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SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Access networks – In premises networks

**Narrowband orthogonal frequency division
multiplexing power line communication
transceivers – Power spectral density
specification**

Recommendation ITU-T G.9901



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Recommendation ITU-T G.9901

Narrowband orthogonal frequency division multiplexing power line communication transceivers – Power spectral density specification

Summary

Recommendation ITU-T G.9901 specifies the control parameters that determine spectral content, power spectral density (PSD) mask requirements, a set of tools to support the reduction of the transmit PSD, the means to measure this PSD for transmission over power line wiring, as well as the allowable total transmit power into a specified termination impedance. It complements the system architecture, physical layer (PHY) and data link layer (DLL) specifications in Recommendations ITU-T G.9902 (G.hnem), ITU-T G.9903 (G3-PLC) and ITU-T G.9904 (PRIME).

This Recommendation uses material from Recommendation ITU-T G.9955 including Amendment 1; specifically material from the main body of the text, and Annexes A, B and E.

This edition integrates material from the 2012 version of this Recommendation with its corresponding Amendment 1, plus the following additional modifications:

- removal of optional FCC-1.a and FCC-1.b bandplans in Annex B.
- clarifications on the use of frequency notching in Annex B.

History

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FOREWORD

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Recommendation ITU-T G.9901

Narrowband orthogonal frequency division multiplexing power line communication transceivers – Power spectral density specification

1 Scope

This Recommendation specifies the control parameters that determine spectral content, power spectral density (PSD) mask requirements, a set of tools to support the reduction of the transmit PSD, the means to measure this PSD for the transmission over power line wiring, as well as the allowable total transmit power into a specified termination impedance. It complements the system architecture, physical layer (PHY), and data link layer (DLL) specifications in Recommendations ITU-T G.9902 (G.hnem), ITU-T G.9903 (G3-PLC) and ITU-T G.9904 (PRIME).

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [ITU-T G.9902] Recommendation ITU-T G.9902 (2012), *Narrowband orthogonal frequency division multiplexing power line communication transceivers for ITU-T G.hnem networks*.
- [ITU-T G.9903] Recommendation ITU-T G.9903 (2014), *Narrowband orthogonal frequency division multiplexing power line communication transceivers for G3-PLC networks*.
- [ITU-T G.9904] Recommendation ITU-T G.9904 (2012), *Narrowband orthogonal frequency division multiplexing power line communication transceivers for PRIME networks*.
- [IEC 60050-161] IEC 60050-161 (1990), *International Electrotechnical Vocabulary, Chapter 161: Electromagnetic compatibility*.
- [IEC 61334-5-1] IEC 61334-5-1 (2001), *Distribution automation using distribution line carrier systems – Part 5-1: Lower layer profiles – The spread frequency shift keying (S-FSK) profile*.
- [CISPR 16-1] IEC CISPR 16-1 (1993), *Specification for radio disturbance and immunity measuring apparatus and methods. Part 1: Radio disturbance and immunity measuring apparatus*.
- [CISPR 16-2] IEC CISPR 16-2 (1996), *Specification for radio disturbance and immunity measuring apparatus and methods. Part 2: Methods of measurement of disturbances and immunity*.
- [EN50065-1] CENELEC EN 50065-1 (2011), *Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz – Part 1: General requirements, frequency bands and electromagnetic disturbances*.

3 Definitions

3.1 Terms defined elsewhere

None.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 bandplan: A specific range of the frequency spectrum where an NB-PLC device is operating. A bandplan is defined by a lower frequency and an upper frequency.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AMN	Artificial Mains Network
LISN	Line Impedance Stabilization Network
LPM	Limit PSD Mask
NB-PLC	Narrowband-Power Line Communications
OFDM	Orthogonal Frequency Division Multiplexing
PHY	Physical layer
PLC	Power Line Communications
PMSC	Permanently Masked Subcarriers
PSD	Power Spectral Density
TN	Termination Network

5 Conventions

None.

6 PSD related specifications relating to CENELEC bands (9-148.5 kHz)

Clauses 6, 7, 8 and 9 of [EN50065-1] shall apply.

Annex A

PSD specifications for G.hnem transceivers

(This annex forms an integral part of this Recommendation.)

NOTE – This annex includes the power spectral density (PSD) specifications relating to [ITU-T G.9902].

