International Telecommunication Union

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Radiocommunication Sector of ITU

Report ITU-R SM.2421-0
(06/2018)

Unwanted emissions of digital radio systems

SM Series

Spectrum management

International Telecommunication Union

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REPORT ITU-R SM.2421-0

Unwanted emissions of digital radio systems

(2018)

Scope

In this Report, measurements of the unwanted emissions of a number of equipment samples of digital radio systems are presented and compared with:

– the OoB emissions limits in Recommendation ITU-R SM.1541, regional agreements, and/or publications of Standards Development Organisations (SDOs);

– the spurious emissions limits in Recommendation ITU-R SM.329, ERC/REC 74-01, and/or publications of Standards Development Organisations (SDOs).

The boundaries of the modulation-based unwanted emissions in these measurements are compared with the limits for the boundary between the out-of-band (OoB) and spurious domains from ITU-R publications.

Abbreviations and acronyms

3GPP	3rd Generation Partnership Project
BCCH	Broadcast control channel
BS	Base station
BW	Bandwidth
CEPT	European Conference of Postal and Telecommunications Administrations
D/A	Digital to analogue
DAB	Digital audio broadcasting
DECT	Digital enhanced cordless telecommunications
DSP	Digital signal processor
DSSS	Direct-sequence spread spectrum
DVB-T	Digital video broadcasting – Terrestrial
ECC	Electronic Communications Committee
ERC	European Radiocommunications Committee
e.i.r.p.	Equivalent isotropically radiated power
e.r.p.	Effective radiated power
ETSI	European Telecommunications Standards Institute
FDD	Frequency division duplex
FS	Fixed service
FSK	Frequency shift keying
GMSK	Gaussian minimum shift keying
GSM	Global system for mobile communications
G-TEM	Gigahertz transverse electromagnetic
IEEE	Institute of Electrical and Electronics Engineers

IMT	International Mobile Telecommunications
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union - Radiocommunication Sector
I/Q	In-phase/Quadrature
LTE	Long term evolution
OFDM	Orthogonal frequency-division multiplexing
OoB	Out-of-band
PMR	Private mobile radio
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RB	Resource block
RF	Radio frequency
RLAN	Radio local area network
RMS	Root mean square
Rx	Receiver
SC-FDMA	Single carrier frequency division multiple access
SRD	Short range devices
TDD	Time division duplex
TDMA	Time division multiple access
TETRA	Terrestrial trunked radio
TFES	TC MSG / TC ERM Task Force for the production of Harmonised Standards under the R&TTE Directive for the IMT family
Tx	Transmitter
UE	User equipment
UMTS	Universal mobile telecommunications system
VHF	Very high frequency
W-CDMA	Wideband code division multiple access
WiMAX	Worldwide interoperability for microwave access
WLAN	Wireless local area network

1 Introduction

This Report addresses unwanted emissions in both the OoB and spurious domains with a focus on narrowband and broadband digital systems.

Modern transmitters of digital systems always generate the RF spectrum digitally in the so-called “baseband”. After digital to analogue (D/A) conversion, the two baseband components are directly shifted into the RF frequency range by applying In-phase/Quadrature (I/Q) modulation. As a result, no distinct peaks occur in the spurious domain. Digital transmitters in comparison to analogue ones have no spikes.

The existing generic limits set for unwanted emissions for digital radio systems were first updated or first developed about 15 years ago, and digital technologies have considerably changed since then. Several Recommendations in the SM Series (Recommendations ITU-R SM.1541, ITU-R SM.329, ITU-R SM.1539 and others) were developed in the period from around 1996 to 2004 when digital radio systems were already predominant over analogue ones. ERC/REC 74-01 is a Recommendation from the European Conference of Postal and Telecommunications (CEPT) administrations on unwanted emissions in the spurious domain regarding category B limits defined in Recommendation ITU-R SM.329.

Measurements of the unwanted emissions of a number of equipment samples of digital systems were performed using the measurement process and setups in Annex 1. The measurement results are presented in Annex 2 and summarized in §§ 2, 3 and 4.

2 Out-of-band emissions

TABLE 1 provides a summary of the comparison of the measurement results of several digital systems with the existing OoB emission limits in Rec. ITU-R SM.1541, RRC06, and relevant ETSI standards.

In the measurements of the following systems, the specific OoB emission masks defined in the relevant ETSI standards were outperformed:

– LTE800 base stations (Fig. 8)

– LTE800 UEs (Fig. 10)

– GSM900 base stations (Fig. 16)

– UMTS base station (Fig. 19)

– RLAN (Fig. 21), and

– 25 GHz Point-to-Point link (Fig. 24).

The generic "safety net" limits given in the masks of Recommendation ITU-R SM.1541 are significantly outperformed in the measurements of DVB-T transmitters (see Fig. 7) and 25 GHz point-to-point link (see Fig. 20); for the other systems in Table 1, there was no information on OoB limits in Recommendation ITU-R SM.1541.

It should be further noted that in some cases (e.g. DECT in Figure 17) the limits are only met marginally.

TABLE 1

Comparison of the measurement results of several digital systems with OoB limits

System	Figure	Comparison with:		
		Rec. ITU-R SM.1541	**RRC06**	**ETSI**
DAB+ transmitter	Figure 5	-	One can see that the critical mask is violated around 2.2 MHz offset, but it is difficult to judge the reason why the mask is violated because of the sensitivity limitation of the measurement equipment.	-
DVB-T transmitters	Figure 7	DVB-T outperforms these limits by ~20 dB or more.	Close fit.	-
LTE800 base stations	Figure 8	No information for OoB limits for this kind of application in this Recommendation.	-	**ETSI EN 301 908-14, Table 4.2.2.2.3-3:** Even if no external filters are applied, the OoB emissions beyond an offset of approximately 15 MHz (150% channel width) are already 20 dB below the limit. However, one of these signals just meets the mask at lower offsets (<10 MHz), and this may change if the measurement time were increased.
LTE800 UEs	Figure 10	No information for OoB limits for this kind of application in this Recommendation.	-	**ETSI EN 301 908-13, Table 4.2.3.1.2-1:** The tested UEs outperform the OoB emission mask to varying degrees and demonstrated asymmetric emissions, with higher suppression above 862 MHz. This suggests the presence of (internal) filtering to address co-existence issues with systems in adjacent frequency bands.
GSM900 base stations	Figure 16	No information for OoB limits for this kind of application in this Recommendation.	-	**ETSI TS 145 005**: Over the full range, the level of unwanted emissions is below the ETSI limit and particularly at 400 kHz offset outperforms the emission mask by approximately 10 dB.

TABLE 1 (*end*)

System	Figure	Comparison with:		
		Rec. ITU-R SM.1541	**RRC06**	**ETSI**
DECT	Figure 17			The OoB levels of both measured DECT devices do not fulfil the requirements from the ETSI standard [17] in the offset range around 1 MHz. As only modulation-related emissions can be seen in the OoB domain, it can be assumed that all DECT devices will have almost the same OoB spectrum in which case it seems that there is a considerable margin between the OoB emissions limit and the actual OoB emissions, especially in the range of the neighbouring channel with 2 MHz offset.
UMTS base station	Figure 19	No information for OoB limits for this kind of application in this Recommendation.	-	**ETSI TS 125 104**, Chapter 6.6.2.1, Table 6.5: The OoB emissions are at least 15 dB below the mask. The unwanted emissions due to modulation already disappear in the broadband noise from the amplifier at offsets around 125% of the channel width.
RLAN	Figure 21	No information for OoB limits for this kind of application in this Recommendation.	-	**ETSI EN 300 328**: At 250% offset, the OoB emissions are typically more than 20 dB below the limit.
25 GHz point-to-point link	Figure 24	The OoB generic FS safety net emission limits from Annex 12 of this Recommendation are met with a margin of about 20 dB.	-	**ETSI EN 302 217-2-2**, section 4.2.4.2.1: The specific limit is met with a margin of at least 10 dB.

3 Spurious emissions

Table 2 provides a summary of the comparison of the measurement results of several digital systems with the existing limits for unwanted emissions in the spurious domain in Recommendation ITU-R SM.329, ERC/REC 74-01, and relevant ETSI standards.

