability and weather conditions:**

- The flight stability of drones is limited by wind, but depends on the model (size, construction). This influences the ability to fly at all as well as measurement accuracy (note: a directive antenna is used for measurements). Sometimes rain is a limiting factor as well.

**7.2 Others measurement campaigns**

- BBC performs helicopter measurement campaigns before a critical transmitter is brought on air.
- Media Broadcast performs, if needed, helicopter measurements of large sites in German cities, while ARD performs mainly measurements by drones.
- Progira (Swedish company) performs measurements, mainly to improve SFN-parameters of the DAB network.

**7.3 Specific studies****7.3.1 The evaluation of the DAB service quality by Rai Way**

Within the incoming year, it is expected the extension of the DAB networks in Italy. Nevertheless, the evaluation of the quality of the service is still an open issue. To overcome the problem, Rai Way undertook some tests in order define a five/three grades quality scale for the assessment of DAB service.

**7.3.1.1 Choice of the parameters**

DAB is a very robust system. In many situations, the signal level is strong enough to evaluate the quality of service but, sometimes, a high signal level is not a synonym of good service.

The literature indicates, as other possible parameters suitable for the evaluation of the service, the cyclic redundancy checksum, CRC, the Main Service Channel BER, MSC BER, the Fast Information Channel BER, FIC BER and the Modulation Error Ratio, MER.

Already in the nineties (see [7]), the CRC was taken into account for the evaluation of the quality of service. This parameter indicates the errors contained in the compressed audio stream of the selected sub-channel, therefore the analysis of the CRC behaviour appeared to be the most suitable approach for this study. For the time being, only few receivers are able to measure this parameter, and for this reason, it was decided to consider in parallel also the Main Service Channel BER, MSC BER.

#### **7.3.1.2 Description of the tests**

The study was carried on analysing two different sets of data: measurements collected driving on the main Italian highways and outputs obtained in laboratory.

In both cases, in order to get closer to the experience of the majority of listeners, a receiving device based on a new chipset designed for car radio DAB-FM was used. In collaboration with a world leader in providing electronic components and semiconductor solutions, the chipset has been assembled with a GPS receiver and a control board in a single box, making a device suitable for testing in mobile reception (MO) as defined in [1]. The box has an audio output, two antenna inputs and an USB port. A specific software permits to control the receiver and to record the measurements at a definite time frame, lasting from 25 ms to 4 s with a 25 ms steps.

The sensitivity of this prototype – minimum input signal at the receiver with EEP-3A level – is around 8 dB $\mu$ V/75 ohm (–99 dBm). The sensitivity has been established passing from normal listening to mute with one dB step.

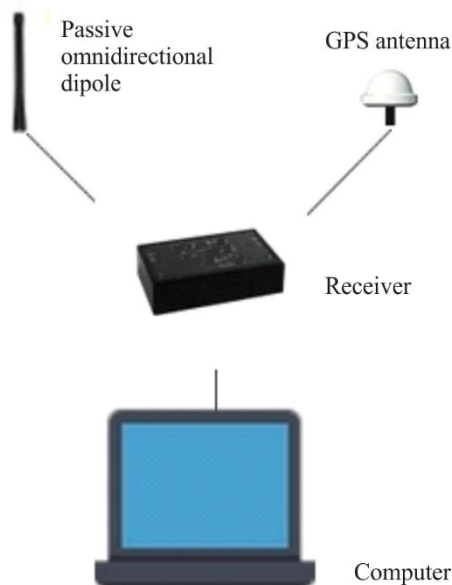
#### **7.3.1.3 Tests in service area**

For the measurement campaign in service area, the receiver was connected to a  $\lambda/4$  omnidirectional antenna placed on the top of an equipped vehicle. Some tests made on this antenna, showed that the antenna factor is around 17 dB, and the horizontal diagram is similar to the one of the ‘ideal antenna’ of [1] (see Annex C).

Data have been acquired every second.

The measurements were carried on 12C frequency block of DAB Italia signal (protection level EEP-3A), which has the most widespread SFN in Italy, and around 22 000 samples have been recorded on the highways, travelling from Padua to Rome.

FIGURE 10  
Equipment used for the measurements in service area



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#### 7.3.1.4 Laboratory tests

Two different sets of data have been considered:

- First test. Fixed signal level at  $-60 \text{ dBm}^2$  and variable  $C/N$ , from 20 dB to 5 dB with 1 dB step, protection level EEP-3A.
- Second test. Fixed signal level at  $-60 \text{ dBm}$ , variable  $C/N$  using TU6 fading profile (Typical Urban, 6 taps, speed of 25 km/h) and RA4 fading profile (Rural Area, 4 taps, speed of 120 km/h), protection level EEP-3A.

The fading profile used for the test have been chosen among the ones suggested for testing DAB receivers (see also [9]) and already implemented in the most common signal generators. The details of TU6 and RA4 are shown in Tables 2 and 3.

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<sup>2</sup> Historical receiver input power used for tests, see Recommendation ITU-R BT.1368-13 [8].



TABLE 2  
Fading profile typical urban 6, TU6

Typical urban 6 – speed 25 km/h		
Doppler category	Attenuation (dB)	Delay (μs)
Rayleigh	3	0
Rayleigh	0	0.2
Rayleigh	2	0.5
Gauss 1	6	1.6
Gauss 1	8	2.3
Gauss 1	10	5

