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Contents

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Integrated broadband cable telecommunication networks (CABLE).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**may not**", "**need**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

As written in the scope the signal characteristics are defined across the operating frequency and in accordance with network equipment built to European standards.

Clause 4 gives an overview of the cable network system architecture characteristics to support delivery of a wide range of digital entertainment and informational programming via the use of a hybrid fibre/coaxial network. It provides details of the frequency allocation and usage for digital television signals carried on the cable plant using channelization though different modulation. This clause presents also characteristcis of the various signals delivered to the non-radio end user equipment for fixed broadcasting and broadband electronic communication services, in particular those services delivered by cable operators in Europe, analogue television, digital television, telephony and high speed data (internet).

Clause 5 gives details of the signal characteristics of European CATV systems and their protection criteria in terms of the minimum and maximum signal levels and the signal to noise level thresholds before the desired signal is disturbed to a level that impacts its reception by the non-radio end user equipment for fixed broadcasting and broadband electronic communication services. Three instances of harmful interference from new radio services (NRS) operating in the frequency bands occupied currently by cable networks is considered , the first is between the NRS and coaxial part of the network (both in-home and external), the second is defined between the NRS system and a remote cable headend receiver and the third type of interference is defined from the NRS system on the non-radio end user equipment itself (e.g. cable modem, settopbox, digital cable receivers, etc.).

Clause 6 gives calculation methods in terms of the limits of unwanted signals and their relevant characteristcis that can influence the reception of the delivered signal by the cable network to non-radio end user equipment for fixed broadcasting and broadband electronic communication services. Equations are derived based on noise margins and maximum interference levels for calculations of acceptable limits across different operating frequency ranges and modulations. The limits derived are based on the characteristcis of cable distribution networks built according to European standards and industry best practices. Calculations of maximum EIRP limits for no degradable service (dBm) i.e. to mitigate impact to the non-radio end user equipment for fixed broadcasting and broadband electronic communication services are presented in relation to the distance between the radio transmitter and cable system. The graphs given present typical use cases with modulation and signal maximum and minimum levels as operated by European cable networks.

Clause 7 contains references to experiments that are representative as realistic situations with respect to the calculated results.

Clause 8 gives a summary of the potential impact from new radio services operating within the frequency bands currently used by cable networks to non-radio end user equipment for fixed broadcasting and broadband electronic communication services.

1 Scope

The present document defines the transmitted signal characteristcis delivered across a HFC cable network to the customer network interfaces distributed within the home network received and processed by the consumer end terminals for reception of multimedia services.

The signal characteristics are defined across the operating frequency and in accordance with network equipment built to European standards.

The present document provides valuable input to engineers and developers containing the technical basis to take into account when developing harmonized technical conditions for new radio services operating in the same frequency range as currently occupied by cable distribution networks.

It presents the technical basis for coexistence between these new radio services and existing non-radio end-user equipment for fixed broadcasting and broadband electronic communication services, specifically those services delivered by European cable based systems (PAL/SECAM, DVB-C, Euro-DOCSIS).

The impact to non-radio end user equipment for fixed broadcast and broadband electronic communication services is given in terms of the operational characteristics of the wanted signals and tolerable limits of the unwanted signals as a factor of the distance between them before the unwanted interfering signal will disrupt the end users equipment for fixed broadcasting and broadband electronic communication services (e.g. digital and analogue television, internet high speed data and telephony services).

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

[1] CENELEC EN 60728-1: "Cable networks for television signals, sound signals and interactive services - Part 1: System performance of forward paths".

NOTE: This European Standard supersedes EN 50083-7:1996 + A1:2000 + corrigendum August 2007.

[2] ETSI TS 102 639-2: "Access and Terminals, Transmission and Multiplexing (ATTM); Third Generation Transmission Systems for Interactive Cable Television Services - IP Cable Modems; Part 2: Physical Layer [ITU-T Recommendation J.222.1 (07/2007), modified]".

[3] Recommendation ITU-T J.222.1: "Third-generation transmission systems for interactive cable television services - IP cable modems: Physical layer specification".

[4] CENELEC EN 50083-2: "Cable networks for television signals, sound signals and interactive services = Part2: Electromagnetic compatibility for equipment".

[5] CENELEC EN 50117-2-1:2005+A1:2008: "Coaxial cables - Part 2-1: Sectional specification for cables used in cabled distribution networks - Indoor drop cables for systems operating at 5 MHz - 3000 MHz".

[6] CENELEC EN 50289-1-6:2002: "Communication cables - Specifications for test methods - Part 1-6: Electrical test methods - Electromagnetic performance".

[7] CENELEC EN 55020: "Sound and television broadcast receivers and associated equipment - Immunity characteristics - Limits and methods of measurement".

[8] CISPR 20: "Sound and television broadcast receivers and associated equipment - Immunity characteristics - Limits and methods of measurement".

[9] G531/01077/09: "Measurement Report: Immunity of integrated TV receivers, settop boxes and data-modems connected to broadband cable and TV networks against radiation from LTE user equipment". .

[10] PG ESKM: Final Report - Project Group: "Investigation of EMC scenarios cable/radio with mobile applications in the frequency range 470 MHz to 862 MHz" of the EMC group of the ATRT.

[11] Carl T. Jones Testing 2008/2009: "Carl-T Jones, TVBD direct pickup interference tests, 2009".

[12] ETSI EN 300 429: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems".

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

Not applicable.

3 Symbols and abbreviations

3.1 Symbols

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

dB	decibel
dBm	decibel-milliwatt
dBmV	decibel-millivolt
dBuV	decibel microvolt
dBuV/m	decibel microvolt per meter
E [V/m]	electric field in Volts/meter
k [1/m]	Antenna factor for half wavelength dipole
MHz	Mega Hertz
Ohm	SI unit of electrical resistance
U [V]	induced voltage in volts
W	Watts

3.2 Abbreviations

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

BER	Bit Error Rate
BS	Base Station
C/I	Carrier to Interference
C/N	Carrier to Noise
CATV	Cable Television
CISPR	Comité international spécial des perturbations radioélectriques
CM	Cable Modem
CMTS	Cable Modem Termination System
DVB-C	Digital Video Broadcasting for Cable
EIRP	Equivalent Isotropically Radiated Power
EMI	Electromagnetic Interference

ESKM	EMC Scenario's Cable and Mobile
Euro-DOCSIS	European Data Over Cable Service Interface Specification
FEC	Forward Error Correction
FM	Frequency Modulation
HE	Headend
HFC	Hybrid Fibre Coax
IP	Internet Protocol
LTE	Long Term Evolution
MPEG2	Motion Picture Experts Group 2
NCTA	National Cable & Telecommunications Association
NRS	New Radio Services
NTSC	National Television System Committee
ON	Optical Node
PAL	Phase Alternative Line
PDU	Protocol Data Unit
PG ESKM	Project Group EMC Scenario's Cable and Mobile
PG	Project Group
PID	Packet Identifier
PSI/SI	Program Specific Information/Service Information
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
SECAM	Sequential Color With Memory
STB	Settopbox
TDM	Time Division Multiplexing
TS	Terminal Station
TS	Transport Stream
TV	Television
TVBD	Television Band Device
UE	User Equipment
US	Upstream
USA	United States of America
VOD	Video on Demand
WDM	Wavelength Division Multiplexing
WSD	White Space Device

4 Cable Network Architecture Characteristics

The architecture of an HFC network is shown in figure 1. A digital backbone is used to bring the different signals to the headends (HE in the figure). From each headend fibers are used to connect to the different optical nodes in the field. The part between the headend and optical node is shown in more detail in figure 2.