Except for the harmonic frequencies in Fig. 13 (LTE800 UE), the limits of Recommendation ITU-R SM.3290 and ERC/REC 74-01 in the spurious domain are typically outperformed by a significant margin of several tens of dB:

- DAB transmitter (Fig. 6)
- DVB-T transmitter (Fig. 7)
- LTE800 base station (Fig. 9)
- LTE800 UE (Fig. 11)
- LTE 2.3 GHz UE (Fig. 14)
- GSM900 Base Station (Fig. 16)
- UMTS base station (Fig. 20)
- RLAN (Fig. 22)
- WIMAX 3.6 GHz UE (Fig. 23)
- 25 GHz Point-to-Point link (Fig. 25).

The following measurements show that the unwanted emission level in the spurious domain is not constant over frequency, as assumed in Recommendation ITU-R SM.329 and the relevant ETSI standards, especially when output filters are applied:

- DAB transmitter (Fig. 6)
- LTE800 base station (Fig. 9)
- LTE800 UE (Fig. 11)
- LTE 2.3 GHz UE (Fig. 14)
- GSM900 Base Station (Fig. 16)
- UMTS base station (Fig. 20)
- 25 GHz Point-to-Point link (Fig. 24).

With increasing frequency offset, the spurious emission levels continuously decrease. Filtered transmitters generally have no measurable spurious emissions at offsets of more than about four times the signal bandwidth, and sometimes already at the 250% boundary (see for example Fig. 26). However, spurious response of filter attenuation is generally expected in the frequency ranges near the harmonics of the centre frequency.

Even unfiltered transmitters show a frequency dependency of the spurious emissions. An exception may be a peak at harmonics, see LTE800 UE in Fig. 13 showing an example of unwanted emissions of the measured UE at the second harmonic frequency, but even there the peak is 1.5 dB below the limit of ERC/REC 74-01.

TABLE 2

Comparison of the measurement results of several digital systems with limits for unwanted emissions in spurious domain

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	ERC/REC 74-01	Relevant ETSI standard
DAB/DAB+ transmitters	Figure 5 (DAB+ transmitter) and Figure 6 (DAB transmitter)	The Category A "all services except those services quoted below" are outperformed by DAB transmitters (Fig. 6).	The spurious emissions from filtered DAB/DAB+ transmitters at offsets from the centre frequency above about 10 MHz and harmonic emissions are below the measurement sensitivity and more than 57 dB below the limits from ERC/REC 74-01.	-
DVB-T transmitters	Figure 7		Due to the filtering required, the unwanted emission level even at the beginning of the spurious domain (20 MHz offset) is below the measurement sensitivity and at least 30 dB below the limit from Table 4.1 of ERC/REC 74-01.	
LTE800 base station	Figure 9	The spurious emission levels are at least 40 dB below the limits of Category B for land mobile service in Recommendation ITU-R SM.329, Table 2.1 of ERC/REC 74-01 and ETSI EN 301 908-14, due to the output filters applied.		
LTE800 UEs	Figure 11	Both UEs outperform the limits from Recommendation ITU-R SM.329 (Cat. B, land mobile service), Table 2.1 of ERC/REC 74-01 and the relevant ETSI standard EN 301 908-13 (Table 4.2.4.1.2-2) by at least 20 dB in this configuration. The actual spurious emissions are lower than shown because of the limitation of the available measurement sensitivity.		
LTE2300 UEs	Figure 14	The spurious emissions for higher frequency offsets outperform the limit by as much as 30 dB. It should be noted however that measurements in the spurious domain are limited by the dynamic range of the measurement equipment. The unwanted emissions from the devices could therefore be even lower than shown in Fig. 14.		

TABLE 2 (*end*)

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	**ERC/REC 74-01**	**Relevant ETSI standard**
GSM900 base station	Figure 16	Outside the assigned GSM band, the spurious limit for Category B, land mobile systems, base stations of Recommendation ITU-R SM.329 and ERC/REC 74-01 is outperformed by at least 30 dB.		Especially outside the assigned GSM band, the level of unwanted emissions is more than 25 dB below the ETSI TS 145 005 limit because of the internal filtering to protect adjacent services.
UMTS base station	Figure 20	Although transmitting on the highest channel and thereby presenting the most critical case for complying with spurious emission limits, the measured station outperforms these limits by approximately 10 dB even at the start of the spurious domain. For offsets higher than 20 MHz, the limits are outperformed by at least 30 dB. The actual spurious emissions for these offsets are even lower than shown. The limitation is the measurement sensitivity.		
RLAN	Figure 22	The limits are met with a margin of typically 20 to 30 dB.		
WiMax 3.6 GHz UE	Figure 23	Although the measurement covers only a small frequency range at a very high offset, it can be seen that the limits are outperformed with a margin of at least 40 dB.		
25 GHz point-to-point links	Figure 25	The spurious emission limit is met with a margin of more than 20 dB.		

4 Boundary between the OoB and spurious domains

With the exception of some public mobile systems (3GPP standards), in general, the boundary between OoB and spurious domain is defined at 250% of the signal bandwidth (necessary bandwidth Bn). For broadband systems, the Radio Regulations (Annex 1 to Appendix 3) defines a tighter boundary of 1.5*Bn. However, this formula often applies only to systems with wider bandwidth than actually used in the band. Examples are:

– between 30 MHz and 1 GHz, the boundary at 1.5 Bn applies only to Bn > 10 MHz. Typical applications such as TETRA, DAB, DVB-T, GSM, UMTS and LTE have smaller bandwidths;

– between 1 GHz and 3 GHz, the reduced boundary applies only to Bn > 50 MHz. Almost all systems in this range including GSM, UMTS, DECT, LTE and RLAN have smaller bandwidths.

As a result, for all the measured systems in this Report, the boundary is at 250% of the signal bandwidth, with exceptions in the public mobile bands where the boundary is often defined relative to the edges of the designated band. For example, in some IMT systems based on a variable channel bandwidth, the boundary is presently specified in § 2.6 of Recommendation ITU-R M.2070 for base stations as 10 MHz beyond the operating band edge.

The measurements in this Report have shown that the modulation based unwanted emissions, especially for wideband systems, often end at offsets well below 250% of the bandwidth. This is especially true for base stations of filtered systems such as DAB (see Fig. 26), DVB-T (see Fig. 7), and GSM/UMTS/LTE (see Figs 15 and 16 for GSM, Fig. 19 for UMTS, Figs 8 and 9 for LTE 800 Base stations, and Fig. 11 for LTE 800 UEs).

5 Summary

In this Report measurements are provided on a limited number of equipment samples of different radio technologies. It is observed that the measured emissions are typically lower than the limits in ITU-R Recommendations and ETSI standards by a significant margin of several tens of dBs in the spurious domain, except for the harmonic frequencies. This finding has an important implication for sharing and compatibility studies which are typically based on the assumption that equipment would only just meet the limits set out in standards.

However, this needs to be justified statistically because the measurements have been made for a limited set of conditions (both environmentally and configured parameters) and on a very limited number of equipment samples.

It is not intended to put additional restrictions or modify limits or boundaries in current ITU-R Recommendations based on the examples presented in this study.

References

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[2] ERC REC 74-01 (Siófok 98, Nice 99, Sesimbra 02, Hradec Kralove 05, Cardiff 11) 'Unwanted emissions in the spurious domain'

[3] Recommendation ITU-R SM.329 – Unwanted emissions in the spurious domain

[4] ITU Radio Regulations, Edition of 2016

[5] Recommendation ITU-R SM.1539 – Variation of the boundary between the out-of-band and spurious domains required for the application of Recommendations ITU-R SM.1541 and ITU-R SM.329

[6] ETSI EN 301 908 'IMT cellular networks; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive'

[7] ETSI EN 301 908-3 v7.1.1 'IMT cellular networks; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 3: CDMA Direct Spread (UTRA FDD) Base Stations (BS)'

[8] ETSI EN 301 908-13 V7.1.1 (2015-12) 'IMT cellular networks; Harmonised EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 13: Evolved Universal Terrestrial Radio Access (E-UTRA) User Equipment (UE)'

[9] ETSI EN 301 908-14 v7.1.1 'IMT cellular networks; Harmonised EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 14: Evolved Universal Terrestrial Radio Access (E-UTRA) Base Stations (BS)'

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[11] Geneva 06 (GE-06) Agreement: Regional Agreement Relating to the planning of the digital terrestrial broadcasting service in Region 1 (parts of Region 1 situated to the west of meridian 170°E and to the north of parallel 40 S, except the territory of Mongolia) and in the Islamic Republic of Iran, in the frequency bands 174 230 MHz and 470-862 MHz (http://www.itu.int/pub/R-ACT-RRC.14-2006/en)