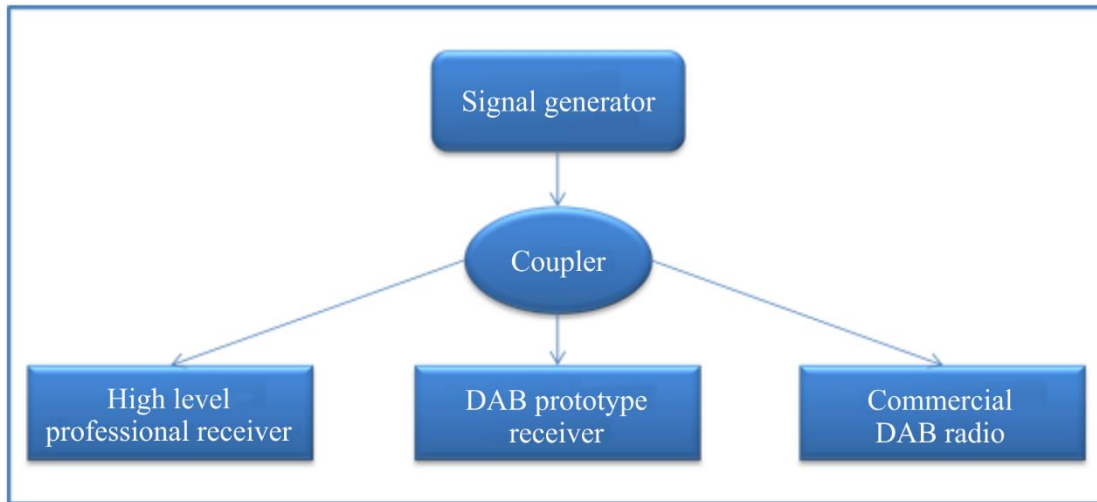
TABLE 3  
Fading profile rural area 4, RA4

Rural area 4 – speed 120 km/h		
Doppler category	Attenuation (dB)	Delay (μs)
Rice	0	0
Rayleigh	2	0.2
Rayleigh	10	0.4
Rayleigh	20	0.6

The laboratory set-up is displayed in Fig. 11. The DAB signal was generated by a high professional equipment with a channel simulator module.  $C/N$  could be adjusted, and a multipath propagation could be simulated. The signal was then split by the mean of a coupler and sent to a high-level professional receiver, to a commercial radio and to the prototype receiver. The prototype receiver was managed by a laptop. The commercial radio reflects the characteristic described in [1].

All the results of the tests are the outcomes of the prototype receiver. The professional receiver was used to confirm the findings.

FIGURE 11  
Test bench for laboratory tests



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### 7.3.1.5 Analysis of the data

The aim of the study was to evaluate the behaviour and the possible correlation of the parameters that could be meaningful for the assessment of the quality of service. The focus of the analysis was on the signal level, the MSC BER and the CRC.

In the MPEG HE-AA Cv2 coding, the CRC is associated to the Access Units (AU) which carry the audio and data information (see [10]). Depending on the sampling rate of the AAC core, an AU contains audio samples of different length. The audio super frame contains a number of AUs which together contain the encoded audio for 120 ms. The audio super frame is then transmitted in five successive DAB logical frames.

In the case of the sample rate of 48 kHz, the audio sample lasts 20 ms, each super frame contains six AU, and each logical frame has 24 ms of length.

The number of CRC's generated per second is 44 at the most because for its calculation it is necessary to have an entire transmission frame which duration is 96 ms.

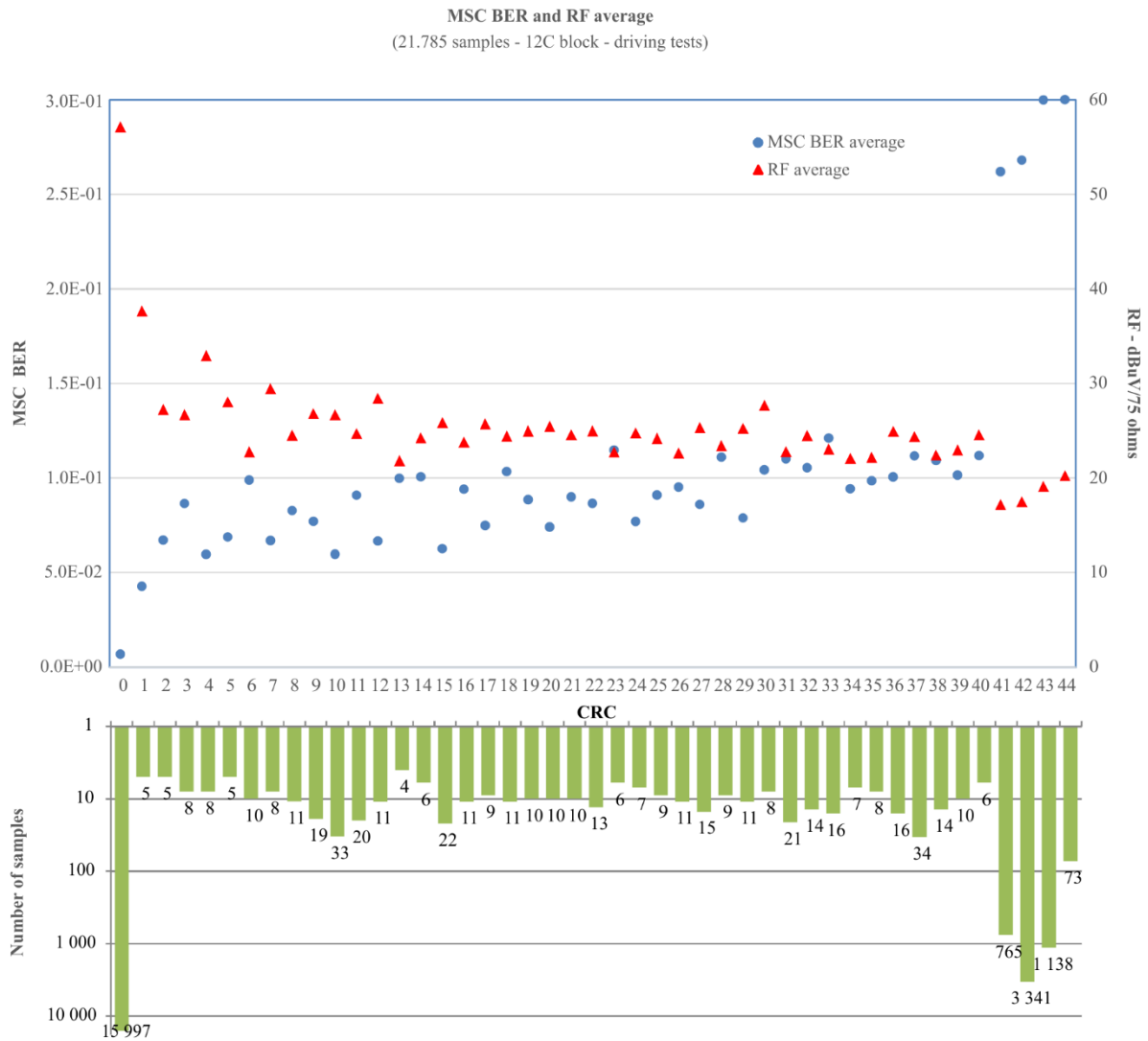
If not corrected errors are detected, CRC value is equal to 1. The prototype receiver is able to add up to 40-44 CRC every second depending on the time of sampling and, in this study, the range of values of the CRC is from 0 to 42 in laboratory test and up to 44 in driving measurements.