A.1 Frequency band specifications

For compliance with this Recommendation it is mandatory to support at least one of the CENELEC bandplans or at least one of the FCC bandplans.

A.1.1 CENELEC band

When operating in the CENELEC band (3-148.5 kHz), a node shall use the control parameters specified in Table A.1 (see clause 8.4.7 of [ITU-T G.9902]).

Table A.1 – OFDM modulator control parameters for the CENELEC band

Notation	Value
N	128
F_{SC}	1.5625 kHz
N_{GI-PL}	12 – 1, 2 bit mapping 24 – 3, 4 bit mapping
N_{GI-HD}	0
N_{GI-CES}	0
B	8
F_{US}	$64 \times F_{SC}$

The CENELEC band is divided into sub-bands, forming bandplans A, B and CD described in the following subclauses.

A.1.1.1 CENELEC-A bandplan

Parameters for CENELEC-A bandplan are defined in Table A.2.

Table A.2 – Parameters for CENELEC-A bandplan

Notation	Value	Note
F_{START}	35.9375 kHz	Lowest frequency of CENELEC-A bandplan (subcarrier number 23)
F_{END}	90.625 kHz	Highest frequency of CENELEC-A bandplan (subcarrier number 58)
PMSC indices	0 to 22, 59 to 127	Clause 8.4.2.1 of [ITU-T G.9902]

A.1.1.2 CENELEC-B bandplan

Parameters for CENELEC-B bandplan are defined in Table A.3.

Table A.3 – Parameters for CENELEC-B bandplan

Notation	Value	Note
F_{START}	98.4375 kHz	Lowest frequency of CENELEC-B bandplan (subcarrier number 63)
F_{END}	120.3125 kHz	Highest frequency of CENELEC-B bandplan (subcarrier number 77)
PMSC indices	0 to 62, 78 to 127	Clause 8.4.2.1 of [ITU-T G.9902]

A.1.1.3 CENELEC-CD bandplan

Parameters for CENELEC-CD bandplan are defined in Table A.4.

Table A.4 – Parameters for CENELEC-CD bandplan

Notation	Value	Note
F_{START}	125 kHz	Lowest frequency of CENELEC-CD bandplan (subcarrier number 80)
F_{END}	143.75 kHz	Highest frequency of CENELEC-CD bandplan (subcarrier number 92)
PMSC indices	0 to 79, 93 to 127	Clause 8.4.2.1 of [ITU-T G.9902]

A.1.2 FCC bandplans

When operating in the FCC band (9-490 kHz), a node shall use the control parameters specified in Table A.5 (see clause 8.4.7 of [ITU-T G.9902]).

Table A.5 – OFDM modulator control parameters for the FCC band

Notation	Value
N	256
F_{SC}	3.125 kHz
N_{GI}	24 – 1, 2 bit mapping 48 – 3, 4 bit mapping
$N_{\text{GI-HD}}$	0
$N_{\text{GI-CES}}$	0
β	16
F_{US}	$128 \times F_{\text{SC}}$

Bandplans FCC, FCC-1 and FCC-2 defined over the FCC band are described in the following subclauses. Additional bandplans over the FCC band are for further study.

A.1.2.1 FCC bandplan

Parameters for the FCC bandplan are defined in Table A.6.

Table A.6 – Parameters for FCC bandplan

Notation	Value	Note
F_{START}	34.375 kHz	Lowest frequency of FCC bandplan (subcarrier number 11)
F_{END}	478.125 kHz	Highest frequency of FCC bandplan (subcarrier number 153)
PMSC indices	0 to 10, 154 to 255	Clause 8.4.2.1 of [ITU-T G.9902]

A.1.2.2 FCC-1 bandplan

Parameters for FCC-1 bandplan are defined in Table A.7.

Table A.7 – Parameters for FCC-1 bandplan

Notation	Value	Note
F_{START}	34.375 kHz	Lowest frequency of FCC bandplan (subcarrier number 11)
F_{END}	137.5 kHz	Highest frequency of FCC bandplan (subcarrier number 44)
PMSC indices	0 to 10, 45 to 255	Clause 8.4.2.1 of [ITU-T G.9902]

A.1.2.3 FCC-2 bandplan

Parameters for FCC-2 bandplan are defined in Table A.8.