[12] ETSI EN 302 077 v1.1.1 'Electromagnetic compatibility and Radio spectrum Matters (ERM); Transmitting equipment for the Terrestrial - Digital Audio Broadcasting (T-DAB) service; Part 1: Technical characteristics and test methods'

[13] ETSI EN 302 296 v1.1.1 'Electromagnetic compatibility and Radio spectrum Matters (ERM); Transmitting equipment for the digital television broadcast service, Terrestrial (DVB-T)'

[14] LTE User Equipment – Coexistence with 862-870 MHz, Ofcom, September 2012: http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/statement/lte-coexistence.pdf

[15] Recommendation ITU-R M.2071 – Generic unwanted emission characteristics of mobile stations using the terrestrial radio interfaces of IMT-Advanced

[16] ETSI TS 145 005 v13.0.0 (2016-01) 'Digital cellular telecommunications system (Phase 2+); Radio transmission and reception (3GPP TS 45.005 version 13.0.0 Release 13'

[17] ETSI EN 300 175-2 v2.6.1 (2015-07) 'Digital Enhanced Cordless Telecommunications (DECT). Common Interface (CI); Part 2: Physical Layer (PHL)'

[18] ETSI TS 125 104 'Universal Mobile Telecommunications System (UMTS); Base Station (BS) radio transmission and reception (FDD)'

[19] ETSI EN 300 328 v1.9.1 'Electromagnetic compatibility and Radio spectrum Matters (ERM); Wideband transmission systems; Data transmission equipment operating in the 2.4 GHz ISM band and using wide band modulation techniques; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive'

[20] ETSI EN 302 217-2-2 v2.0.0 'Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas'

[21] ETSI EN 301 390 v1.3.1 'Fixed Radio Systems; Point-to-point and Multipoint Systems; Unwanted emissions in the spurious domain and receiver immunity limits at equipment/antenna port of Digital Fixed Radio Systems'

[22] ECC Recommendation (02)05 'Unwanted emissions'

[23] ETSI EN 301 406 v1.5.1 'Digital Enhanced Cordless Telecommunications (DECT); Harmonized EN for Digital Enhanced Cordless Telecommunications (DECT) covering the essential requirements under article 3.2 of the R&TTE Directive; Generic radio'

[24] Liaison Statement from ECC PT1 to ETSI ERM RM and ERM/MSG TFES on "IMT 2000/UTRA Category B spurious emission limits", Doc ECC PT1(06)184 Annex 12

[25] ETSI Technical Specification TS 136 521 'LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) conformance specification; Radio transmission and reception'

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[27] ECC Report 174 'Compatibility between the mobile service in the band 2500-2690 MHz and the radiodetermination service in the band 2700-2900 MHz'

[28] IEEE 802.11-2012: IEEE Standard for Information technology – Telecommunications and information exchange between systems Local and metropolitan area networks – Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

[29] ETSI EN 301 908-21 v5.2.1 'IMT cellular networks; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 21: OFDMA TDD WMAN (Mobile WiMAX) FDD User Equipment (UE) '

[30] Recommendation ITU-R M.1580 – Generic unwanted emission characteristics of base stations using the terrestrial radio interfaces of IMT-2000

[31] Recommendation ITU-R M.1581 – Generic unwanted emission characteristics of mobile stations using the terrestrial radio interfaces of IMT-2000

[32] Recommendation ITU-R M.2070 – Generic unwanted emission characteristics of base stations using the terrestrial radio interfaces of IMT-Advanced

[33] Recommendation ITU-R SM.1540 – Unwanted emissions in the out-of-band domain falling into adjacent allocated bands

[34] Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014

[35] 3GPP TS 36.211: V13.1.0 'Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation'

[36] ETSI EN 302 408 V8.0.1 'Digital cellular telecommunications system (Phase 2+); GSM Cordless Telephony System (CTS), Phase 1; CTS-FP Radio subsystem'

[37] ETSI EN 301 502 V12.1.1 'Global System for Mobile communications (GSM); Harmonized EN for Base Station Equipment covering the essential requirements of article 3.2 of the R&TTE Directive'

[38] Recommendation ITU-R SM.328 – Spectra and bandwidth of emissions

Annex 1

Measurement process and setup

Table of content

This Annex shows typical setups for the measurement of OoB and spurious emissions. Which setup is to be used depends on the required dynamic range of the result and on whether the emission is pulsed or continuous.

For conducted measurements of transmitters not requiring a return path, the signal is derived directly from the transmitter output, after suitable attenuation (dummy load) or from a measurement output (if provided). In case external output filtering is applied, the measurement point is after the filter.

For conducted measurements of transmitters requiring a return path to operate and not having a measurement output, the signal is taken from the output of a directional coupler that is inserted into the transmit path. A major disadvantage of this method is that the signal to be measured is attenuated by the directional coupler (typically 20 dB) which limits the detection level of unwanted emissions especially for devices with very low power. Some systems allow access to the transmit line before the Rx/Tx splitter which is then the preferred measurement point.

Those transmitters that do not have an antenna port have to be measured radiated, preferably in a G-TEM cell with known RF properties.

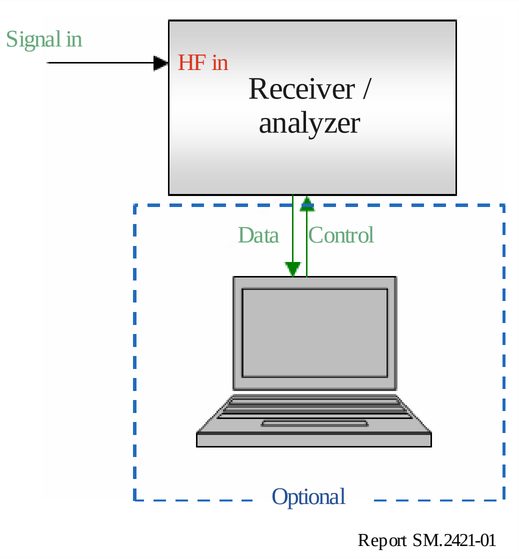
For radiated measurements of bigger transmitters, the signal is taken from a measurement antenna. In this case the most critical issue is to gather as much RF energy as possible, and that the frequency range of interest is free of emissions from other transmitters. Both issues can be addressed by using an antenna with high directivity (and therefore high gain) pointing directly into the transmit antenna at the shortest distance possible.

1 Setup Type 1

If the required dynamic range is not higher than the difference between the maximum level that the measurement receiver can handle without being overloaded and its own noise level, the simplest setup can be used for continuous signals:

FIGURE 1

Principle measurement setup Type 1



2 Setup Type 2

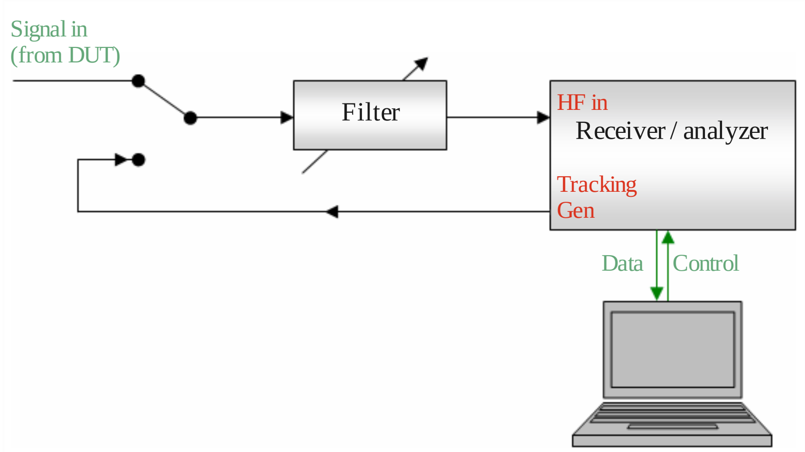
This setup can be used for continuous signals when the required dynamic range of the result exceeds the capabilities of the measurement receiver/analyser.

To enhance the dynamic range of the measurement receiver/analyser, the wanted signal has to be suppressed by a (tuneable) filter. First, the filtered spectrum on the wanted channel/frequency as well as in the OoB or spurious domain is measured and recorded. In a second measurement, using the same receiver/analyser settings, the attenuation (frequency response) of the filter is measured and recorded. Then, using a software tool (e.g. Microsoft Excel), both curves are added to retain the original spectrum of the signal. The measurement is most efficient if controlled by a computer.