### 7.3.1.6 Analysis of driving measurements

The analysis of the measurements collected in service area showed up the following findings, also plotted in Fig. 12:

- the CRC is generally null (73.4% of the measurements) or greater than 39 (24.4% of the measurements);
- when the CRC is greater than zero, the RF signal is generally lower than 30 dBμV and decreases when the CRC increases;
- for each CRC value, the averages of the MSC BER (MSC BER is measured before the Viterbi decoder) samples were calculated. The trend of the averages shows two main sharp jumps: the first one when the CRC is greater than zero (CRC = 0 MSC BER =  $6.8 \cdot 10^{-3}$  and CRC = 1 MSC BER =  $4.3 \cdot 10^{-2}$ ) and the second one when the CRC reaches 41 (CRC = 40 MSC BER =  $1.1 \cdot 10^{-1}$  CRC = 41 MSC BER =  $2.6 \cdot 10^{-1}$ ).

FIGURE 12  
Driving tests – MSC BER and signal level averages with respect to CRC values



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### 7.3.1.7 Analysis of measurements of laboratory tests

#### First test. Modification of the $C/N$ value

This test highlights that the CRC has little dynamics. The CRC, verified on a Gaussian-type channel (cable), assumes two values: 0 when  $C/N \geq 6$  dB or the maximum value with lower  $C/N$  values.

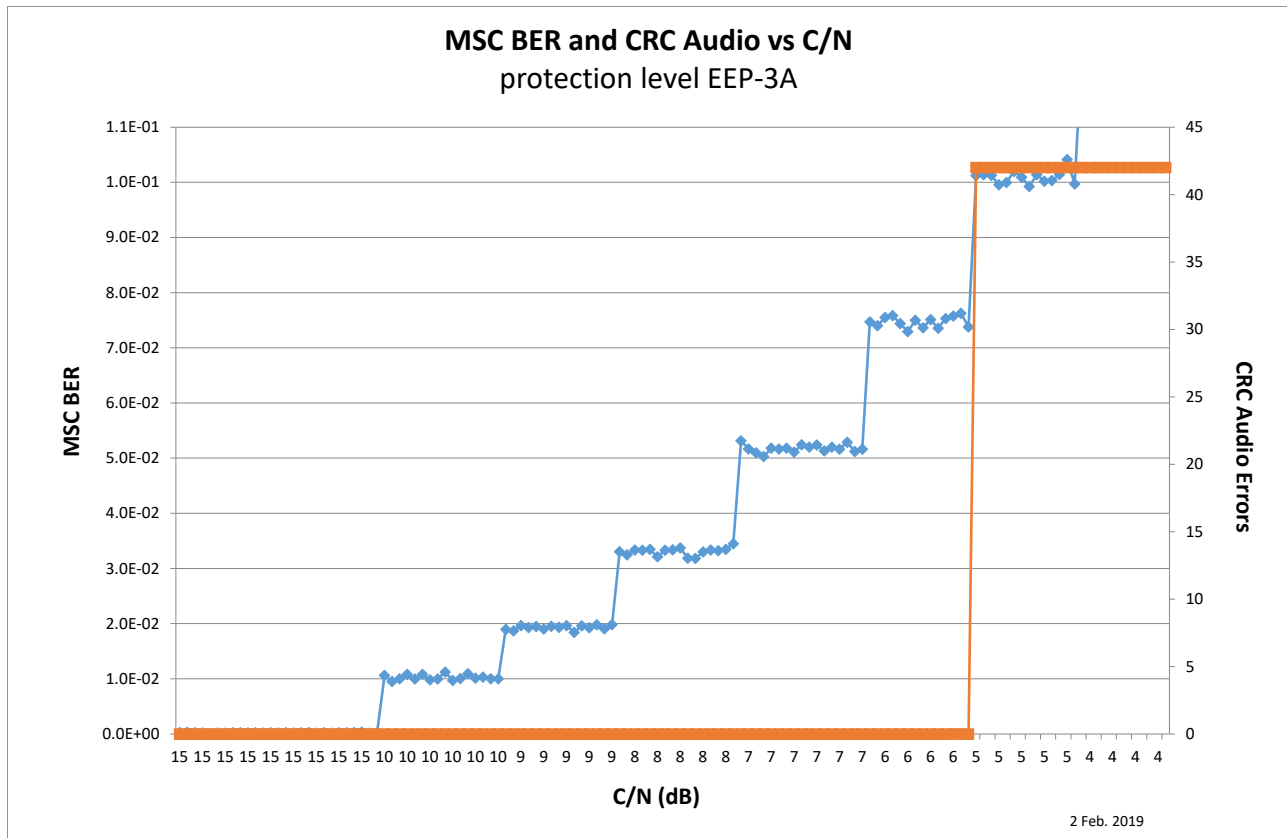
On the other hand, the MSC BER has a good dynamic and decreases accordingly to  $C/N$ .