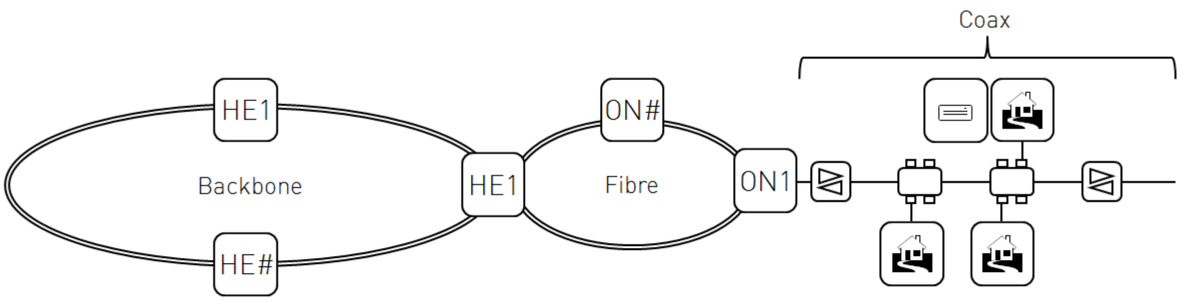

Figure 1: Architecture of cable network

Logically, two fibers are used between each node and the headend. One for the downstream (forward) signal and one for the upstream (return) signal. It is possible to also carry multiple signals over a single fiber using techniques like WDM.

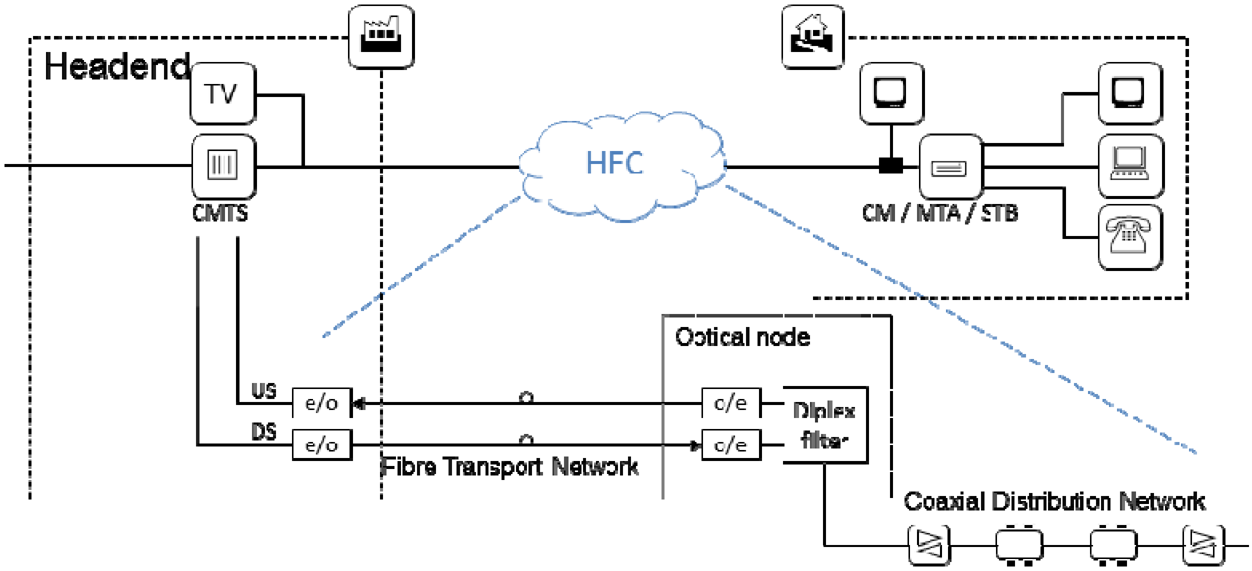

Figure 2: HFC-part of cable operator network

On the coaxial part of the network, both the upstream and downstream signals are present. By using a different frequency band, it is possible to use bidirectional electrical amplifiers in the coaxial part of the network. In the coaxial part, taps are used to bring the signal to each individual household. The upstream spectrum that is used in Europe goes from 5 to 65 MHz. In the downstream the frequencies between 87,5 MHz up to 1 002 MHz are used. Coaxial cables used in CATV networks have a characteristic impedance of 75 Ohm.

4.1 RF Spectrum Usage

The spectrum in the downstream is used for the delivery of different services to the households:

- Analogue Television and FM radio.
- Digital Television (including VOD).
- Internet (IP).
- Telephony (runs over IP).

In CATV networks signals for analogue TV, digital TV and EuroDOCSIS (IP) are placed in the cable frequency spectrum one next to the other without causing interference to each other. It is important to note that due to the broadcast nature of a cable network the **full spectrum** is typically occupied.

An example of a possible spectrum allocation is shown in figure 3.

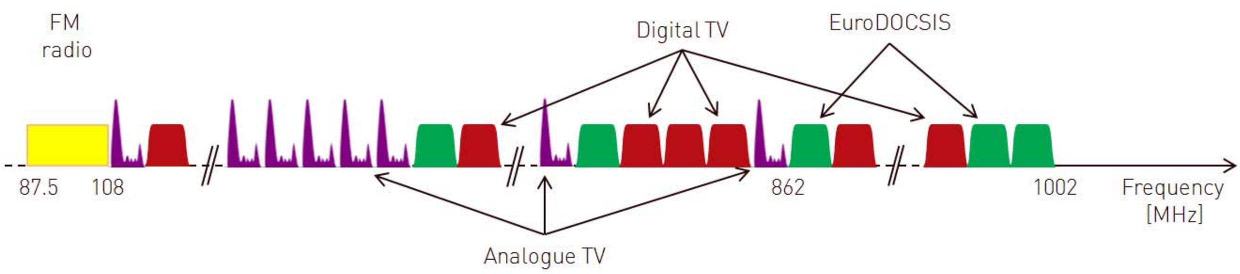

Figure 3: Example spectrum usage

4.1.1 Analogue television

In Europe, analogue television is offered using PAL or SECAM modulation, PAL and SECAM are analogue modulation techniques. One TV-channel occupies 7 or 8 MHz of bandwidth. Operators typically offer a significant number of analogue TV channels (30 or more). The biggest advantage of analogue television is that users only need a TV-set, and as such can easily (inexpensively) watch television on multiple sets.

Analogue television channels can be located anywhere in the RF spectrum from 108 up to 862 MHz.

4.1.2 Digital Television

Digital Television includes both broadcast digital TV and Video-on-Demand services. DVB-C is the technology used on cable networks for the transmission of the signal on the cable. DVB-C defines the digital modulation technique (QAM) and Forward Error Correction. The FEC-scheme is fixed and is Reed-Solomon with 16 bytes for error correction/detection per 188 useful bytes. As modulation 64QAM and 256QAM are used. The bandwidth used for a DVB-C signal is 8 MHz. This corresponds to a raw bitrate of about 42 Mbit/s for 64QAM and about 56 Mbit/s for 256QAM. The DVB-C system (framing structure, channel coding and modulation) is described in EN 300 429 [12].

The content of this bitstream is called an MPEG2 transport stream (TS). Within such a transport stream multiple TV-channels are present, packets of the different channels are multiplexed in this stream. Each packet has an identifier (PID) that identifies to which stream it belongs. Within this stream, special packets (predefined PIDs) are used to also transport signaling information (PSI/SI) to the receivers. These packets also contains information on where other streams are located, which programs are available.

Digital television channels can be located anywhere in the RF spectrum from 108 up to 1 002 MHz.

4.1.3 Internet (EuroDOCSIS)

Internet services in a cable network are provided over EuroDOCSIS technology. EuroDOCSIS uses the same modulation techniques as digital television (i.e. DVB-C with 64QAM or 256QAM). The cable modem termination system (CMTS) is the device located in the headend that generates the downstream signals and receives the upstream signals. In EuroDOCSIS one or more downstream channels (each 8 MHz) are used to transport data and signaling packets to the cable modems. Cable modems share the bandwidth of these channels. Up to EuroDOCSIS 2.0 a cable modem is only demodulating a single downstream channel of 8 MHz (note that this is still shared with other modems). With EuroDOCSIS 3.0 channel bonding is used, with this technology a single modem can use multiple (currently typically 4 to 8) downstream channels at the same time, these are of course still shared with other modems. The downstream channels are placed in the same spectrum as digital television and can be allocated anywhere in the RF spectrum from 108 MHz up to 862 MHz. EuroDOCSIS 3.0 defines the frequency space above 862 MHz and up to 1 002 MHz as an option.