Depending on the application, frequency and bandwidth of the signal under test, a band pass filter or a band stop filter may be used. For spurious emissions, a band stop filter tuned to the wanted frequency is preferred as it allows measuring the whole spurious range at once. For OoB measurements, band pass filters tuned to the frequency range of the OoB domain to be measured, could also be used.

FIGURE 2

Principle measurement setup Type 2



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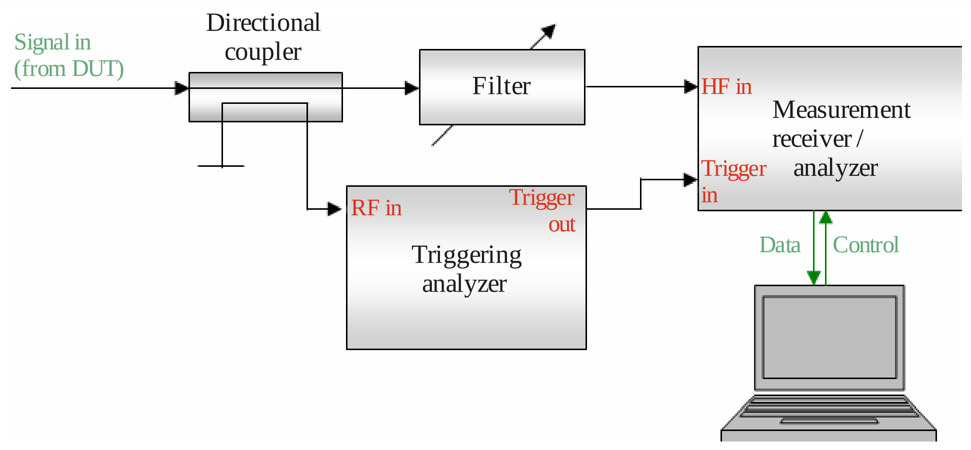
3 Setup Type 3

For TDMA systems that transmit in bursts, the limits usually apply to the times where the transmitter is on. Unless the peak level is specifically mentioned in the relevant Recommendation, the average burst level has to be measured which is the RMS level during the burst only. This is done by externally triggering the measurement receiver to the burst start and adjusting the measurement time to match the burst length. The trigger is derived from a second spectrum analyser, operated in zero span mode and tuned to the wanted frequency.

The measurement process is identical to the setup Type 2.

FIGURE 3

Setup Type 3 for measurements of TDMA systems



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Data processing

The measurement bandwidth is always chosen to be equal to, or smaller than, the reference bandwidth stated in the relevant recommendation or standard. Especially in the vicinity of peak spurious emissions and in the OoB domain close to the wanted frequency, it is necessary to use a narrow measurement bandwidth because otherwise the measured spectrum would be unduly widened, leading to an overestimation of the unwanted level.

The signal levels (or spectral densities) taken in the selected measurement bandwidth are linearly converted to the corresponding levels or power densities in the reference bandwidths using the formula:

$$P_{refBW} = P_{measBW} + 10 * \log_{10}\left(\frac{refBW}{measBW}\right)$$

with

P_{refBW} : signal level in reference bandwidth

P_{measBW} : signal level in measurement bandwidth

$refBW$: reference bandwidth

$measBW$: measurement bandwidth.

4 Peak and average cases of spectrum masks

With fixed limits for unwanted emissions that are not to be exceeded at any time, it would be necessary to measure the emissions with a peak detector. The 0 dB reference for OoB spectrum masks, however, is in most cases the total in-channel power or a pfd in a given reference bandwidth, both of which are RMS values.

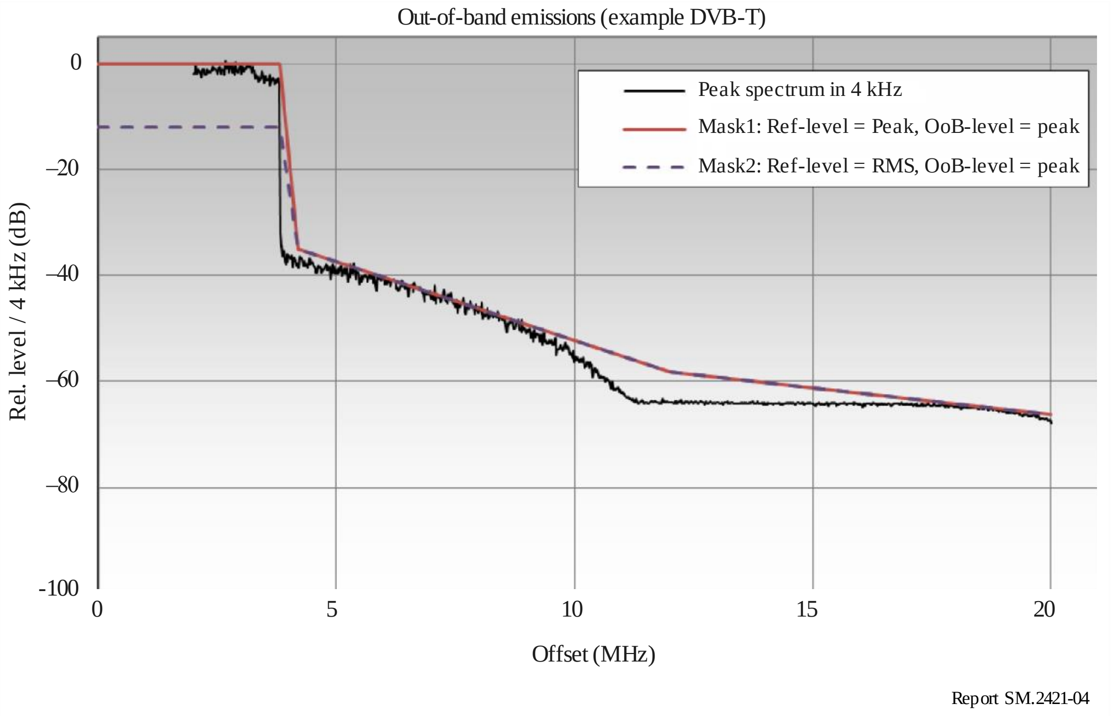
Whereas for analogue victim receivers the interference potential of an unwanted emission is mainly dependant on its peak level, it is the RMS level that determines the interference potential to a digital receiver. This has been proven by various measurements for compatibility studies.

In digital systems, nearly all of the unwanted emissions as well as the wanted emission are noise-like, which means that there is usually a fixed difference between RMS and peak level of about 13 dB. For these systems it would be possible to define either RMS or peak limits because the corresponding other level could be calculated. Exceptions include spikes due to harmonics or mixing products.

It may, however, be useful to consider systems on a case-by-case basis and to define both OoB/spurious levels and the 0 dB reference level on the same basis (either both in RMS or both in peak) and adapted to the specific case because this would enable direct comparison of a measured spectrum against a mask. Figure 4 shows an example (DVB-T OoB emissions) where the OoB limits of the mask are always defined in peak levels. Mask 1 is the peak spectral density in 4 kHz reference bandwidth. This mask can directly be compared with the measured OoB spectrum. For Mask 2, however, the 0 dB reference level is the RMS spectral power in 4 kHz. In this case there is a difference of approximately 13 dB between measured in-channel spectral density and the 0 dB reference of the Mask.

FIGURE 4

Different mask definitions – an example (DVB-T OoB emissions)



In many cases, the reference level for a spectrum mask is the power of the unmodulated carrier. In digital systems, the carrier is never unmodulated and can therefore not be measured directly. Instead, the total in-channel power of the modulated signal can be measured RMS as this is equal to the power of an unmodulated carrier. However, the reference bandwidth for this measurement has to be the occupied bandwidth of the signal which may be different from the reference bandwidth for the unwanted emissions. In these cases, a spectrum mask compared with a measured spectrum has no in-channel reference line. In the example in Fig. 4, the horizontal line between 0 MHz and 4 MHz offset would be missing, and the 0 dB reference level would be shifted by the difference resulting from the bandwidth correction (in case of DVB-T: $10*\log_{10}(8 \text{ MHz}/4 \text{ kHz})=23$ dB).