TABLE 4  
Gaussian Channel –  $C/N$ , MSC BER and CRC audio errors

<i>EEP-3A</i>		
$C/N$ (dB)	$MSC\ BER$	$CRC \neq 0$
15	$1.90 \cdot 10^{-4}$	0
10	$1.02 \cdot 10^{-2}$	0
9	$1.93 \cdot 10^{-2}$	0
8	$3.31 \cdot 10^{-2}$	0
7	$5.18 \cdot 10^{-2}$	0
6	$7.47 \cdot 10^{-2}$	0
5	$1.01 \cdot 10^{-1}$	42
4	$1.27 \cdot 10^{-1}$	42

In Fig. 13, the results of this trial are displayed.

FIGURE 13  
MSC BER and CRC with respect  $C/N$  – Protection level EEP-3A



During this test, listening the audio, it was noted that the first perceptible audible errors appear when  $CRC = 3$  in the case of the radio prototype, and when  $CRC = 20$  in the case of the commercial radio.

A second test was done in order to better evaluate the relationship between the parameters and a longer period of sampling was chosen. The final output, shown in Table 5, is the average over a two minutes of data collection.

TABLE 5  
Test results MSC BER over  $C/N$  for Gaussian channels

$C/N$ (dB)	MER (dB)	MSC BER professional receiver	MSC BER prototype	% wrong CRC
5	4	$1.0 \cdot 10^{-1}$	$10^{-1}$	100%
6	4.4	$7.4 \cdot 10^{-2}$	$7.37 \cdot 10^{-2}$	3.1%
7	4.8	$5.1 \cdot 10^{-2}$	$5.00 \cdot 10^{-2}$	0
8	5.4	$3.2 \cdot 10^{-2}$	$3.19 \cdot 10^{-2}$	0
9	6.1	$1.8 \cdot 10^{-2}$	$1.92 \cdot 10^{-2}$	0
10	6.9	$9.1 \cdot 10^{-3}$	$9.70 \cdot 10^{-3}$	0
11	7.7	$4.0 \cdot 10^{-3}$	$4.71 \cdot 10^{-3}$	0
12	8.7	$1.4 \cdot 10^{-3}$	$1.97 \cdot 10^{-3}$	0

### Second test. TU6 and RA4 profiles

For both profiles, it was decided to increase the  $C/N$  value starting from 13 dB, considering that 13.5 dB is the minimum value, for EEP-3A, at which a commercial receiver should correctly demodulate the signal (see [1]).

With the TU6 profiles, errors appear ( $CRC \neq 0$ ) when  $C/N$  is equal to 15 dB. In the case of the RA4 profile, the same result is obtained when the  $C/N$  is 18 dB. It should be noted that the behaviour of the prototype is worse than a typical commercial receiver. No clear reasons have been discovered for the understanding of this bad performance and it should be considered as a limit of the equipment.

In Table 6, the details of the tests are reported. For each  $C/N$  values, the upper threshold of MSC BER and its percentage are shown. It is also given the percentage of not null CRC related to the entire set of measurements.

TABLE 6  
Test results MSC BER over  $C/N$  for Rayleigh channels

$C/N$ (dB)	TU6			
	MSC BER 99%	MSC BER 90%	% samples with CRC $\neq 0$	% CRC $\neq 0$
13	$7.9 \cdot 10^{-2}$	$6.2 \cdot 10^{-2}$	13.3%	4.3%
13.5	$7.3 \cdot 10^{-2}$	$5.6 \cdot 10^{-2}$	9.0%	1.7%
14	$6.5 \cdot 10^{-2}$	$5.3 \cdot 10^{-2}$	4.6%	1.0%
15	$5.6 \cdot 10^{-2}$	$4.3 \cdot 10^{-2}$	1.4%	0.3%
16	$4.5 \cdot 10^{-2}$	$3.5 \cdot 10^{-2}$	0.0%	0.0%
17	$3.9 \cdot 10^{-2}$	$2.9 \cdot 10^{-2}$	0.0%	0.0%
$C/N$ (dB)	RA4			
	MSC BER 99%	MSC BER 90%	% samples with CRC $\neq 0$	% CRC $\neq 0$
13	$8.9 \cdot 10^{-2}$	$7.2 \cdot 10^{-2}$	38.0%	10.9%
13.5	$8.7 \cdot 10^{-2}$	$6.8 \cdot 10^{-2}$	27.5%	7.8%
14	$7.5 \cdot 10^{-2}$	$6.0 \cdot 10^{-2}$	15.1%	3.6%
15	$7.0 \cdot 10^{-2}$	$5.4 \cdot 10^{-2}$	11.0%	2.2%
16	$6.1 \cdot 10^{-2}$	$4.8 \cdot 10^{-2}$	2.0%	0.3%
17	$5.6 \cdot 10^{-2}$	$4.2 \cdot 10^{-2}$	1.6%	0.4%
18	$5.1 \cdot 10^{-2}$	$3.8 \cdot 10^{-2}$	1.0%	0.2%

In Figs 14 and 15, histograms of MSC BER percentages are presented for some considered  $C/N$  values.

For each  $C/N$  value, the measures were collected for different periods, between 150 and 600 seconds, in order to evaluate with sufficient statistics, the occurrence of the perceived audio errors and the resulting quality of the service.