For the return path EuroDOCSIS uses the frequency spectrum between 5 and 65 MHz. Modems are assigned upstream channels to use by the CMTS. A single upstream channel is shared in a TDM-way by different modems, the CMTS acts as the master and controls which modem is allowed to transmit at what time.

4.1.4 Telephony

Telephony in a cable network is provided over IP. As such it runs on top of EuroDOCSIS. This means that if the EuroDOCSIS system is not functional, telephony will not be functional anymore as well.

5 Signal characteristics and protection criteria

This clause provides an overview and requirements of the signal characteristics of European CATV systems. The minimum, maximum and typical signal levels together with their required signal-to-noise ratio shall be specified and are determining factors when a maximum tolerated noise level is defined.

Once this noise level is reached in the band of the desired signal (which is considered 8 MHz bandwidth in the present document), either as a result of background noise in the CATV network or induced by a LTE transmitter, the service will be disturbed.

The threshold levels shall be defined in terms of a noise level which, if reached, will render the quality of the services provided to a level which is unacceptable.

5.1 Protection analogue TV signals as per EN 60728-1

Depending on the S/N level at the TV receiver the picture quality will degrade. For analogue TV picture quality is function of the power level in the main carrier versus the noise in the relevant bandwidth (typically called Carrier to Noise C/N), and the power level of the carrier with respect to a smallband interferer (typically called Carrier to Interference, C/I).

Operational requirements for analogue television signals shall be in accordance with the requirements defined in CENELEC EN 60728-1 [1].

The minimum and maximum signal levels for analogue television at the system outlet shall be in accordance with requirements defined in CENELEC EN 60728-1 [1]. These values shall be valid for a system with 8 MHz spacing and more than 20 channels.

Table 1: Minimum and maximum system outlet levels as per EN 60728-1 [1]

System	Minimum level	Maximum level
PAL/SECAM	-3 dBmV	17 dBmV

For an analogue television system used in Europe following minimum distance between noise signal and desired signal are required:

Table 2: Minimum carrier-to-noise and interference as per EN 60728-1 [1]

C/N random noise	C/I smallband interferer
> 44 dB	> 57 dB

With a receive level of 0 dBmV a NRS interfering signal shall not impact the CATV network service such that the noise level exceeds s 0 – 44 = **-44 dBmV/8MHz**.

If the interferer signal would be smallband then a value of -57 dBmV shall be respected. With LTE signals not classified to be as smallband interference, then -44 dBmV shall be taken as the representative threshold level.

The following table shows the result of combining the receive levels with the required C/N ratio of 44 dB. The minimum and maximum power levels shall be as defined in EN 60728-1 [1], noting the typical level is purely indicative.

Table 3: Minimum and maximum system outlet levels as per EN 60728-1 [1]

Signal level [dBmV/8MHz]	Maximum noise level [dBmV/8MHz]
Min level: -3	-3 – 44 = -47
Typical level: 5	-39
Max level: 17	-27

5.2 Protection digital television signals (DVB-C) as per EN 60728-1

The minimum and maximum power levels for digital television signals (DVB-C) shall be as defined in CENELEC EN 60728-1 [1] and as included in the table below.

Table 4: Minimum and maximum system outlet levels as per EN 60728-1 [1]

System	Minimum level	Maximum level
DVB-C 64 QAM	-13 dBmV	7 dBmV
DVB-C 256 QAM	-6 dBmV	14 dBmV

Furthermore the CENELEC EN 60728-1 [1] shall define requirements for the signal-to-noise ratio of the DVB-C signals. The values assume simultaneous distribution of analogue and digitally modulated signals. Furthermore these values assume that intermodulation noise is not present or can be neglected and a BER of 10^-4 before Reed-Solomon decoder is achieved.

Table 5: S/N requirements for digital television (DVB-C) signals

System	Minimum S/N ratio [dB]
DVB-C 64 QAM	26
DVB-C 256 QAM	32

Based upon the minimum S/N requirements and system outlet signal levels the maximum noise level without service degradation can be calculated and is presented in the table below. A NRS shall be engineered such that any interference from the NRS does not result in the maximum tolerated noise level of the CATV network to be reached.

Table 6: Maximum tolerated noise for digital television (DVB-C) signals

Signal [dBmV/8MHz]	Maximum noise level tolerated [dBmV/8MHz]
DVB-C (64 QAM) @ Minimum level -13 @ Typical level -4 @ Max level +7	 -39 -30 -19
DVB-C (256 QAM) @ Minimum level -6 @ Typical level 0 @ Max level +14	 -6 - 32 = -38 -32 -18

5.3 Protection digital signals (DVB-C as used for EuroDOCSIS)

The minimum carrier-to-noise requirements for normal operation at various power-levels and modulations shall be as described in DOCSIS physical layer specification ETSI TS 102 639-2 [2] or Recommendation ITU-T J.222.1 [3], clause B.6.3.

A modem operating in these ranges will achieve a post-FEC BER less than or equal to 10^-8.

Table 7: Signal level and C/N requirements for EuroDOCSIS cable modems

Power-level range per 8MHz channel [dBmV/8MHz]	Minimum C/N ratio [dB]
-17 to +13 for QAM64	25,5
-13 to -6 for QAM256	34,5
-6 to +17 for QAM256	31,5

Based upon the minimum C/N requirements and the signal levels the maximum noise level without service degradation in any 8 MHz in the cable is calculated as summarized in the table below.

Table 8: Signal level and maximum tolerated noise for EuroDOCSIS DVB-C signals

Signal [dBmV/8MHz]	Maximum noise level tolerated [dBmV/8MHz]
DVB-C (64 QAM) @ Minimum level -17 @ Typical level -4 @ Max level +13	 -42,5 -29,5 -12,5
DVB-C (256 QAM) @ Minimum level -13 @ Typical level 0 @ Max level +17	 -13 - 34,5 = -47,5 -31,5 -14,5

Depending on the operational receive level at the cable modem interface the service will be degraded starting from a noise level as high as -47,5 dBmV/8MHz.

A NRS shall be engineered such that any interference from the NRS does not result in the maximum tolerated noise level of the CATV network to be reached.

5.4 Important remarks on signal characteristics

The various maximum noise levels presented in this clause are purely the result of norms and specifications. Therefore it is important to account for following remarks when a realistic maximum tolerated noise level is to be defined.

It should be noted that the values of EN 60728-1 [1] are defined at the system outlet and that the EuroDOCSIS specification is defined at the cable modem cable interface. EuroDOCSIS defines lower signal levels than specified in EN 60728-1 [1], certainly if 256 QAM is considered.

There is no clear specification on the DVB-C end-device input receiver levels, apart from EN 60728-1 [1] which assumes almost no signal degradation between system outlet and the end customer device. E.g. the actual receive levels supported/required will differ between vendors/operators, they will all include the range defined by EN 60728-1 [1] and in their best interest still perform well beyond these ranges. It can generally be accepted to state that realistic receive levels will be more in line with the EuroDOCSIS defined levels.

Furthermore it needs to be noted that in real life networks typically the level of the analogue signal is about 6 to 10 dB stronger than this is of a 64 QAM carrier, and about 2 to 6 dB stronger than the level of a 256 QAM carrier. The reason for this is mainly to avoid intermodulation noise of the digital signal to interfere with the analog signal.

Table 9 shows the summary of levels that are realistic and representative limits for signals that are delivered by the HFC network to the house system outlet, and with extension the final receiving equipment (cable modem, TV, settop box, etc.).

Table 9: Summary of specification and norm based signal levels and resulting maximum noise levels at end-device terminal input

Signal type	Min level [dBmV/8MHz]	Typical level [dBmV/8MHz]	Max level [dBmV/8MHz]	Maximum tolerated noise level [dBmV/8MHz]
Analogue TV (PAL)	-3	5	17	-47
DVB-C 64 QAM Digital Television	-13	-4	7	-39
DVB-C 256 QAM Digital Television	-6	0	14	-38
DVB-C 64 QAM TV and EuroDOCSIS	-17	-4	13	-42,5
DVB-C 256 QAM TV and EuroDOCSIS	-13	0	17	-47,5

A value of -47,5 dBmV/8MHz is a representative value as maximum noise level tolerated in the receiver lead used to connect the system outlet with the receiving end-device. As long as noise is below this threshold level no unacceptable interference will happen.