Annex 2

Measurements of the unwanted emissions of common digital systems

Table of content

1 General remarks

This section shows the results of measurements of unwanted emissions (both OoB and spurious domain) from several common digital systems. The measurements are based on a limited number of equipment samples which may not necessarily be representative of the wider population of equipment.

For immediate comparison, the relevant limits are also included in the figures with the measurements. Where limits are defined as absolute power levels, they are recalculated into relative values using the same reference power level on the transmitted carrier as for the measured spectra. Where limits are defined as power spectral density in bandwidths other than the measurement bandwidth, the measured spectra are converted to the reference bandwidth using a sliding integration window. For easier comparison with the measured spectrum, the OoB limit lines are drawn from 0 MHz offset from the centre frequency as a reference line indicating the relative in-band power spectral density.

Each figure includes the reference OoB limit (e.g. spectrum mask) taken from the relevant standard. When available, also the "safety-net" limit in Recommendation ITU-R SM.1541 for the service concerned is included as a comparison with the more stringent actual standardised limit.

It should be noted that the measurement sensitivity may be different in the different plots but is not always exactly known. Therefore, the spectra sometimes seem to end in a (nearly) horizontal gradient which is in fact the noise floor of the measurement receiver and not unwanted emissions coming from the transmitter. This is especially true for transmitters having a filter at the output which limits the unwanted emissions in order to meet certain system requirements (e.g. protecting the corresponding receive band). Such systems almost never have any measurable emissions for larger offsets in the spurious domain. Please note that in some figures the notation "receiver noise" should be read as "spectrum analyser noise floor".

For explanations on when peak and average cases of spectrum masks are to be used, see Annex 1 § 4.

2 DAB / DAB+

This OFDM system is one of the possible digital successors of the analogue sound broadcasting system. The relevant RF parameters are equal for DAB and DAB+ systems[1]:

– Modulation: OFDM with 1 736 active carriers
– Transmitter bandwidth: 1.536 MHz
– Transmitter power: 780 W = 28.9 dBW (Tx output), 10 kW (e.r.p.)
– Tx output filter: yes
– OoB domain ends at: 3.84 MHz (250% of necessary bandwidth).

2.1 Out-of-band emissions

In Fig. 5, measurements of a DAB+ transmitter are shown with the relevant limits.

One of the masks defined in the GE-06 Special Agreement (Fig. 3-2 and the associated Table 3-10 thereof) gives the limit for the out-of-band radiated signal spectrum in any 4 kHz band. The centre frequency of the transmitter was 174.928 MHz, which is the lowest block in the VHF band. Therefore, the most critical mask was used as a reference for the measurements of the lower sideband.

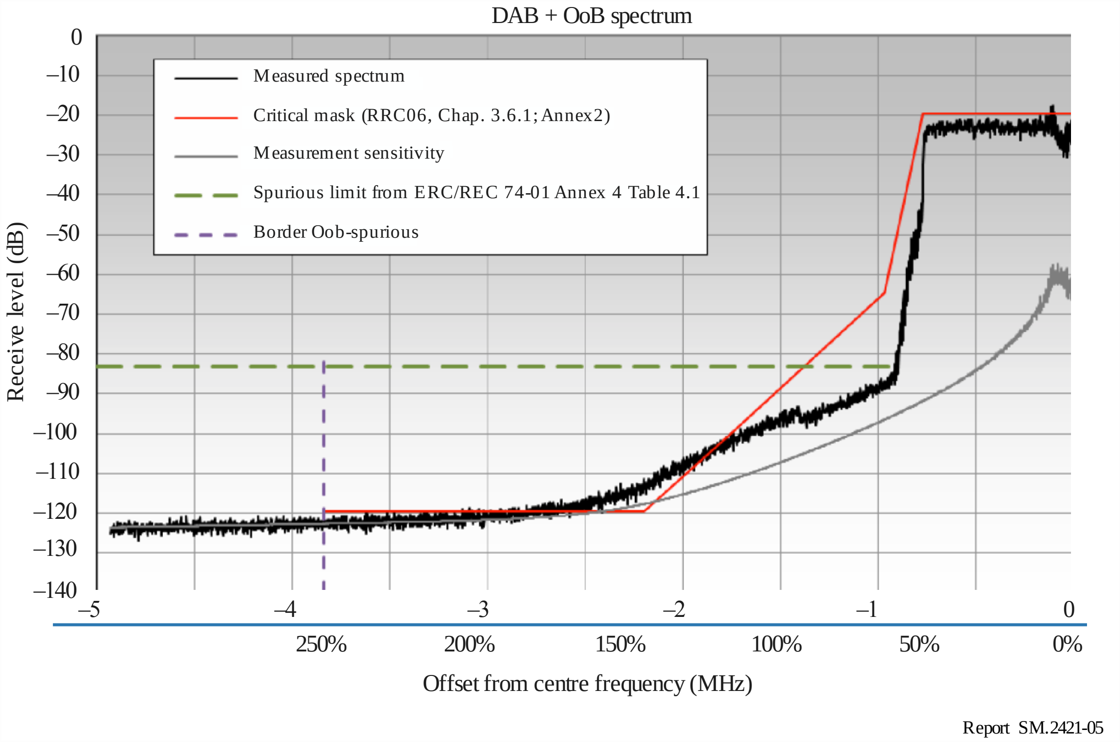
The measurements were made at the antenna port of the transmitter with a resolution bandwidth of 3 kHz. The spectrum mask from GE-06 has an original reference bandwidth of 4 kHz. It was converted into a spectrum mask in 3 kHz; the resulting spectrum mask is shown in Fig. 5.

For information, the relevant limit for spurious emissions from ERC/REC 74-01 is also shown in Fig. 5.

[1] Since the difference between DAB and DAB+ lies only in the digital coding; the same transmitters are used for both standards resulting in the same typical unwanted emissions.

FIGURE 5

OoB measurements from a DAB+ transmitter



Because the measured levels of spectral emissions at offsets greater than 2.5 MHz are very close to the sensitivity level of the measurement equipment, it can only be said that the actual levels of OoB emissions greater than this offset are lower than the critical mask (most stringent) from the GE-06 Special Agreement. However, due to the limited dynamic range of the measurements, it was not possible to determine by how much the emissions from the transmitter were below the critical mask. The actual sensitivity of the system used in the measurement was between −115 and −120 dBm at the frequency offset of 2.2 MHz.

Observation from Fig. 5:

– One can see that the critical mask is violated around 2.2 MHz offset, but it is difficult to judge the reason why the mask is violated because of the sensitivity limitation of the measurement equipment.

System	**Figure**	**Comparison with:**	
		Rec. ITU-R SM.1541	**RRC06**
DAB+ transmitter	Figure 5		One can see that the critical mask is violated around 2.2 MHz offset, but it is difficult to judge the reason why the mask is violated because of the sensitivity limitation of the measurement equipment.