FIGURE 14  
TU6 – EEP-3A –  $C/N$  15 dB

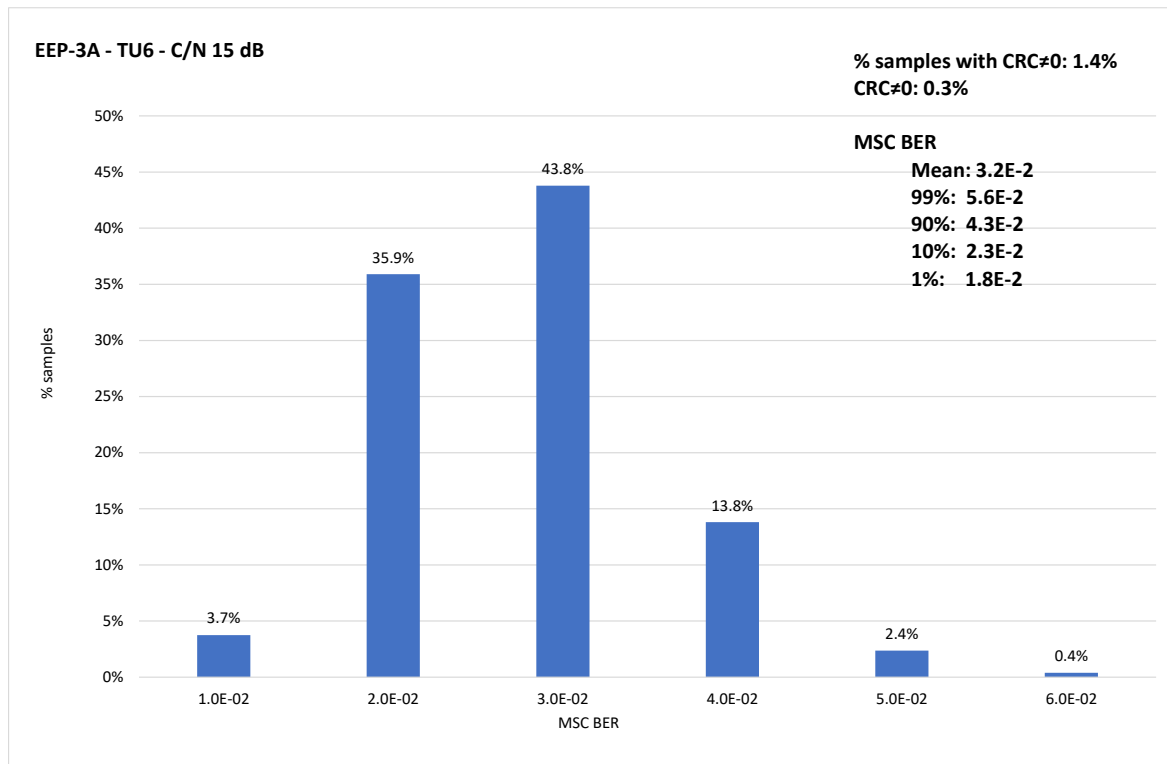
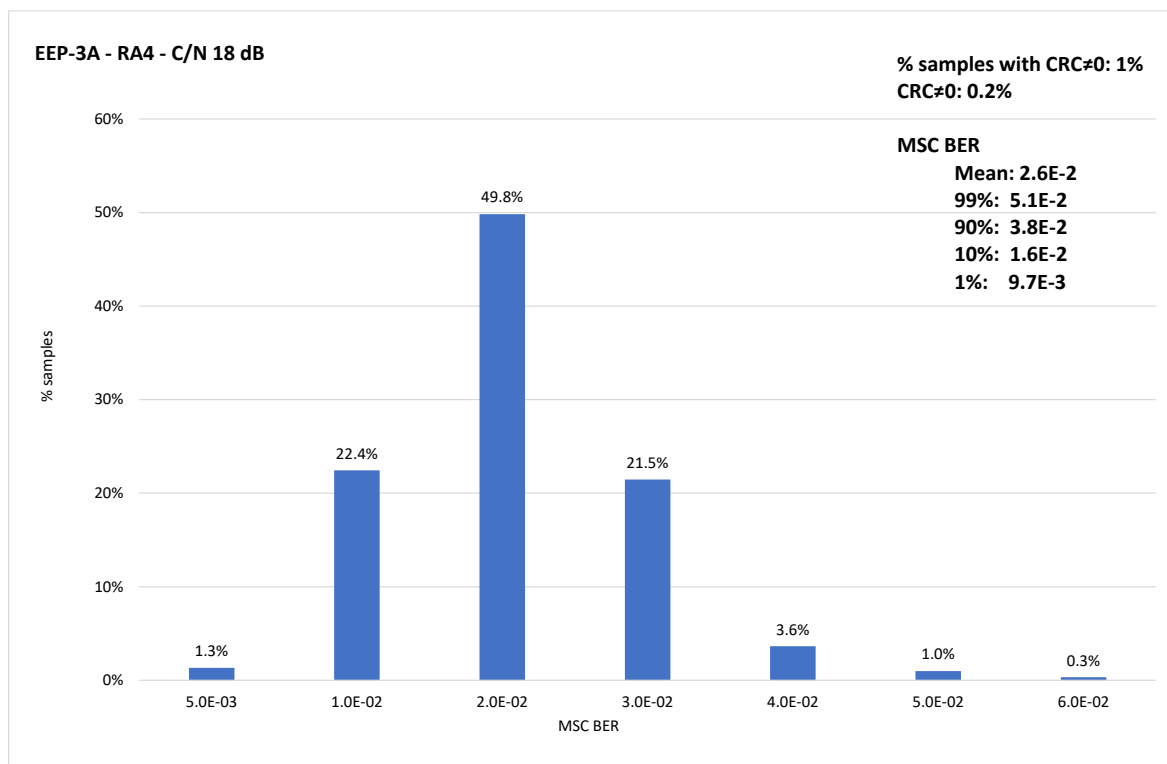


FIGURE 15  
RA4 – EEP-3A – 18 dB



### 7.3.1.8 Conclusion

This study highlighted that the use of CRC for the assessment of the quality of service does not permit to define a quality scale. Unluckily, only few receivers are able to give the CRC and for this reason, it is not possible to further study the behaviour of this parameter.

On the other hand, the trials revealed that there is a good relation between the MSC BER (MSC BER is measured before the Viterbi decoder) and the noise level in the reception channel which is reflected directly on the perceived quality of the service. Considering that every possible cause of radiofrequency signal degradation and every possible benefit of the so-called ‘network gain’ are reflected in the noise level, the indirect mapping of the MSC BER can be the most reliable reference basis for the evaluation of the quality of the DAB area coverage.