Table A.8 – Parameters for FCC-2 bandplan

Notation	Value	Note
F_{START}	150 kHz	Lowest frequency of FCC bandplan (subcarrier number 48)
F_{END}	478.125 kHz	Highest frequency of FCC bandplan (subcarrier number 153)
PMSC indices	0 to 47, 154 to 255	Clause 8.4.2.1 of [ITU-T G.9902]

A.1.3 ARIB bandplan

The ARIB bandplan shall follow the requirements set out in section 3.4 of [ARIB STD-T84].

When operating in the ARIB bandplan, a node shall use the parameters specified in clause A.1.2 with the following modification: tones 134-153 are defined as PMSC (see clause 8.4.2.1 of [ITU-T G.9902] for the definition of PMSC tones).

A.2 Transmit PSD mask

A.2.1 Frequency notching

[ITU-T G.9902] supports frequency notching for regulatory and coexistence purposes. Notching shall apply to all components of a PHY frame (preamble, PFH, CES, and payload) and to all PHY frames transmitted in the domain.

If frequency notching is implemented by masking subcarriers, masked subcarriers shall be determined using the following rules:

- A frequency region between any two consecutive subcarriers (F_{SC}) is divided into 4 equally-spaced sections, which are further grouped into two equal regions: R1 that is around each subcarrier and R2 that is in the middle of two subcarriers, as shown in Figure A.1.
- If the notched frequency falls in the R1 region of a subcarrier, this subcarrier and two adjacent subcarriers shall be masked (i.e., total of three subcarriers, which indices are $(n - 1)$, n , and $(n + 1)$ shall be masked if the notched frequency falls in the R1 region that contains subcarrier n).
- If the notched frequency falls in the R2 region, the two nearest subcarriers on both sides shall be masked (i.e., total of four subcarriers, which indices are $(n - 1)$, n , $(n + 1)$, and $(n + 2)$ shall be masked if the notched frequency falls in the R2 region between subcarriers n and $(n + 1)$).

NOTE – Depending on the relative position of the required to be notched frequency with respect to subcarriers, the number of masked subcarriers can vary, but the notched frequency is at least $(7 \times F_{SC}/4)$ kHz away from the nearest subcarrier that is not masked.

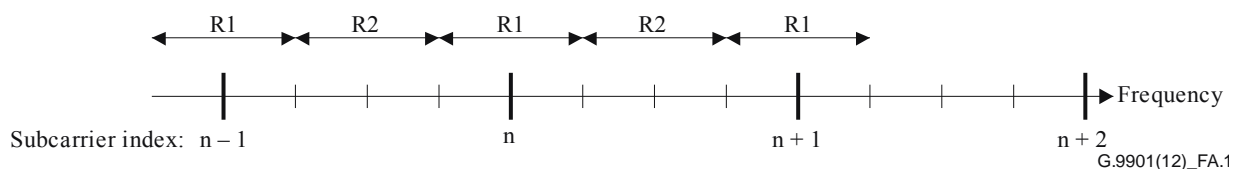


Figure A.1 – Frequency notching

A.3 Electric specification

A.3.1 Transmit signal limits

The measurement methods and apparatus used for quasi-peak, peak and average detectors shall be as defined in [IEC 60050-161].

A.3.1.1 CENELEC bandplans

For all CENELEC bandplans specified in clause A.1.1, ITU-T G.9902 transceivers shall comply with the in-band and out-of-band transmit signal limits specified in clause 6 of [EN50065-1]. These limits shall be met when loaded on the standard artificial mains network (AMN) specified in Figure 1 of [EN50065-1], connected as specified in clause 6 of [EN50065-1], for single phase and 3-phase devices.