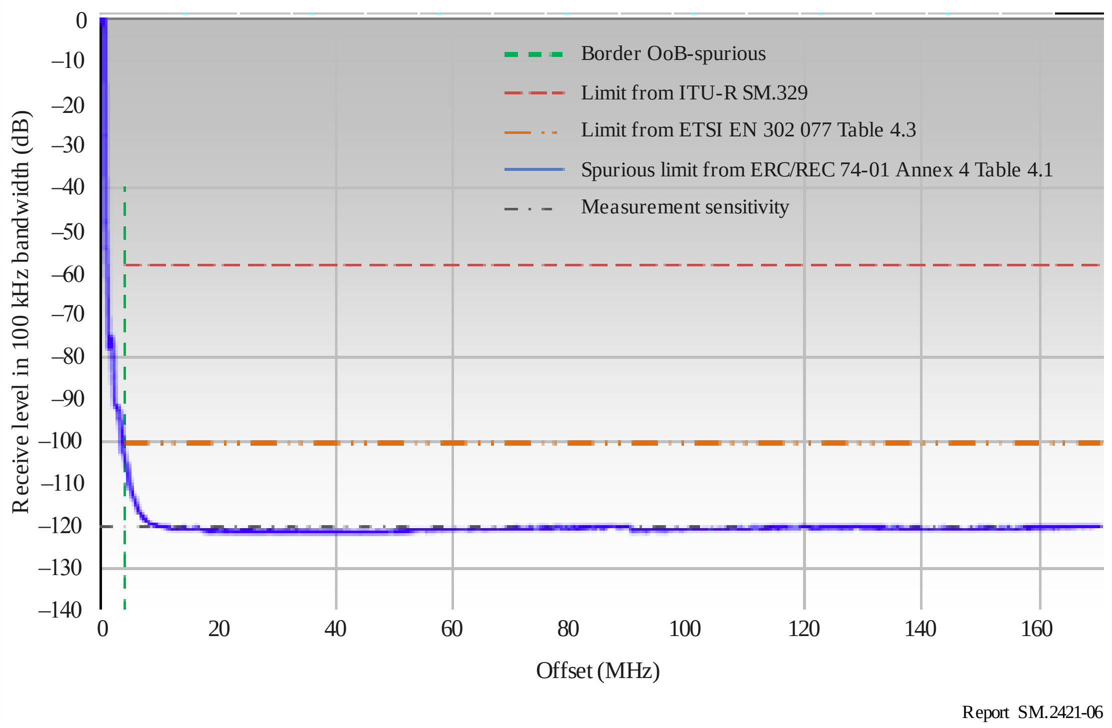
2.2 Spurious emissions

As mentioned above, DAB/DAB+ transmitters always have output filters to limit unwanted emissions. Measurements on several DAB transmitters in Germany have shown that unwanted emissions in the spurious domain for high frequency offsets from the centre frequency as well as harmonic emissions above the noise floor of the measurement system could not be detected.

Figure 6 shows measurements of the spurious emissions from a DAB transmitter (in dark blue) and the relevant regulatory limits.

FIGURE 6

Spurious emissions from a DAB transmitter (shown in blue line)



Comparison of the measurements in with regulatory limits:

– Recommendation ITU-R SM.329 does not contain specific spurious emission limits for DAB in Category B (Europe). Therefore, the limit for Category A "all services except those services quoted below" is used.

– The measurement was performed at the antenna port of a DAB transmitter with 780 W output power (10 kW e.r.p.). The spurious emission limit from Category A "all services except those services quoted below" of Recommendation ITU-R SM.329 in 100 kHz is 70 dBc. Since Fig. 6 is normalised to the in-band spectral level in 100 kHz bandwidth, this limit was converted to a relative attenuation of 70 dBc − 10*log10(1 536/100) = 58.2 dBc. ERC/REC 74-01, Annex 4, Table 4.1 specifies a limit of 75 dBc for transmitters between 8 and 800 W output power, with a reference bandwidth of 100 kHz. This leads to an in-channel power spectral density in 100 kHz; the limit would be at 75 dBc − 10*log10(1 536/100) = 63.2 dBc.

– ETSI EN 302 077-1 Table 4.3 [12] defines a relative limit of 126 dBc in a 4 kHz reference bandwidth for a mean transmitter output power between 25 and 1000 W. Because Fig. 6 is normalized to the in-band spectral level in 100 kHz bandwidth, this limit converts to a relative attenuation of 126 dBc − 10*log10(1 536/4) = 100.2 dBc.

Observations from Figs 5 and 6:

– The relative suppression of spurious emissions with respect to the carrier power near the OoB boundary is approximately 100 dB (see also Fig. 5 for offsets below −3.84 MHz);

– The spurious emissions from filtered DAB/DAB+ transmitters at offsets from the centre frequency above about 10 MHz and harmonic emissions are below the measurement sensitivity and more than 57 dB below the limits from ERC/REC 74-01;
– The OoB mask reaches the spurious emission limit from ERC/REC 74-01 at offsets of around 1.4 MHz or 90% of the signal bandwidth (see Fig. 5).

System	**Figure**	**Comparison with:**	
		Rec. ITU-R SM.329	**ERC/Rec 74-01**
DAB/DAB+ transmitters	Figure 5 (DAB+ transmitter) and Figure 6 (DAB transmitter)	The Category A "all services except those services quoted below" are outperformed by DAB transmitters (Fig. 6).	The spurious emissions from filtered DAB/DAB+ transmitters at offsets from the centre frequency above about 10 MHz and harmonic emissions are below the measurement sensitivity and more than 57 dB below the limits from ERC/REC 74-01.

3 DVB-T

This is the digital terrestrial television system used in Europe. In order to protect adjacent channels and/or radiocommunication services, the OoB limits from Recommendation ITU-R SM.1541 were regarded as insufficient. Therefore, more stringent limits were defined in the GE-06 agreement. To meet these requirements, DVB-T transmitters always have to be fitted with band-limiting filters after the final amplification stage.

The parameters of the measured DVB-T system are:

Modulation:	8k OFDM with 6 817 active carriers
Bandwidth:	7.61 MHz
Transmitter power:	1 kW (Tx output), 10 kW e.r.p.
Tx output filter:	yes
OoB domain ends at:	20 MHz (see Recommendation ITU-R SM.1541 Annex 6, § 2.2.1).

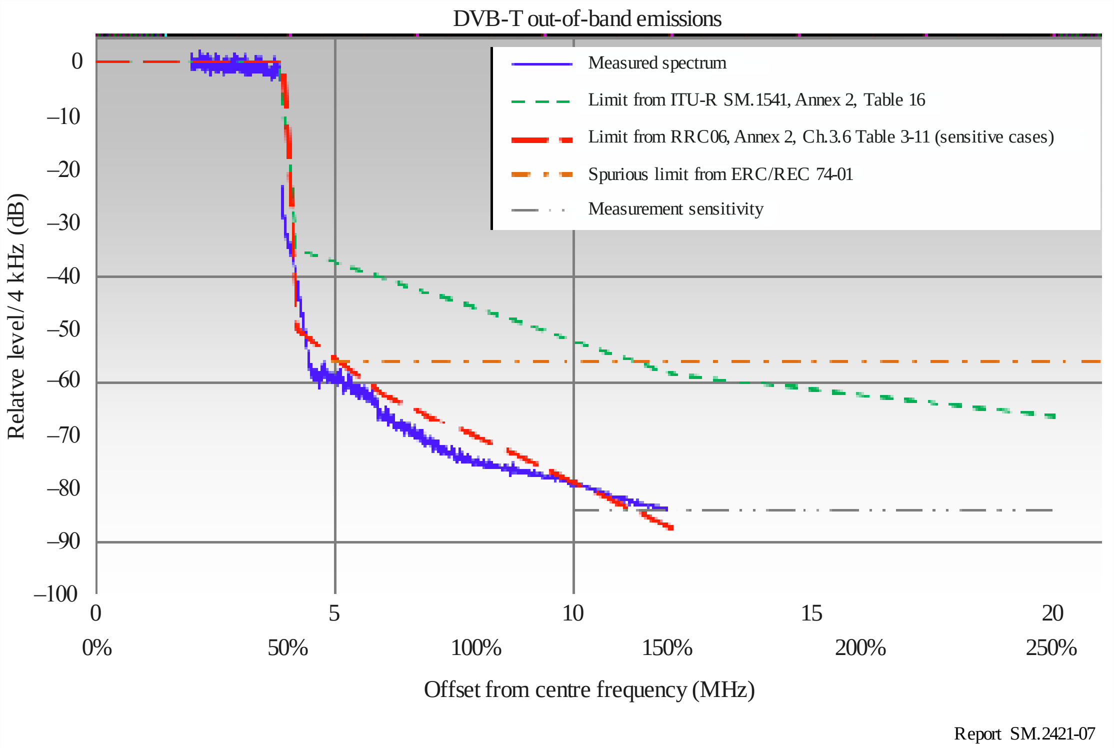
For additional explanations, see also Annex 1, § 4.

3.1 Out-of-band emissions

The measurements were made at the antenna feed with a measurement bandwidth of 7.5 kHz and are presented in Fig. 7 with a reference bandwidth of 4 kHz. The measured levels are normalised to the in-band power spectral density in a 4 kHz bandwidth. Recommendation ITU-R SM.1541 specifies relative limits for the whole OoB range. To protect radiocommunication services in adjacent bands, the output filter of the measured transmitter was designed to meet the most stringent mask of GE-06, Chapter 3.6, Table 3-11 for sensitive cases. It should be noted that in most cases the non-critical RRC06 spectrum mask is applied.

FIGURE 7

OoB measurements of DVB-T transmitters



Observation from Fig. 7:

– The OoB emissions could only be measured down to the level of the breakpoint of the mask from GE-06 at 12 MHz. OoB emissions for higher frequency offsets are below this most stringent mask but could not be quantified due to the limited measurement sensitivity.