A five grades quality scale is consequently proposed. Considering the minimum reference field strength,  $E$ , at 1.5 m a.g.l. in 99% locations which is 35 dB( $\mu$ V/m), the scale is:

- Q1:  $E < 35$  dB( $\mu$ V/m)
- Q2:  $E \geq 35$  dB( $\mu$ V/m) and MSC not detected or MSC BER  $> 5 \cdot 10^{-2}$  (no or bad audio – FIC could be detected)
- Q3:  $E \geq 35$  dB( $\mu$ V/m); MSC detected and MSC BER  $\leq 5 \cdot 10^{-2}$
- Q4:  $E \geq 35$  dB( $\mu$ V/m); MSC detected and MSC BER  $\leq 2 \cdot 10^{-2}$
- Q5:  $E \geq 35$  dB( $\mu$ V/m); MSC detected and MSC BER  $\leq 5 \cdot 10^{-3}$ .

TABLE 7

#### Quality of service criteria

	$E < 35$ dB( $\mu$ V/m)	$E \geq 35$ dB( $\mu$ V/m)	Note
MSC BER	Quality of service		
Not detected or $> 5 \cdot 10^{-2}$	Poor (Q1)	Poor (Q2)	No or bad audio – FIC could be detected
$\leq 5 \cdot 10^{-2}$	“	Acceptable (Q3)	MSC detected; $C/N$ Gauss 7 dB
$\leq 2 \cdot 10^{-2}$	“	Good (Q4)	MSC detected; $C/N$ Gauss 8-9 dB
$\leq 5 \cdot 10^{-3}$	“	Good (Q5)	

A three grades quality scale is also suggested:

- No service:  $E < 35$  dB( $\mu$ V/m) or  $E \geq 35$  dB( $\mu$ V/m) and MSC not detected (no audio – FIC could be detected)
- Adequate service:  $E \geq 35$  dB( $\mu$ V/m); MSC detected and MSC BER  $\leq 5 \cdot 10^{-2}$
- Good/excellent service:  $E \geq 35$  dB( $\mu$ V/m); MSC detected and MSC BER  $\leq 2 \cdot 10^{-2}$ .

This scale is defined considering the value of  $C/N$  of the 99% of the samples. For example, a low percentage of CRC errors, 1%, is obtained, with the RA4 profile, when the  $C/N$  is 18 dB and the corresponding MSC BER is  $\leq 5 \cdot 10^{-2}$ . The same value of MSC BER is also obtained when the  $C/N$  is 7 dB in the Gaussian channel and when the  $C/N$  is around 15 dB with the TU6 profile. Subsequent to these considerations, this threshold of MSC BER has been chosen for the Q3 level. Then the Q4 and the Q5 grades have been derived considering the  $C/N$  of Gaussian Channel and adding 2 dB each step, i.e. Q4 corresponds to a  $C/N$  of 9 dB with the associated MSC BER of  $2 \cdot 10^{-2}$ . These values are few dB higher than the minimum values of the proper operation of the receivers, listed in Table 108, Chapter 7.1.4 of [3].



Although the quality scale is conservative, in the case of Q3, a very few audible audio errors could be detected.

Moreover, it should be noted that it was not possible to use the QEF value ( $\text{BER} < 2 \cdot 10^{-4}$  after Viterbi decoder) because the values of the BER after Viterbi decoder provided by the prototype are not reliable and the professional equipment does not supply this parameter.

### 7.3.2 Referencing overall system noise figure of a measurement receiver

The challenge of a measurement campaign is to measure radio parameters and reception quality for different reception use cases by one mobile outdoor campaign in a realistic manner and efficiently. DAB quality measurements require a referenced measurement receiver and setup. Annex 1 provides a common approach.

## 8 Conclusions

This Report confirms the relevance of assessing the quality of DAB services and networks.

With this Report, the major use cases for DAB quality measurements have been addressed. For each use case the target, the measuring techniques, the relevant measuring parameters and the requirements for the measurement setup have been described. With the functional reference model, this Report defines reference points for radio parameters and quality measurements. Further, this Report explains how to reference the measurement setup to a specific use case as well as to the different criteria of broadcasters and broadcast network operators.

Planning a measurement campaign in detail is not part of this Report. Designing the optimal approach is often a challenging broadcaster's task that could be described in a next version of this Report.

Further a close collaboration with the industry of measurements equipment would be beneficial to implement the findings of this Report.

A trend in off-line post-processing of sampled radio data after a measurement campaign have been recognized. This approach requires a further proof of concept as well as a high degree of consciousness about the measurement process. Both could be investigated in a next step.

## 9 References

- [1] EBU Tech 3391 – Guidelines for DAB network planning. *Geneva, May 2018.*
- [2] Recommendation ITU-R BS. 1660 – Technical basis for planning of terrestrial digital sound broadcasting in the VHF band.
- [3] Report ITU-R BS.2214 – Planning parameters for terrestrial digital sound broadcasting systems in VHF bands.
- [4] ETSI TR 101 496-3 v1.1.2 – Digital Audio Broadcasting (DAB); Guidelines and rules for implementation and operation; Part 3: Broadcast network. *May 2001.*
- [5] Recommendation ITU-R SM.1708 – Field-strength measurements along a route with geographical coordinate registrations.
- [6] ERC Report 77 – Field Strength measurements along a route. *January 2000.*
- [7] EBU Technical Review 261 – Maddocks et al.; Lau *et al.* *Autumn 1994.*
- [8] Recommendation ITU-R BT.1368-13 – Planning criteria, including protection ratios, for digital terrestrial television services in the VHF/UHF bands.
- [9] International Standard IEC 62104 – Characteristics of DAB receivers. Edition 3.0 2015-07.

- [10] ETSI TS 102 563 v2.1.1 – Digital Audio Broadcasting (DAB); DAB+ audio coding (MPEG HE-AACv2). *January 2017*.