A.3.1.2 FCC bandplans

For all FCC bandplans specified in clause A.1.2, the following limits shall be met:

- 1) The output signal voltage measured using a peak detector with a 200 Hz bandwidth in no part of the frequency band shall exceed 120 dB (μ V) when loaded on a standard termination network (TN).
- 2) The output signal voltage measured using a peak detector over the entire bandplan when loaded on a standard TN shall not exceed 134 dB(μ V) for FCC-1 and shall not exceed 137 dB (μ V) for FCC and FCC-2. Higher transmit signal limits for medium voltage (MV) lines are for further study.
- 3) The output signal voltage measured outside the spectral bandwidth of the bandplan shall not exceed:

- In the frequency range from 9 kHz to 150 kHz, the limit for the output signal voltage measured by a quasi-peak detector with resolution bandwidth 200Hz shall decrease linearly with the logarithm of frequency from 89 dB (μV) at 9 kHz to 66 dB (μV) at 150 kHz.
- In the frequency range from 150 kHz to 535 kHz, the limit for the output signal voltage measured by a quasi-peak detector with resolution bandwidth 9kHz shall decrease linearly with the logarithm of frequency from 66 dB (μV) at 150 kHz to 60 dB (μV) at 535 kHz.

The spectral bandwidth definition shall comply with Figure 1 of [EN50065-1].

A.3.1.3 Notched frequency bands

The output signal voltage measured using a quasi-peak detector with a 200 Hz bandwidth in no part of the notched frequency band shall exceed 70 dB (μV) when loaded on a standard termination network (TN).

A.3.1.4 FCC standard termination network

The standard termination network, TN, shall be used exclusively for transmit signal limit verification purposes. The TN impedance shall be formed as a 50 Ohm resistive load connected in parallel with a 50 μH inductance, FCC line impedance stabilization network (LISN).

Other types of termination networks are for further study.

Annex B

PSD specifications for G3-PLC transceivers

(This annex forms an integral part of this Recommendation.)

NOTE – This annex includes the power spectral density (PSD) specifications relating to [ITU-T G.9903].

B.1 CENELEC band specifications

When operating in the CENELEC bands (3-148.5 kHz), a node shall use the control parameters specified in Table B.1.

Table B.1 – OFDM modulator control parameters for the CENELEC bands

Number of FFT points	$N = 256$
Number of overlapped samples	$N_O = 8$
Number of cyclic prefix samples	$N_{CP} = 30$
Number of FCH symbols	$N_{FCH} = 13$
Sampling frequency	$F_s = 0.4 \text{ MHz}$
Number of symbols in preamble	$N_{pre} = 9.5$

B.1.1 CENELEC-A bandplan

When operating in the CENELEC-A bandplan, a node shall use the parameters specified in Table B.2.

Table B.2 – Parameters for CENELEC-A bandplan

	Number of subcarriers	First subcarrier (kHz)	Last subcarrier (kHz)
CENELEC-A	36	35.9375	90.625

B.1.2 CENELEC-B bandplan

When operating in the CENELEC-B bandplan, a node shall use the parameters specified in Table B.3.

Table B.3 – Parameters for CENELEC-B bandplan

	Number of subcarriers	First subcarrier (kHz)	Last subcarrier (kHz)
CENELEC-B	16	98.4375	121.875

B.2 FCC band specifications

When operating in the FCC band (9-490 kHz), a node shall use the control parameters specified in Table B.4.

Table B.4 – OFDM modulator control parameters for FCC band

Number of FFT points	$N = 256$
Number of overlapped samples	$N_O = 8$
Number of cyclic prefix samples	$N_{CP} = 30$
Number of FCH symbols	$N_{FCH} = 12$
Sampling frequency	$F_s = 1.2 \text{ MHz}$
Number of symbols in preamble	$N_{pre} = 9.5$

B.2.1 FCC bandplan

When operating in the FCC bandplan, a node shall use the parameters specified in Table B.5.

Table B.5 – Parameters for the FCC bandplan

Bandplan	Number of subcarriers	First subcarrier (kHz)	Last subcarrier (kHz)
FCC	72	154.6875	487.5

B.3 PSD mask specifications (notching)

The ITU-T G.9903 PHY is provisioned to have programmable notches in order to:

- 1) Provide flexibility in complying with regional regulations, e.g., facilitating coexistence with radio services.
- 2) Allow coexistence with other power line communication technologies operating in the same band, e.g., S-FSK systems in compliance with [IEC 61334-5-1].
- 3) Allow flexibility in separating ITU-T G.9903 domains by frequency division, e.g., by assigning non-overlapping bands to different ITU-T G.9903 domains.

The transmitter shall use an appropriate scheme to insert deep notches in the spectrum. In particular, two frequencies referred to in [IEC 61334-5-1] as mark and space frequencies f_M and f_S , shall be notched in order to cohabitate with S-FSK systems.