System	Figure	Comparison with:	
		Rec. ITU-R SM.1541	RRC06
DVB-T transmitters	Figure 7	DVB-T outperforms these limits by ~20 dB or more.	Close fit

3.2 Spurious emissions

Comparison with regulatory limits:

– The GE-06 agreement does not contain any spurious emission limits.

– Since Recommendation ITU-R SM.329 does not contain specific values for DVB-T, the general Category A limits for 'broadcast television' transmitters may be taken. A limit of 46 dB + 10*$\log_{10}$(P/W) or 60 dBc is specified, whichever is less stringent, but without exceeding 12 mW (10.8 dBm). For transmitters with more than 50 W output power, the attenuation of 60 dBc in 100 kHz bandwidth is relevant; for transmitters above 12 kW, the required attenuation is 19 dB + 10*$\log_{10}$(P/W).

– ERC/REC 74-01 Table 4.1 specifies a spurious limit of –16 dBm in 100 kHz bandwidth for a transmitter with 1 kW mean output power at the antenna port.

With the output power of 59 dBm in 8 MHz bandwidth, this limit leads to a relative attenuation of 59 dBm −10*$\log_{10}$(8 000/100) − (−16 dBm) = 56 dB. This limit is shown in Fig. 7.

– The relevant ETSI standard, EN 302 296 [13], specifies spurious limits that are more stringent than the ones from Recommendation ITU-R SM.329. As an example, for transmitter output powers of more than 1 kW, the limit in this ETSI standard is −36 dBm in 100 kHz bandwidth (400-790 MHz and 862-1 000 MHz), resulting in a relative attenuation of more than 96 dBc.

As mentioned above, DVB-T transmitters always have output filters to meet the requirements of the GE-06 agreement. The most critical point is the offset of 12 MHz where the lowest OoB level has to be reached. At the boundary between the OoB and spurious domains at 20 MHz, the output filter further reduces unwanted emissions well below any limit. As a consequence, no spurious emissions or harmonics can be expected that are above the measurement sensitivity. Measurements in Germany by BNetzA have shown that the spectral density of DVB-T unwanted emissions in the spurious domain are attenuated by more than 100 dB, relative to the in-band reference power spectral density in the same bandwidth.

Observations from Fig. 7:

– Due to the filtering required, the unwanted emission level even at the beginning of the spurious domain (20 MHz offset) is below the measurement sensitivity and at least 30 dB below the limit from Table 4.1 of ERC/REC 74-01.

  The OoB mask from GE-06 reaches the spurious emission limit of Table 4.1 of ERC/REC 74-01 already at frequency offsets of 5 MHz or 62% of the signal bandwidth.

System	**Figure**	**Comparison with:**	
		Rec. ITU-R SM.329	**ERC/Rec 74-01**
DVB-T transmitters	Figure 7		Due to the filtering required, the unwanted emission level even at the beginning of the spurious domain (20 MHz offset) is below the measurement sensitivity and at least 30 dB below the limit from Table 4.1 of ERC/REC 74-01

4 LTE800 Base stations

The 4th generation of the mobile communication standard (LTE) is currently being introduced by many network providers. 3GPP TS 36.211 allows many RF parameters to be flexible, including the RF bandwidth. Measurements were performed on several LTE800 base stations from different manufacturers. The key RF parameters of the measured base stations are:

Frequency range: 796 MHz for Tx1 and Tx2, 816 MHz for Tx3

Modulation: OFDM

Bandwidth: 10 MHz

Transmitter power: 46 dBm (40 W) Tx output, 60.5 dBm (1122 W) e.i.r.p.

Tx output filter: None for transmitter 1 and 3; transmitter 2 has an additional external filter in order to comply with DVB-T protection requirements (in practice the lower side band of Tx2 was measured, and the result was mirrored at the centre frequency to the upper sideband to allow direct comparison with the result from Tx1 and Tx3 in one graph)

OoB domain ends at: for Tx1 at 35 MHz, for Tx2 and Tx3 at 15 MHz offset from the centre frequency.

Although no external output filters were applied for Tx1 and Tx3, they have internal filters to limit the spurious emissions outside the allocated downlink band in order to protect their own receivers in the uplink band (832 to 862 MHz).

The measurements are based on a limited number of equipment samples, and worst case performance may considerably deviate from the results shown due to the inherent dynamic nature of the 3GPP LTE systems. Also, the specific resource block configuration during the measurements was not always known.

4.1 Out-of-band emissions

The system transmits in bursts of different length and bandwidth, depending on base station configuration and traffic. The measurements were done while the base stations were in a test mode using all available resource blocks and thereby stimulating the maximum sideband emissions. Measurement bandwidths were between 30 and 100 kHz. The transmitter output power of all three LTE base stations was 40 W = 16 dBW = 46 dBm. The radiated power was 60.5 dBm.

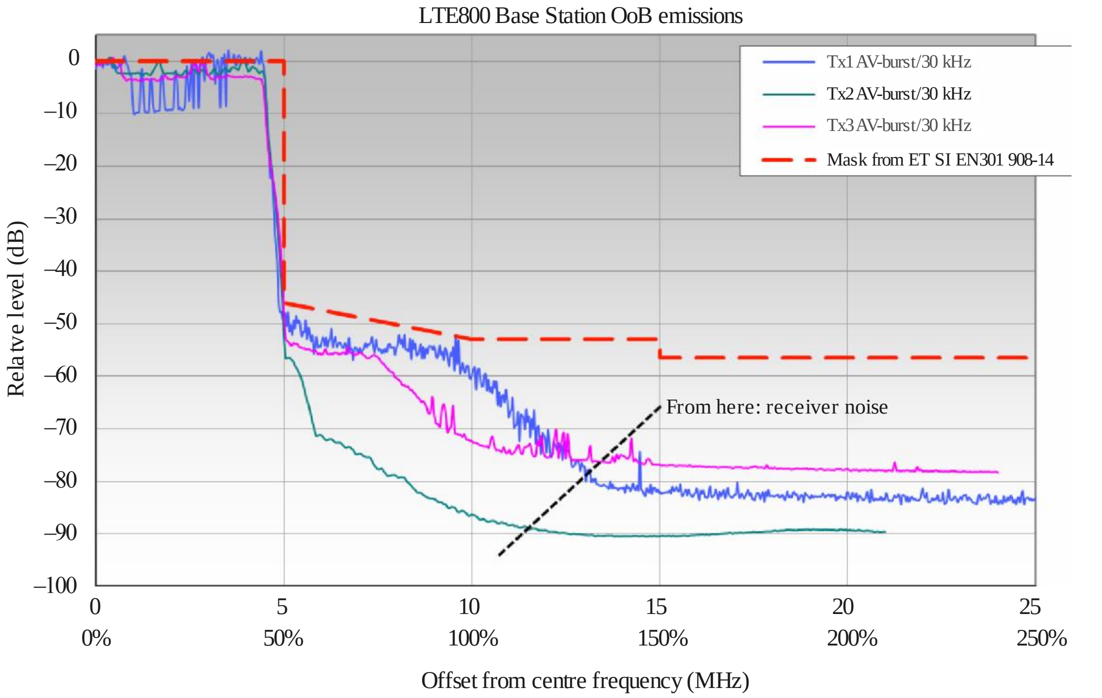
Since Recommendation ITU-R SM.1541 does not contain any information for OoB limits for this kind of application, the masks from ETSI EN 301 908-14, Table 4.2.2.2.3-3 are shown for comparison in Fig. 8.

The levels of both measured values and limits were converted into a bandwidth of 30 kHz and normalised.

Values to the right of the black dashed line in Fig. 8 show technical limitations due to the receiver noise.

FIGURE 8

OoB emissions from LTE800 base stations



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Observation from Figure 8:

– Even if no external filters are applied (see Tx1 and Tx3), the OoB emissions beyond an offset of approximately 15 MHz (150% channel width) are already suppressed by 80 dB, or 20 dB below the limit (see also Fig. 27, upper sideband).

– However, it is noted that Tx1 only just meets the mask at lower offsets (<10 MHz), and this may change if the measurement time were increased.