## Annex 1

### Referencing the overall noise figure of the measurement receiver

The challenge of a measurement campaign is measuring radio parameters and reception quality for different reception use cases by one mobile outdoor campaign in a realistic manner and efficiently.

Key criteria of interest might be:

- minimum field strength for mobile outdoor reception;
- minimum field strength for portable indoor reception;
- service quality (BER) for mobile outdoor reception;
- service quality (BER) for portable indoor reception<sup>3</sup>.

DAB quality measurements require referencing the noise performance of the measurement setup in line with the use case. This Annex provides an approach, which is common to all use cases and criteria of EBU / BNE members.

#### 1 Introduction of conceptual overall system noise figure

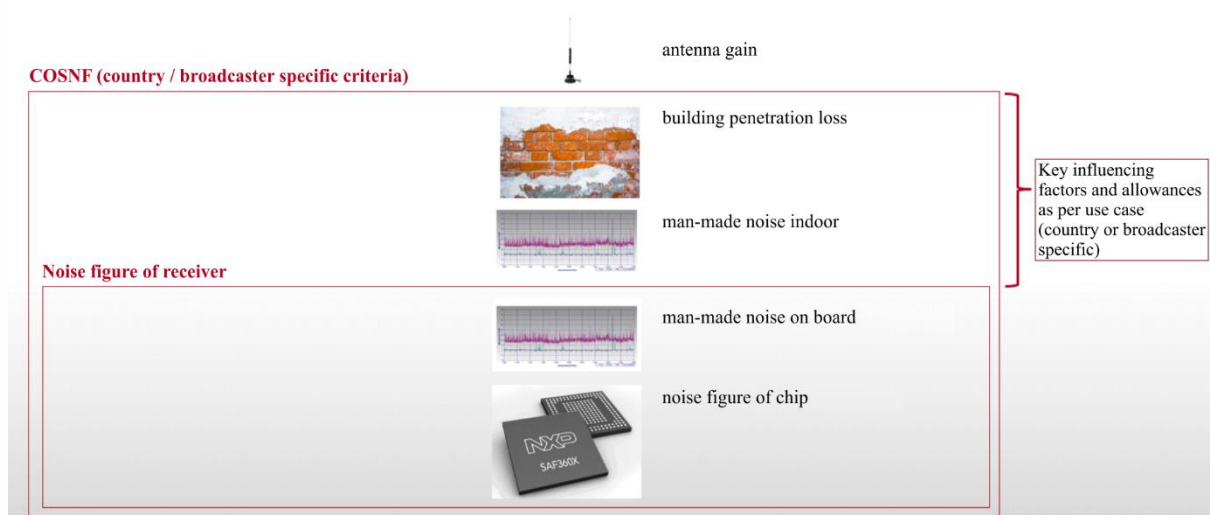
For any desired use case and e.g. broadcaster's criteria (e.g. according to Table 8 in [1]) a Conceptual Overall System Noise Figure (COSNF) can be calculated as shown in Fig. 16. The COSNF represents the above-mentioned reference and is calculated before antenna gain. The COSNF comprises all desired allowances of the use case in addition to the noise figure of the DAB reference receiver. This concept is flexible to all possible use cases for indoor and outdoor reception and planning criteria of broadcasters and broadcast network operators.

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<sup>3</sup> Keeping in mind that a mobile measurement campaign will never address the quality of a stationary indoor use case perfectly.

FIGURE 16

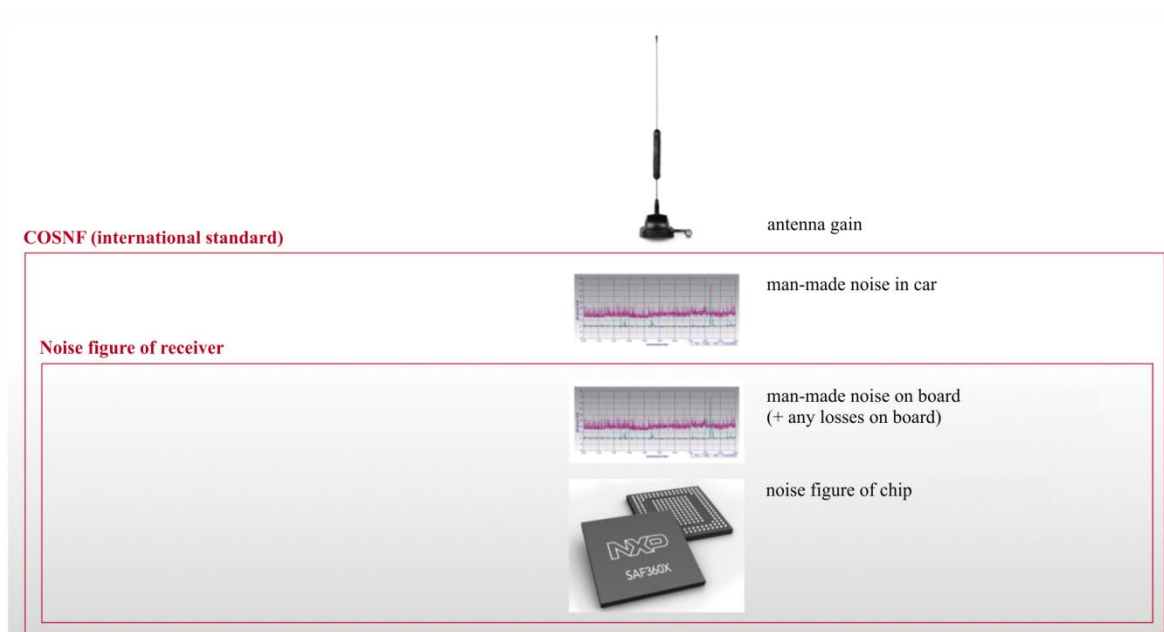
Definition of conceptual overall system noise figure COSNF for the use case  
‘portable indoor / urban reception’ e.g. use case 3 from Table 8 in [1]