Considering the above remarks, a NRS shall be engineered such that any interference from the NRS does not result in the maximum tolerated noise level of the CATV network to be reached.

6 Emission limits of new broadband radio services (e.g. LTE)

Cable service can get disturbed if the signal that gets to the receiver (STB, TV-set or CM) is too low in quality (power level or C/N). Another cause for disturbance can be an interferer relatively close to the receiver that causes problems to the operation of the receiver.

Typically the signal quality is the main cause for service degradation, the power level of the wanted signals on the cable network is well controlled and not subject to high variations of external factors. The amount of noise on the network and in the receiver can go up if a transmitter operating in the same RF spectrum is used in the neighbourhood of cable networks or cable network equipment.

The amount of disturbance depends on a number of factors:

- Type of interferer (bandwidth, signal characteristics)
- Type of wanted signal (analog, 64QAM, 256QAM)
- Field strength of interferer-signal at victim
- Amount of interferer-signal that can enter the device or network (shielding)
- Natural (background) noise floor on the coaxial cable

A NRS shall be engineered such that any interference from the NRS does not degrade the performance of the service by affecting the wanted signal carried on the cable network.

In order to estimate the interference from the NRS on CATV systems a calculation method is presented in the next clause. The method shall be used to calculate the interference of a radio system (e.g. TVBD, WSD, LTE, etc.) on cable systems.

NOTE: In the present document and subsequent clauses three use cases of a NRS operating in a frequency band are calculated, use case (i) for NRS operating in the frequency band 470 - 790 MHz band such as with WSD, use case (ii) for NRS operating in the frequency band 694 - 790 MHz (700 MHz band) and use case (iii) for NRS operating in the frequency band 790 - 862 MHz band such as with LTE800 devices.

6.1 General calculation of maximum radiate NRS interference on CATV systems

The equations derived in this clause shall apply to define the maximum noise level in terms of the CATV network noise and NRS interference.

The radiated interference reaches an unacceptable level if the noise contributed by the new radio service (NRS) transmitter (e.g. LTE transmitter) on an operational CATV system is resulting in a violation of the defined protection criteria. At all times following expression shall be valid:

$$\text{Networknoise}_{[W]} + \text{NRS interfernce}_{[W]} < \text{maximum noise level}_{[W]} \quad (1)$$

The networks own noise accounts for all kinds of noise that define the noise floor in the operational network.

The interference from the NRS (e.g. LTE) is the signal induced in the CATV system by the NRS transmitter (TS or BS).

The maximum noise level was defined in the previous clause (clause 5).

Consider following example:

A system with 256QAM signal at -13 dBmV requires that the maximum noise level is below -47,5 dBmV. If we assume the network noise to be 1 dB below that level, then the network noise is located at -48,5 dBmV. This difference is defined as the *noise margin*.

This requires any extra interference noise power to be no greater than the difference between -47,5 dBmV and -48,5 dBmV which is equal to -54,4 dBmV.

-47,5 dBmV = (10^(-47,5/20))/1 000)^2)/75 Ohm = -96,3 dBm = 2,34E-13 W

-48,5 dBmV = (10^(-48,5/20))/1 000)^2)/75 Ohm = -97,3 dBm = 1,88E-13 W

The difference is 2,37E-13 W – 1,88E-13 W = 4,88E-14 W = -103,12 dBm = -54,4 dBmV

This latter value is the maximum allowed power of the interference induced in the CATV system.

Note that the noise margin of 1 dB results in a (-47,5 – (-54,4)) = 6,9 dB reduction compared to the maximum noise level.

Table 10 summarizes the generalized relation between the noise margin and a correction factor that can be used during calculations. It defines by what value the maximum noise levels needs to be reduced for a given noise margin.

Table 10: Relation noise margin and correction factor

Noise margin [dB]	$C_{noisemargin}$ [dB]
0,5	9,6
1	6,9
2	4,3
3	3,0
4	2,2
7	1,0
10	0,5

Using this reduction factor equation 2 is defined which now provides the relation between NRS interference (e.g. LTE interference) and the protection criteria at a given noise margin. This formula will be convenient to calculate the maximum tolerated interference from the new radio service.

$$NRS\ interference_{[dBmV]} < maximum\ interference\ level_{[dBmV]} - C_{noisemargin[dB]} \qquad (2)$$

In CATV networks the network noise floor is only a couple of dBs away from the required maximum interference level. The noise margin for realistic networks is between 0,5 and 6 dB (which results in a $C_{noisemargin}$ between 9,6 dB and 1,3 dB) and will fluctuate over time (seasonal fluctuations).

6.1.1 Methodology for calculation of NRS interference

The amount of signal picked up by a coaxial cable, cable modem, settop box, … in a certain field (interferer) is depending on the frequency of the interferer and the shielding effectiveness of the system. The induced voltage U [V] by an electrical field E [V/m] on a piece of wire or a complete system is determined by a coupling factor, as given by Equation 3, where k [1/m] is the antenna factor for half wavelength dipole, which is given by Equation 4.

$$U = \frac{E}{k} \qquad (3)$$

With:

$$k = \frac{f}{c_0}\sqrt{\frac{4.\pi.Z_0}{Z_A.G}} \qquad (4)$$

In which:

$Z_0 = 377\ Ohm$ (free space impedance)

$$Z_A = 73\ Ohm \text{ (impedance of half wavelength dipole)}$$

$$G = 1.64\ (2.1\ dB) \text{ (Gain of a half wavelenght dipole)}$$

$$c_0 = 2.997925\ .\frac{10^8 m}{s} \text{ (speed of light)}$$

If one defines k* as 20 log10(k) one gets:

$$k^* = 20.log10(f[MHz]) - 33.57\ [\frac{dB}{m}] \tag{5}$$

Any additional attenuation on the NRS signal by construction elements, building walls, ... can be included as a_b . A typical value for attenuation introduced by a wall is 10 dB.

Expressing equation 3 in the logarithmic domain and including attenuation by system shielding and building losses results in:

$$U_{ind[dBV]} = E_{[dBV/m]} - k^* - a_b - a_s \tag{6}$$

As an example an E-field of 106 dBµV/m at 700 MHz induces on a system with shielding effectiveness of 85 dB and no building losses a voltage of 106 – 23,3 – 0 – 85 = -2,3 dBµV.

The E-field generated by an isotropic radiating antenna at a certain distance away is calculated using following equations:

The power density S [W/m2] as a result of a magnetic- (H) and electrical- (E) field coming from an isotropic antenna at distance r [m] away is calculated from the equation below.

$$S = E.H = \frac{P_t}{4.\pi.r^2} \tag{7}$$

For far-field magnetic and electrical field strengths are perpendicular and the relation is linked using the free-space impedance Z_o which is 377 Ohm (~$120.\pi$).

$$H = \frac{E}{Z_0} \tag{8}$$

Substitution of 8 in 7 leads to following equation that calculates the E-field at a given distance from an isotropic radiator.

$$E[V/m] = \sqrt{\frac{P_{t[W]}.Z_0}{4.\pi.r^2}} \tag{9}$$

Expressed in the logarithmic domain equation 9 results in following expression:

$$E_{[dBV/m]} = P_{t[dBW]} - 10\log(\frac{4.\pi.r^2}{Z_0}) \tag{10}$$

Finally Equation 4 can be completed to calculate the induced voltage in a coaxial cable at any distance away from an antenna with known gain. Substitution of equation 10 and 5 in 6 one gets:

$$U_{ind[dBV]} = P_{t[dBW]} - 10.\log\left(\frac{4.\pi.r^2}{Z_0}\right) - (20.\log(f[MHz]) - 33.57) - a_s - a_b + G_t \tag{11}$$

This can be simplified and adjusted to units used in the present document:

$$U_{ind[dBmv]} = P_{t[dBm]} - 20.\log(r[m]) - 20.\log(f[MHz]) - a_s - a_b - G_t + 78,34 \tag{12}$$

Some constraints need to be taken into account for Equation 12 to be valid.