Depending on the relative position of the required notch frequency with respect to subcarriers, a few subcarriers are masked. No data is sent over the masked subcarriers. According to Figure B.1 below, if the notch frequency is in the R1 region, $SC(n-1)$, $SC(n)$ and $SC(n+1)$ are masked (total three subcarriers). If the notch frequency is in the R2 region the two nearest subcarriers on either side (i.e., $SC(n-1)$, $SC(n)$, $SC(n+1)$ and $SC(n+2)$) are masked (a total of four subcarriers).

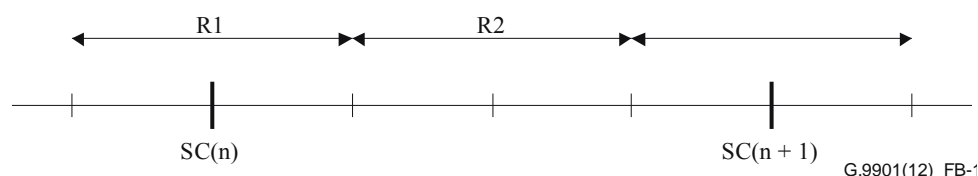


Figure B.1 – Frequency notching

A notching map should be a global parameter that is set in the initialization step of the devices. As described above, to provide sufficiently deep notches for a particular frequency band, it is required to zero one (or sometimes two) extra subcarriers before and after that band, depending on the position of the notch with respect to the subcarriers. The following pseudo code can be used for the decision between one/two extra subcarriers.

if NotchFreq / SamplingFreq \times FFTSize is in R1

$$Sc(n-1) = Sc(n) = Sc(n+1) = 0$$

if $\text{NotchFreq} / \text{SamplingFreq} \times \text{FFTSize}$ is in R2

$$Sc(n-1) = Sc(n) = Sc(n+1) = Sc(n+2) = 0$$

SamplingFreq and FFTSize are 400 kHz and 256 respectively.

Sc is an array that determines which subcarriers are used to transmit data (if $Sc(i)$ is zero, no data is sent using that subcarrier).

Frequency notching reduces the number of active tones that are used for transmitting information. Since notching is done for all the transmit signals, including FCH, the number of symbols in the FC depends on the number of active tones.

The following piece of code can determine the number of OFDM symbols that are used for transmitting the 33-bit FC:

```
fcSize = 33; // Size of FC
```

```
rxFCSymNum = ceil(((fcSize + 6) * 2 * 6) / freqNum);
```

where freqNum is the number of available subcarriers after frequency notching and *ceil* is the ceiling function.

In order to have the minimum effect on S-FSK, the OFDM modem shall not transmit any signal in between S-FSK frequencies i.e., in 63 kHz to 74 kHz band. The notched subcarriers in this mode are shown in Table B.6.

Table B.6 – Notched subcarriers in cohabitation mode

Subcarrier number	Frequency of the subcarrier
39	60.9375
40	62.5000
41	64.0625
42	65.6250
43	67.1875
44	68.7500
45	70.3125
46	71.8750
47	73.4375
48	75.0000
49	76.5625

Therefore 11 subcarriers cannot transmit data. Considering the fact that there are a total of 36 subcarriers available, 25 subcarriers remain for data transmission, resulting in an FC with 19 OFDM symbols because $\text{ceil}((33 + 6) \times 2 \times 6 / 25) = 19$.