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FIGURE 17

Definition of conceptual overall system noise figure COSNF for the use case  
‘mobile outdoor / rural reception’ e.g. use case 1 from Table 8 in [1]



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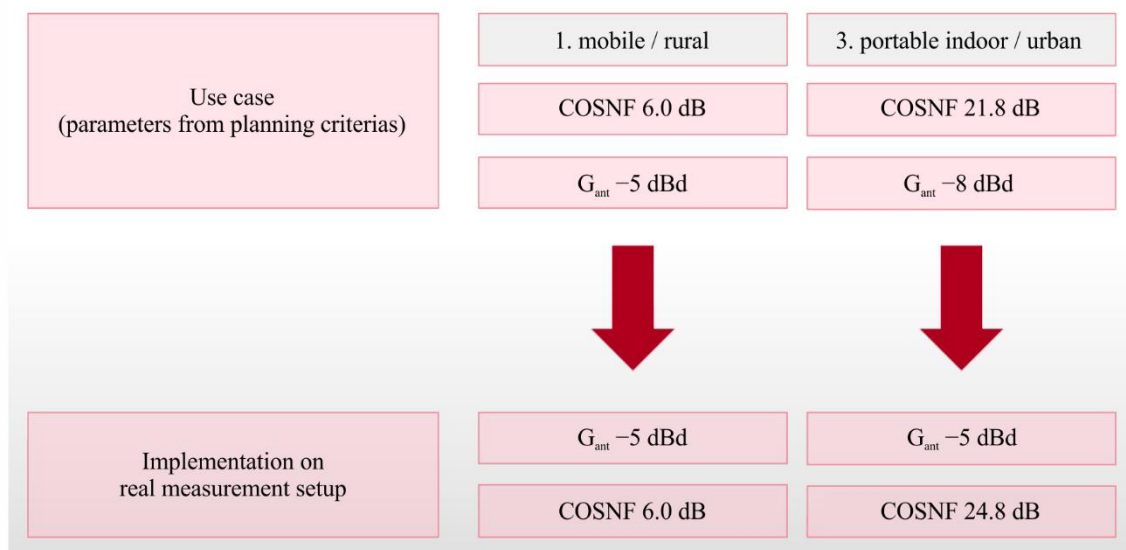
Example referring to Table 8 in [1] for use case 3, urban portable indoor:  $\text{COSNF} = \text{noise figure reference receiver (6 dB)} + \text{allowance for man-made noise (5.3 dB)} + \text{building entry loss (17.6 dB)} = 28.9 \text{ dB}$ .

## 2 Implementation of COSNF into the measurement setup

The above defined COSNF is recalculated into an overall noise figure of the measuring setup before antenna as shown in Fig. 18. The real antenna gains of the measurement vehicle (e.g. equal for all use

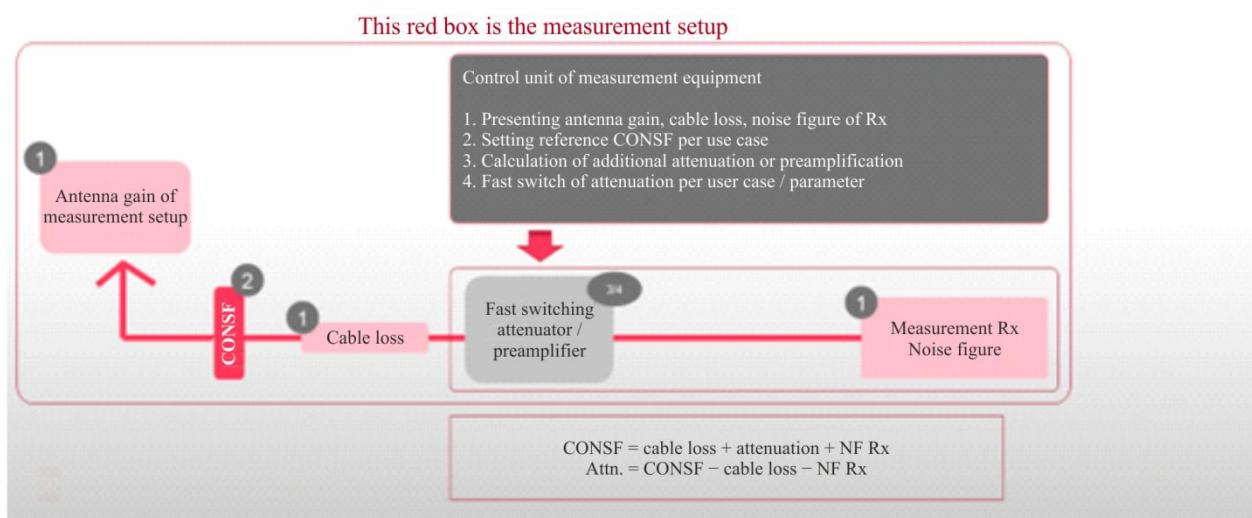
cases) are considered. If the measurement antenna has e.g. a higher gain than defined in [1] Table 8, the COSNF is adapted accordingly.

FIGURE 18  
Implementation of COSNF



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FIGURE 19  
Implementation of calculated COSNF into the measurement setup



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The calculated COSNF per use case at /the foot of the measurement antenna is implemented by adding additional attenuation while respecting any losses, e.g. of the cable, and the noise figure of the measurement receiver used. From the COSNF, the cable loss and the receivers noise figure are subtracted to determine the additional attenuation.

The COSNF of a measurement setup is set according to Fig. 19 per every desired use case by adjusting the additional attenuation. If the needed attenuation is negative, a preamplification with an according improvement of the noise figure is foreseen. All these calculations might be done by the controller unit of the measuring setup.

To drive a measurement campaign efficiently, a fast switching built-in internal attenuation/preamplification would be beneficial.

In a single use case campaign one COSNF is defined, and parameters are set accordingly. In a multiple use case campaign, several COSNF are defined. In case of a multiple use case campaign, the receiver with single tuner switches between different COSNF.

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