The radiating antenna is expected to be far enough (far-field) away from the coaxial system. Practically the far field is defined as 2 wavelengths away from the antenna:

- for NRS operating at 694 MHz (wavelength of 43,2 cm) the far-field starts at 86 cm, use case (i);

- for NRS operating at 790 MHz (wavelength of 38 cm) the far-field starts at 76 cm, use case (ii); and
- for NRS operating at 862 MHz (wavelength of 35 cm) the far-field starts at 70 cm, use case (iii).

6.1.2 Determination of shielding effectiveness

When an estimate is made of the NRS interference on cable technology the shielding effectiveness parameter (a_s) shall be selected according to the various definitions of shielding effectiveness that exist and are listed below.

6.1.2.1 Passive cable equipment shielding effectiveness

The shielding efficiency (screening effectiveness) of passive cable equipment (taps, splitters, wall outlets, etc.) is normalized according to CENELEC EN 50083-2 [4]. For the frequency range 470 MHz to 1 000 MHz, passive equipment is classified either as class A or class B.

Table 11: Passive cable equipment shielding classes as defined per CENELEC EN 50083-2 [4]

Passive cable equipment classification	Screening effectiveness limit [dB]
Class A	≥ 75
Class B	≥ 65

The CENELEC EN 50083-2 [4] recommends the use of Class A for planning and implementation of new networks, legacy installations are typically class B.

The shielding effectiveness value in CENELEC EN 50083-2 [4] classification shall not be used directly in the calculation of system shielding effectiveness as this value is the result of a specific measurement using an absorbing clamp.

6.1.2.2 Coaxial cable shielding effectiveness

The shielding effectiveness of coaxial cables is normalized according to CENELEC EN 50117-2-1 [5]. Coaxial cables are classified in Class A+, A , B or C (table 12). For cable networks at least class A, preferably A+, is to be used for deployments.

Table 12: Coaxial cable shielding classes as defined per CENELEC EN 50117-2-1 [5]

Coaxial cable shielding classification	Effective shielding [dB] for frequency range 30 MHz ...1 GHz
A+	≥ 95
A	≥ 85
B, C	≥ 75

The coaxial cable shielding effectiveness is a useful parameter when comparing different coaxial cables however the shielding effectiveness values found in coaxial cable specifications shall not directly be used in the calculation method of system shielding effectiveness as they are the result of a specific measurement method. The values of the coaxial cable shielding effectiveness are the result of a measurement technique as given by CENELEC EN 50289-1-6 [6], the triaxial method.

6.1.2.3 Device shielding effectiveness

All broadcast receivers are required to fulfil the requirements defined in CENELEC EN 55020 [7] or CISPR 20 [8]. These standards define a screening effectiveness requirement of 50 dB.

Practically it means that if a device (e.g. television set, not powered) is in an E-field of x dBmV/m then the voltage measured at the coaxial cable connecting interface shall be lower than (x – 50) dBmV.

The result of CISPR 20 [8], 50 dB shielding effectiveness tests will be representative for the amount of shielding that the device provides towards an incandescent field, however the value (50 dB) shall not be used directly as the value for shielding effectiveness in the calculation model.

6.1.2.4 System shielding effectiveness

The model used in the present document is equal to the model used to estimate the LTE interference on cable systems as described in the final report of the PG ESKM workgroup [10]. This project group had a strong representation of members of the CATV industry (manufacturers, cable operators, cable organizations).

The model and proposed shielding effectiveness parameter values used in the report are representative for calculations to end-to-end cable systems, which include cabling and end devices. The shielding effectiveness of individual components might be 75 dB (coaxial cable, splitters, etc. each according to specific measurement methods) but the total system shielding effectiveness will be a different value. (For sure the total shielding effectiveness can only be as high as the component with lowest shielding effectiveness).

The working group final report favours the values of 55 dB, 65 dB and 75 dB as system shielding effectiveness for a cable network connected end device (cable modem, settop box and TV). Additionally the remark is made that a value of 75 dB shielding effectiveness is considered very high and will only be attained by future devices.

The workgroup proposed values are best suited as shielding effectiveness parameter in the calculation model.

6.1.3 Resulting NRS TS interference on cable system

Based upon the calculation methodology described and taking into account the protection criteria and noise margin correction explained, calculations can be done to find maximum EIRP of a NRS TS under various conditions.

During the calculation examples no building loss was included and a_b was set to 0 dB. Furthermore no antenna gain G_t was taken in account. The $C_{noisemargin}$ used was 6,9 dB which implies a noise margin of 1 dB.

6.1.3.1 Case I: Typical Rx level vs. Shielding effectiveness

The first graphs (figures 4a and 4b) shows the relation between the tolerable maximum EIRP of a NRS transmitter in function of the distance away from a CATV systems in combination with various shielding effectiveness values. The reference signal used is a 256 QAM signal at 0 dBmV at 750 MHz for use case (iii) given by figure 4a and 600 MHz for use case (ii) given by figure 4b which classifies as a typical and representative level signal.

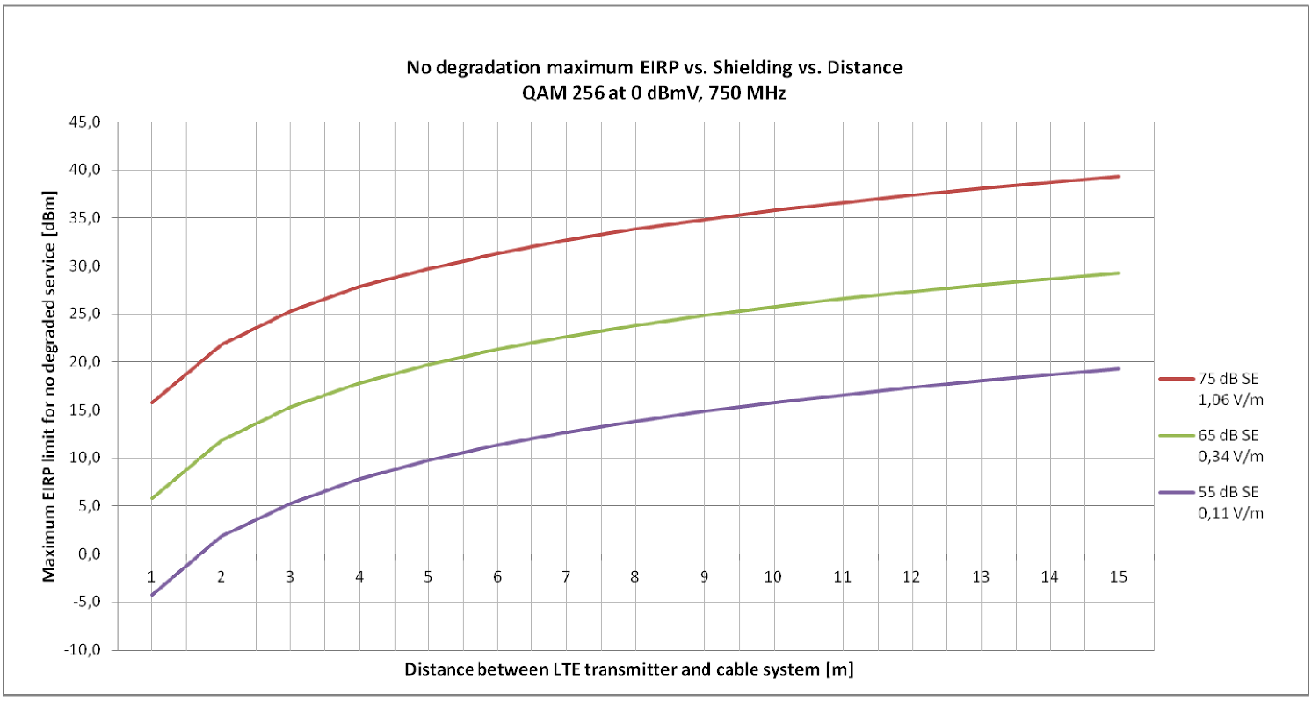

Figure 4a: Typical QAM 256 operation combined with low, medium and high shielding factors

EXAMPLE 1: A 256QAM signal at 0 dBmV requires according to table 8 a maximum noise level of -31,5 dBmV which is reduced with $C_{noisemargin}$ to -38,4 dBmV. A NRS transmitter (e.g. a LTE transmitter)at a distance of 4,5 m away from the cable system with shielding effectiveness of 65 dB, will induce this power level if it is transmitting at an EIRP of 20 dBm (equation 12). The E-field needed to reach the unacceptable interference level of -38,4 dBmV is 0,38 V/m.