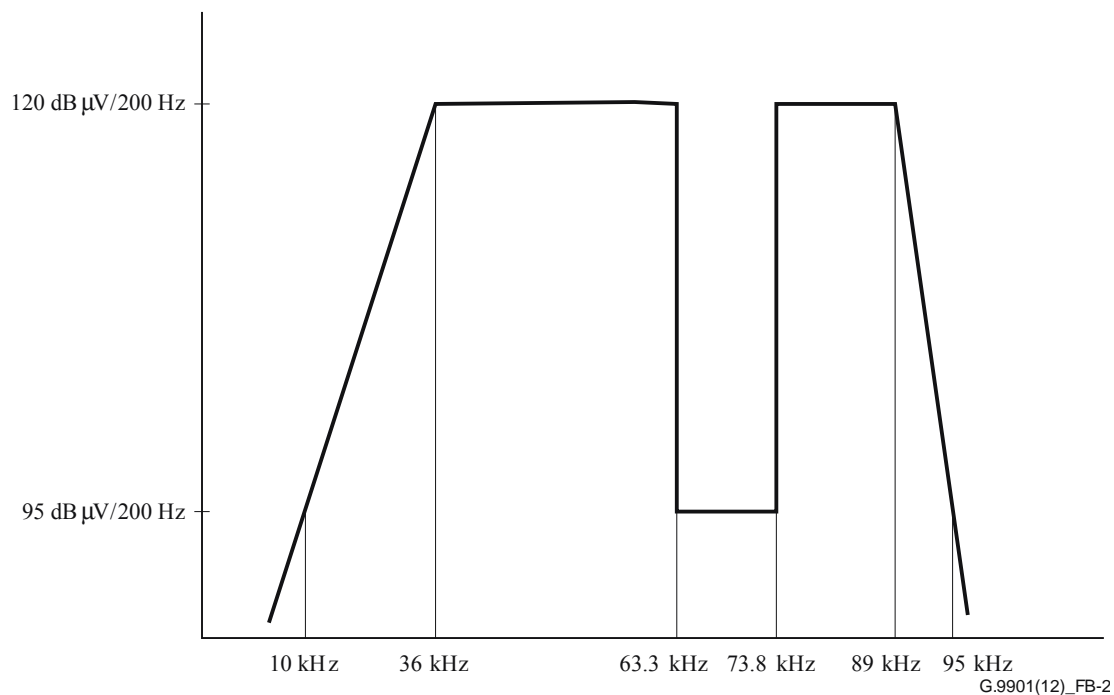


Figure B.2 – Spectrum with two notches inserted to cohabitate with S-FSK PLC modem

All stations shall use tone masking on the subcarriers specified in each substation in order to be compliant with the transmit spectrum mask. The transmitted power spectral density of a notched frequency shall be 25 dB below the limits specified for the rest of the subcarriers – see for example Figure B.2.

Measurements are made using a spectrum analyser with a resolution bandwidth of 200 Hz and a quasi-peak detector. The transmitter shall be configured to repeatedly transmit maximum length rolling data pattern packets.

B.3.1 Spurious transmission

It is the obligation of the manufacturer to ensure that spurious transmissions conform to regulations in effect for the country in which this station is used.

B.3.2 Transmitter spectral flatness

No individual carrier shall have average power outside of the range ± 2 dB with respect to the average power in all of the subcarriers as measured into a 50 Ω impedance.

Annex C

PSD specifications for PRIME transceivers

(This annex forms an integral part of this Recommendation.)

NOTE – This annex includes the power spectral density (PSD) specifications relating to [ITU-T G.9904].

C.1 Introduction

This annex specifies the power spectral density (PSD) specifications relating to [ITU-T G.9904]. [ITU-T G.9904] is an OFDM based PLC communications scheme in the CENELEC-A band as defined in the main body of this Recommendation. The PHY entity uses frequencies in the 3 kHz up to 95 kHz band and is restricted to electricity distributors and their licensees. However, it is well known that frequencies below 40 kHz show several problems in typical LV power lines. For example:

- Load impedance modulus seen by transmitters is sometimes below 1 Ω , especially for base nodes located at transformers.
- Coloured background noise, which is always present in power lines and caused by the summation of numerous noise sources with relatively low power, exponentially increases its amplitude towards lower frequencies.
- Meter rooms pose an additional problem, as consumer behaviour is known to have a deeper impact on channel properties at low frequencies, i.e., operation of all kinds of household appliances leads to significant and unpredictable time-variance of both the transfer function characteristics and the noise scenario.

Consequently, the OFDM signal will use a frequency bandwidth of 47.363 kHz located on the high frequencies of CENELEC-A band.

The OFDM signal itself will use 97 (96 data plus one pilot) equally-spaced subcarriers with a short cyclic prefix.

C.2 PHY parameters

Table C.1 lists OFDM control and timing parameters.