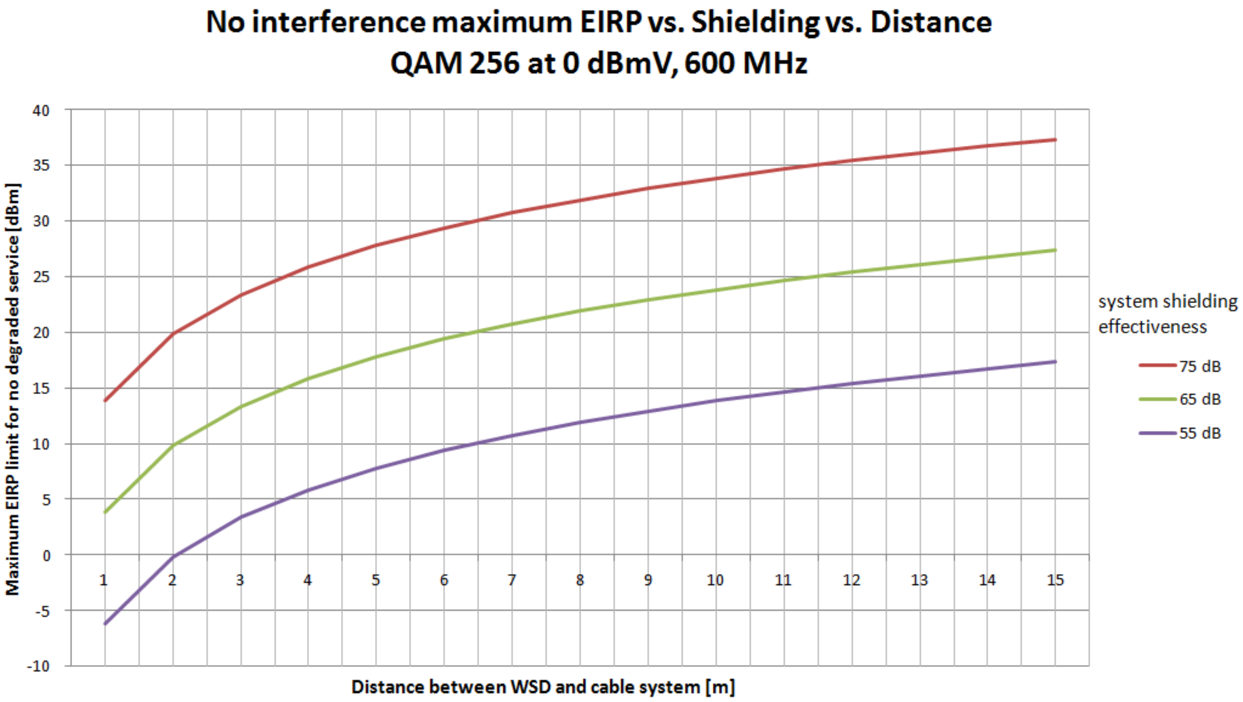

Figure 4b : Typical QAM 256 operation combined with low, medium and high shielding factors

EXAMPLE 2: A 256QAM signal at 0 dBmV requires according to table 4 a maximum noise level of -31,20 dBmV which is reduced with $C_{noisemargin}$ to -38,1 dBmV. A NRS at a distance of 2 m away from the cable system with shielding effectiveness of 75 dB will induce this power level if it is transmitting at an EIRP of 20 dBm (equation 12).

6.1.3.2 Case II: High shielding vs. Receive level

A second graph (figures 5a and 5b) clearly shows the scenario for different receiver level (low level, typical and high) per modulation profiles used by EuroDOCSIS cable modems (and with extension all DVB-C receivers). The shielding factor used is 75 dB which is considered very high and only to be attained by future networks and systems. The frequency used for use case (iii) is 750 MHz as given by figure 5a and 600 MHz for use case (iii) as given by figure 5b and will provide moderate coupling of the NRS signal on the cable system.