Table C.1 – Frequency and timing parameters of the PRIME PHY

Baseband clock (Hz)	250 000	
Subcarrier spacing (Hz)	488.28125	
Number of data subcarriers	84 (header)	96 (payload)
Number of pilot subcarriers	13 (header)	1 (payload)
FFT interval (samples)	512	
FFT interval (μ s)	2 048	
Cyclic prefix (samples)	48	
Cyclic prefix (μ s)	192	
Symbol interval (samples)	560	
Symbol interval (μ s)	2 240	
Preamble period (μ s)	2 048	

C.3 Preamble parameters

Preamble parameters are: $T = 2\,048\ \mu\text{s}$, $f_0 = 41\,992\ \text{Hz}$ (start frequency), $f_f = 88\,867\ \text{Hz}$ (final frequency) and $\mu = (f_f - f_0) / T$.

C.4 Electrical specification of the transmitter

C.4.1 General

The following requirements establish the minimum technical transmitter requirements for interoperability and adequate transmitter performance.

C.4.2 Transmit PSD

Transmitter specifications will be measured according to the following conditions and set-up.

For single-phase devices, the measurement shall be taken on either the phase or neutral connection according to Figure 4 of [EN50065-1].

For three-phase devices which transmit on all three phases simultaneously, measurements shall be taken in all three phases as per Figure 6 of [EN50065-1]. No measurement is required on the neutral conductor.

The artificial mains network in Figures 4 and 6 of [EN50065-1] is shown in Figure C.1. It is based on Figure 5 of [EN50065-1]. The $33\ \mu\text{F}$ capacitor and $1\ \Omega$ resistor have been introduced so that the network has an impedance of $2\ \Omega$ in the frequency band of interest.

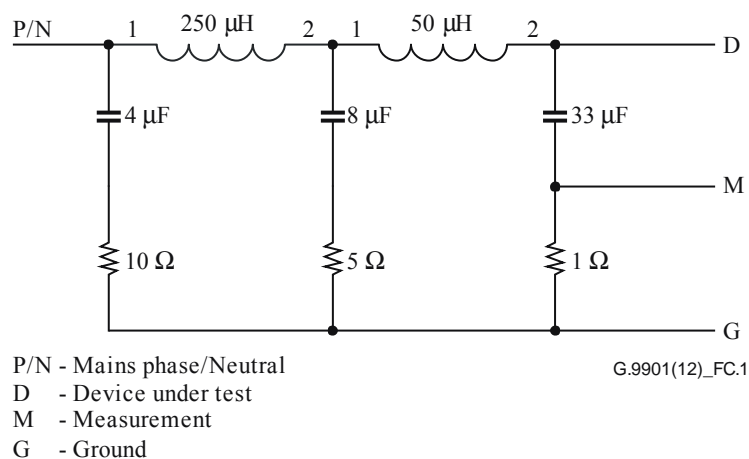


Figure C.1 – Artificial mains network

All transmitter output voltages are specified as the voltage measured at the line terminal with respect to the neutral terminal. Accordingly, values obtained from the measuring device shall be increased by 6 dB (voltage divider of ratio 1/2).

All devices will be tested to comply with PSD requirements over the full range of temperatures, which depend on the type of node:

- base nodes in the range -40°C to $+70^\circ\text{C}$
- service nodes in the range -25°C to $+55^\circ\text{C}$

All tests shall be carried out under normal traffic load conditions.

In all cases, the PSD shall be compliant with the regulations in force in the country where the system is used.

The power amplifier shall be capable of injecting a final signal level in the transmission node (S1 parameter) of $120\ \text{dB}\mu\text{Vrms}$ ($1\ \text{Vrms}$) when connected to the artificial network of Figure C.1 as

described in Figure 4 of [EN50065-1] for single-phase devices and in Figure 6 of [EN50065-1] for three-phase devices injecting into one phase at a time. For three-phase devices injecting simultaneously into all three phases, the final signal level shall be 114 dB μ Vrms (0.5 Vrms). As specified previously, the measurements taken by the measurement instrument shall be increased by 6 dB to compensate for the artificial network insertion loss.

C.4.3 Conducted disturbance limits

Regional regulations may apply. For example, in Europe, transmitters shall comply with the maximum emission levels and spurious emissions defined in the main body of this Recommendation for conducted emissions in AC mains in the bands 3 kHz to 9 kHz and 95 kHz to 30 MHz. European regulations also require that transmitters and receivers shall comply with impedance limits defined in the main body of this Recommendation in the range 3 kHz to 148.5 kHz.

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