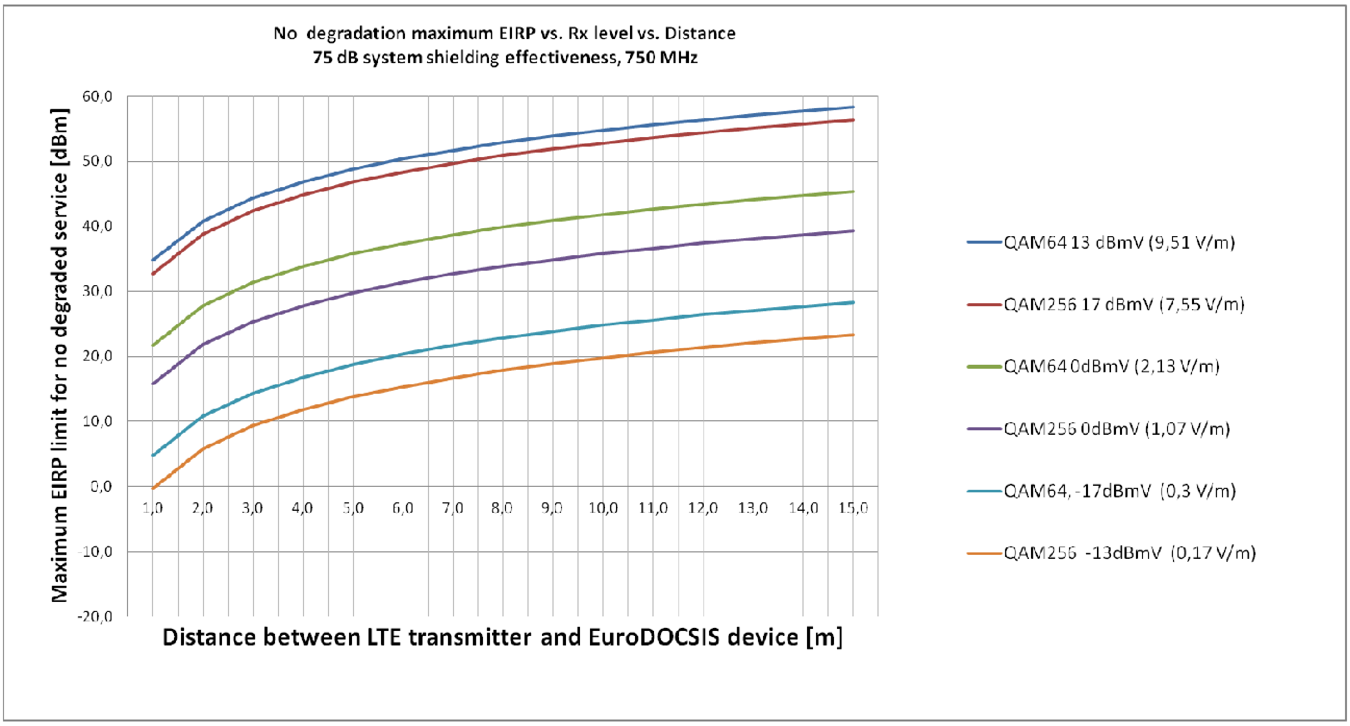

Figure 5a: High shielding case

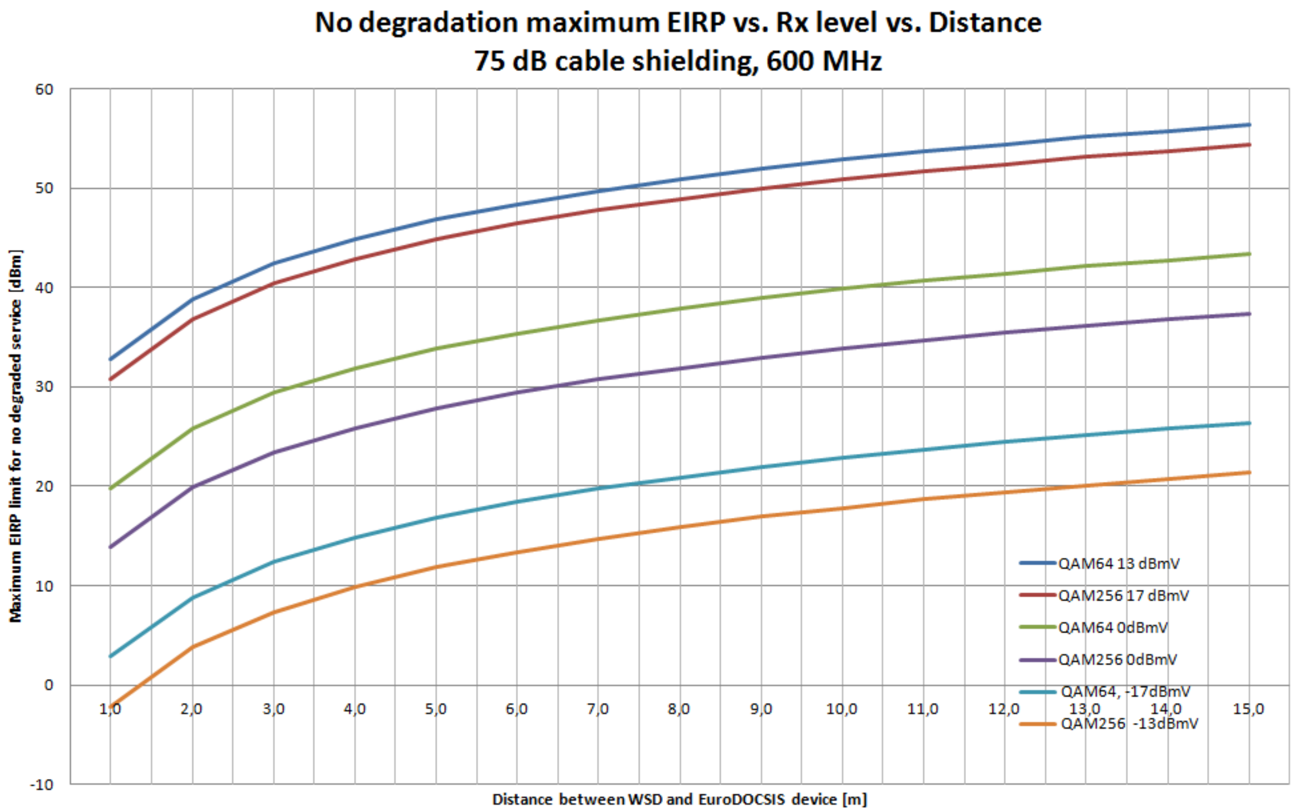

Figure 5b : High shielding case

6.1.3.3 Case III: Worst shielding and best coupling vs. Receive level

The worst case NRS interference will happen at lower NRS frequencies and lowest shielding. A shielding effectiveness of 55 dB can be considered as worst case representative value.

For use case (ii) the frequency used as given in figure 6a is 694 MHz as this will provide the best coupling of the signal on the coaxial cable. It is noteworthy that changing the frequency to 790 MHz will only introduce an additional coupling attenuation of 1,1 dB.

For use case (iii) the frequency used as given in figure 6b is 790 MHz as this will provide the best coupling of the signal on the coaxial cable. It is noteworthy that changing the frequency to 862 MHz will only introduce an additional coupling attenuation of 0,8 dB.

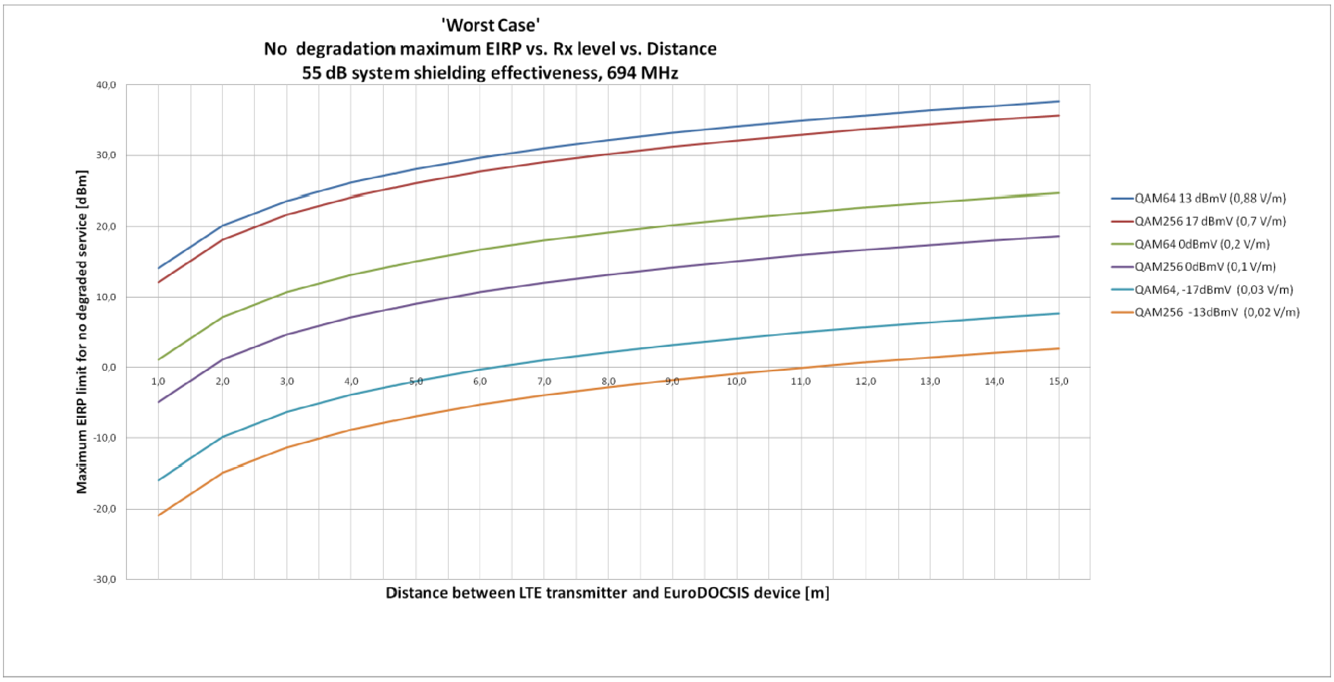

Figure 6a: Low shielding case at various operational levels

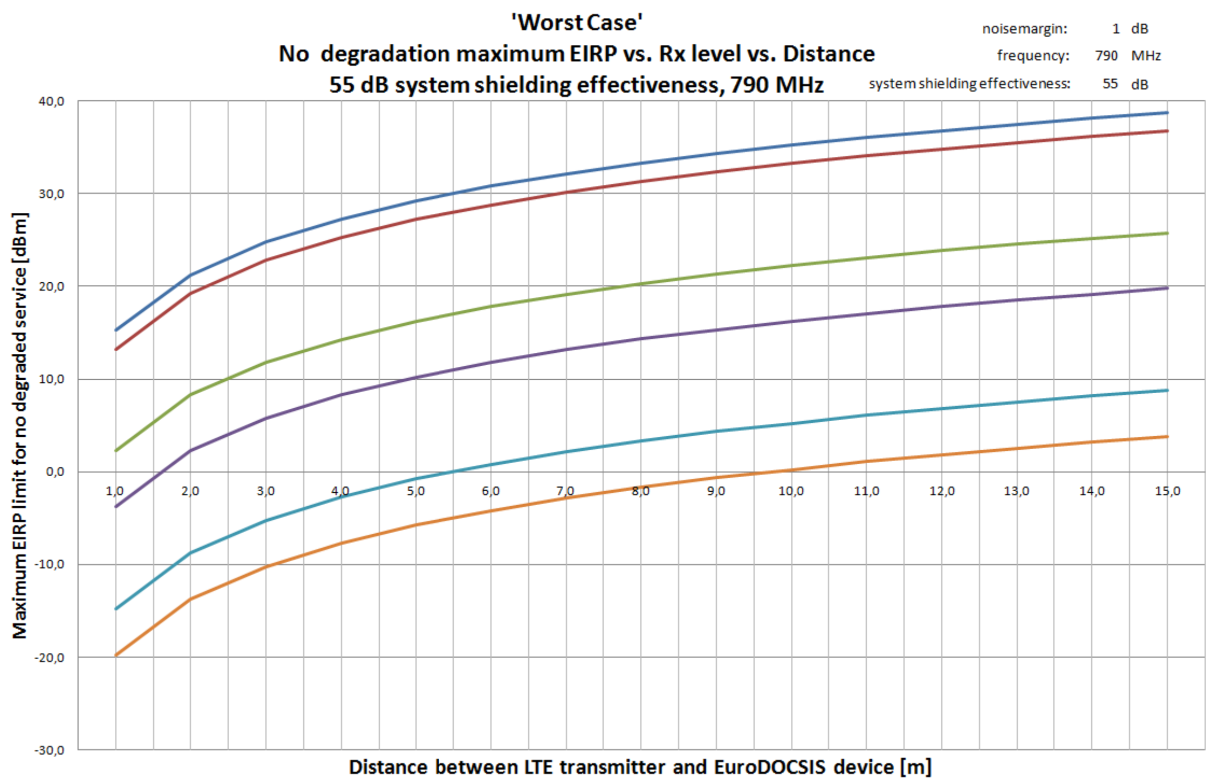

Figure 6b: Low shielding case at various operational levels

6.1.4 Remarks on the NRS bandwidth

- The calculations assume the NRS signal (e.g. an LTE signal) to be no larger than 8 MHz in bandwidth. If the signals were wider then interference will be lower.
  E.g. if the NRS signal was to be 16 MHz in bandwidth then EIRP power can be increased another 3 dB to reach the same interference level.

- For the NRS signals smaller than 8 MHz it was assumed that only a **single** NRS signal is disturbing the desired EuroDOCSIS/DVB-C signal.
  If 5 MHz wide NRS signals are **stacked** one next to the other, then one 5 MHz + 3/5 of the neighbour channel will be captured by the 8 MHz wide DVB-C demodulator, which results in an additional 2 dB (=10*log(8/5)) of induced power to be accounted for.

- If WSD signals are proposed with 1 MHz in bandwidth and they are **stacked** in the 8 MHz band that the WSD maximum EIRP power level needs to be reduced by 9 dB as to cause the same disturbance as a single 8 MHz wide WSD signal.

7 Experimental evidence of interference

This clause contains references to experiments that are representative as realistic situations with respect to the calculated results.

These measurements are based on LTE800 Operation however when considering NRS operating in 700 MHz the coupling factor and other criteria needs to be assessed. Experimental evidence is currently only available with respect to the operation of LTE in the 800 MHz band.

When considering operation of NRS transmitters (e.g. LTE transmitters) within the 700 MHz band it is important to realize the effect of the beam forming of the UE signal (trp) against the experimental evidence in 800 MHz band. This needs to be further assessed for the 700 MHz frequency band.

7.1 Carl-T Jones Corporation, TVBD direct pickup interference tests, 2009

Testing in the USA testing executed by Carl T. Jones Corporation for NCTA [11] has shown that disturbance to analogue reception can already occur at E-fields as low as 97 dBμV/m, with average (over all polarizations) value of about 103 dBμV/m.

Table 13 shows the required separation distance for disturbance free operation in these cases calculated using free space equation (Equation 8). The analogue NTSC signal was received at 0 dBmV.

Table 13: Required separation distance for analogue TV (USA)

Transmit power	Required distance [meters]	
	Avg. E-field < 103 dBuV/m	Min. E-field < 97 dBuV/m
23 dBm	17	34
15 dBm	7	14
10 dBm	4	8
5 dBm	2	4
0 dBm	1 [a]	2
NOTE: [a] = small distances are not representative for the formulas used, the formulas expect far-field distances.		

The same study showed that E-fields as low as 107 dBμV caused disturbance for 256QAM reception (received at -12 dBmV), with an average (over all polarizations) value of about 112 dBμV.

Table 9 shows the required separation distance for disturbance free operation in these cases.

Table 14: Required separation distance for 256QAM (USA)

Transmit power	Required distance [meters]	
	Avg. E-field < 112 dBuV/m	Min. E-field < 107 dBuV/m
23 dBm	6	10
15 dBm	2	4
10 dBm	1 a	2
5 dBm	0,7 a	1 a
0 dBm	0,4 a	0,8 a
NOTE: a = small distances are not representative for the formulas used, the formulas expect far-field distances.		

The values for a European case will be different since other modulation techniques, frequencies and reception levels are used. However as indicative values they are representative.

7.2 LTE interference test, Kolberg Germany, December 2009

The tests executed in Kolberg verified immunity of integrated TV receivers, settop boxes and data-modems (EuroDOCSIS) connected to broadband cable and TV networks against radiation from LTE user equipment.

The measurement report G531/01077/09 [9] produced as a result of the testing contains similar results as the calculated values. Test signals were 256QAM received at -4 dBmV, analogue PAL was available for demodulation at 0 dBmV.

Two statements from the report are inlined:

- The minimum LTE field strength at the location of the measured receivers causing disturbance heavily depends on the receiver itself and the radiation direction. Average immunity of the receivers tested ranges from 114 dBµV/m (0,5 V/m) to 148 dBµV/m (25 V/m) (AV-burst/10MHz, co-channel). The average is calculated across all measured directions and polarizations for a single receiver. The minimum LTE field strength that caused disturbance at the location of one tested receiver is 100 dBµV/m or 0,1 V/m when the receiver is exposed to radiated emissions from the most sensitive tested direction. At the most immune tested position one receiver still operated at interfering co-channel LTE field strengths of 150 dBµV/m or 31 V/m.
- Analogue PAL reception is not more sensitive to LTE interference than DVB-C.

Based upon these values following table can be calculated:

Table 15: Required separation distance based on Kolberg test results

Transmit power	Required distance [meters]		
	Min. E-field 100 dBuV/m	Avg. E-field 114 dBuV/m	Max. E-field 150 dBuV/m
23 dBm	24	5	0,07 a
15 dBm	10	1,9	a
10 dBm	5	1 a	a
5 dBm	3	0,6 a	a
0 dBm	1,7	0,3 a	a
NOTE: a = small distances are not representative for the formulas used, the formulas expect far-field distances.			

8 Summary of impact to non-radio end-user equipment

Harmful interference from new radio services (NRS) such as LTE on cable systems can be characterized by three types of interference. The first interference exists between the NRS and the coaxial part of the HFC network (both in-home and external). The second type of interference is defined between the NRS system (e.g. a LTE system) and a remote cable headend receiver. A third type of interference is the interference from the NRS system (e.g. a LTE system) on a cable device itself (cable-modem, settopbox, digital cable television receivers, etc.).

The present document bundles the technical argumentation for the first and third type of interference, the direct pick-up (PDU) of signals from the NRS by the coaxial part of cable-television systems and EMI on cable devices. During the argumentation interference from the NRS is considered on the end-to-end system, both on coaxial cable and on the end device itself.

From the calculation examples of eirp limits for NRS and referenced measurements data shows that if the NRS transmitters would be operating at EIRPs of 20 to 23 dBm they will cause severe and unacceptable interference (loss of service) in many households.

Reducing their maximum EIRP to 10 dBm would still prohibit users to adjust the NRS transmitter position as to minimize/eliminate interference since interference distance is still considerable.

Operating at 5 dBm would most likely result in an interference which allows a user to adjust the transmitter position or orientation to minimize/eliminate the disturbance.

It should also be advised to use wide channels for the NRS as this will also reduce the interference on CATV coaxial cable deployed services. Should bandwidths smaller than 8 MHz be considered then an additional 3, 6 to 9 dB EIRP reduction is advised as to reduce the total power captured by 8MHz wide CATV receivers.

Given the above a NRS shall be engineered such that any interference from the NRS does not result in the maximum tolerated noise level of the CATV network to be reached, so that it does not impact (service degradation) the services as delivered to the non-radio fixed end user equipment for fixed and broadband electronic communications services.

History

Document history		
V1.1.1	July 2014	Publication