System	Figure	Comparison with:	
		Rec. ITU-R SM.1541	**ETSI EN 301 908-14, Table 4.2.2.2.3-3**
LTE800 base stations	Figure 8	No information for OoB limits for this kind of application in this Rec.	Even if no external filters are applied, the OoB emissions beyond an offset of approximately 15 MHz (150% channel width) are already 20 dB below the limit. However, one of these signals just meets the mask at lower offsets (<10 MHz), and this may change if the measurement time were increased.

4.2 Spurious emissions

Comparison with regulatory limits:

– Since Recommendation ITU-R SM.329 (Cat. B) does not contain specific values for Broadband Wireless Access systems below 1 GHz, the general Category B limit for land mobile service of −36 dBm in 100 kHz bandwidth was taken for comparison in Fig. 9.

– The relevant ETSI standard EN 301 908-14 section 4.2.4.2.1 and Table 2.1 of ERC/REC 74-01 also specify a spurious limit of -36 dBm in 100 kHz bandwidth, measured conducted at the transmitter output. This limit has to be referenced to a total in-band power of 40 W = 46 dBm in 10 MHz, which corresponds to an in-band power spectral density of 46 dBm − $10\log_{10}(10\,000/100)$ = 26 dBm in 100 kHz bandwidth. The resulting relative attenuation of spurious emissions is then 26 dBm − (−36 dBm) = 62 dB.

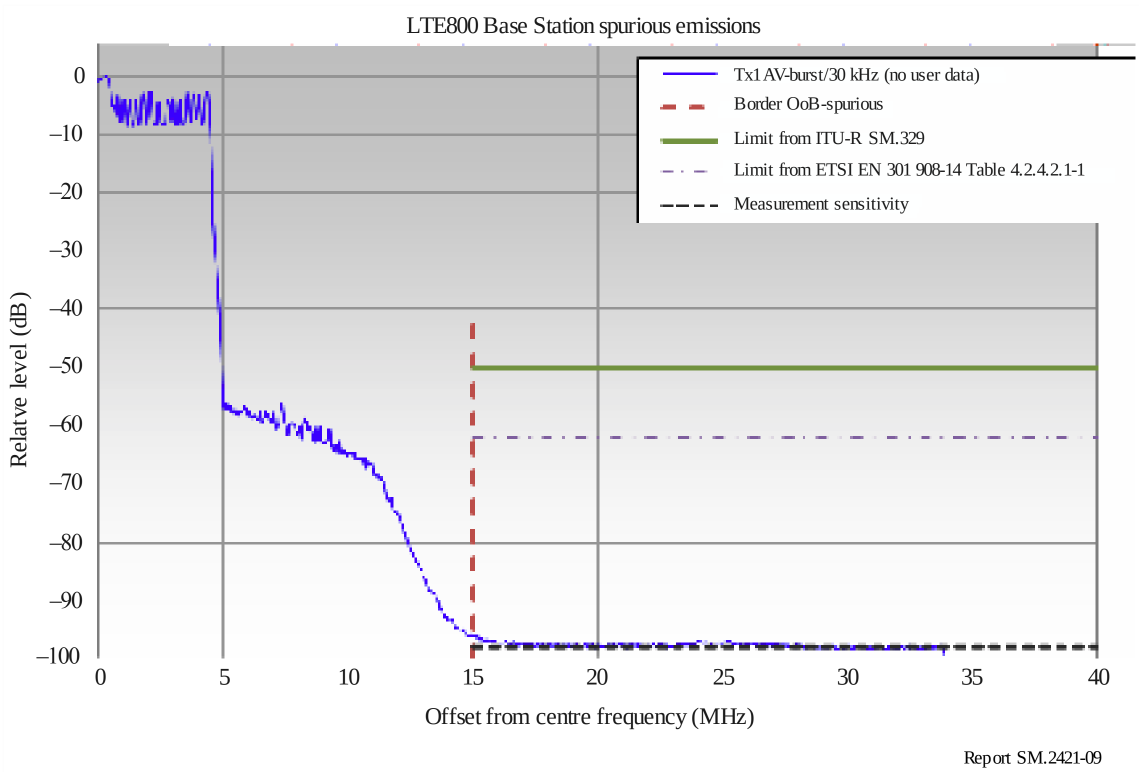
As seen in the OoB measurements, the level of emissions in Fig. 8 is already below the sensitivity of the measurement system at the boundary of the spurious domain. Because all LTE base stations have at least internal filters to protect their own receive bands, no spurious emissions could be detected at any further frequency offsets.

Figure 9 below shows conducted measurements at the transmitter output of an LTE base station, operating at 796 MHz. The base station has been configured to transmit with maximum power, although not all resource blocks have been allocated to the user data. The operational mode when the base station transmits at maximum power and all resource blocks are allocated to user data can stipulate a higher level of unwanted emissions and can be referred to as “worst case”.

Considering the principles described in § 3.2, the spurious domain starts at an offset of 15 MHz, depicted by the red dashed line in Fig. 9 below.

FIGURE 9

Emissions from an LTE800 base station



Observations from Fig. 9:

– Modulated signals already disappear below measurement sensitivity at around 15 MHz offset (150% bandwidth).

– The spurious emission levels are at least 40 dB below the limits of Category B for land mobile service in Recommendation ITU-R SM.329, Table 2.1 of ERC/REC 74-01 and ETSI EN 301 908-14 due to the output filters applied.

– Although the station was not operated in "worst case" mode, it can be seen that the output filter has most effect at offsets above 12 MHz, although the spurious domain begins at 25 MHz offset.

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	ERC/Rec 74-01	ETSI
LTE800 base station	Figure 9	The spurious emission levels are at least 40 dB below the limits of Category B for land mobile service in Recommendation ITU-R SM.329, Table 2.1 of ERC/REC 74-01 and ETSI EN 301 908-14 due to the output filters applied.		

5 LTE 800 User Equipment

User equipment (UE) for LTE800 may be modems installed in houses with internal or external antennas, or smartphones. During active connections, the UE always transmits a control channel with a bandwidth of 180 kHz. The scheduler in the base station assigns an additional part of the channel width at certain times to the mobile in order to transmit user data. This results in a constantly changing bandwidth of the UE signal, depending on the traffic situation. In addition, power control constantly adjusts the output power of the UE in a way that the signal is just receivable at the base station.

Measurements were performed using several LTE800 UEs from different manufacturers. It is acknowledged that ideally a statistically representative number of equipment samples/reference designs should be analysed in order to derive statistical models for the performance of mobile devices deployed in practice. For practical reasons, the measurements are based on a limited number of equipment samples and worst case performance may considerably deviate from the results shown due to the inherent dynamicity of the 3GPP LTE systems. For example, the LTE configuration used (i.e. the number of resource blocks, where are resource blocks located in time/frequency, etc.) is not always specified. Even a "full load" where the UE transmits on all possible resource blocks with maximum power, does not necessarily result in the maximum unwanted emissions, which is the reason why in ETSI standards used for conformance tests the equipment has to be operated in a number of different configurations, none of which may produce unwanted emissions above the limit[2]. However, the measurement results may provide valuable data for sharing and compatibility studies.

The key RF parameters of the measured UEs are:

Frequency range:	832 MHz - 862 MHz
Modulation:	SC-FDMA
Bandwidth:	180 kHz to 10 MHz
OoB domain ends at:	20 MHz offset from the centre frequency (see ETSI EN 301 908-13, Table 4.2.4.1.2-1)
Transmitter power:	up to 23 dBm (200 mW) e.i.r.p.
Tx output filter:	None.

Although no external output filters were applied, there is some internal filtering to limit the spurious emissions outside the allocated uplink band in order to protect their own receivers operating in the band 791 to 821 MHz, or adjacent services.

Since only the FDD mode is of interest in this frequency range, TDD operation has not been investigated.

5.1 Out-of-band emissions

Measurements on four different LTE800 UEs are published in [14]. The report notes the measurements were recorded as RMS power in a 10 kHz resolution bandwidth, with each UE set to transmit at maximum power (23 dBm) and using 16QAM modulation which was the maximum modulation order supported by all the devices under test. This ensured maximum levels of unwanted emissions. Since Recommendation ITU-R SM.1541 does not contain any information for OoB limits for this kind of application; the masks from ETSI EN 301 908-13, Table 4.2.3.1.2-1 are shown in Fig. 10 for comparison. Note that this standard also defines the OoB boundary for 10 MHz LTE signals to be at 20 MHz offset which is equal to 200% of the channel bandwidth.

The levels of both measured values and limits were converted into a bandwidth of 10 kHz and normalized.

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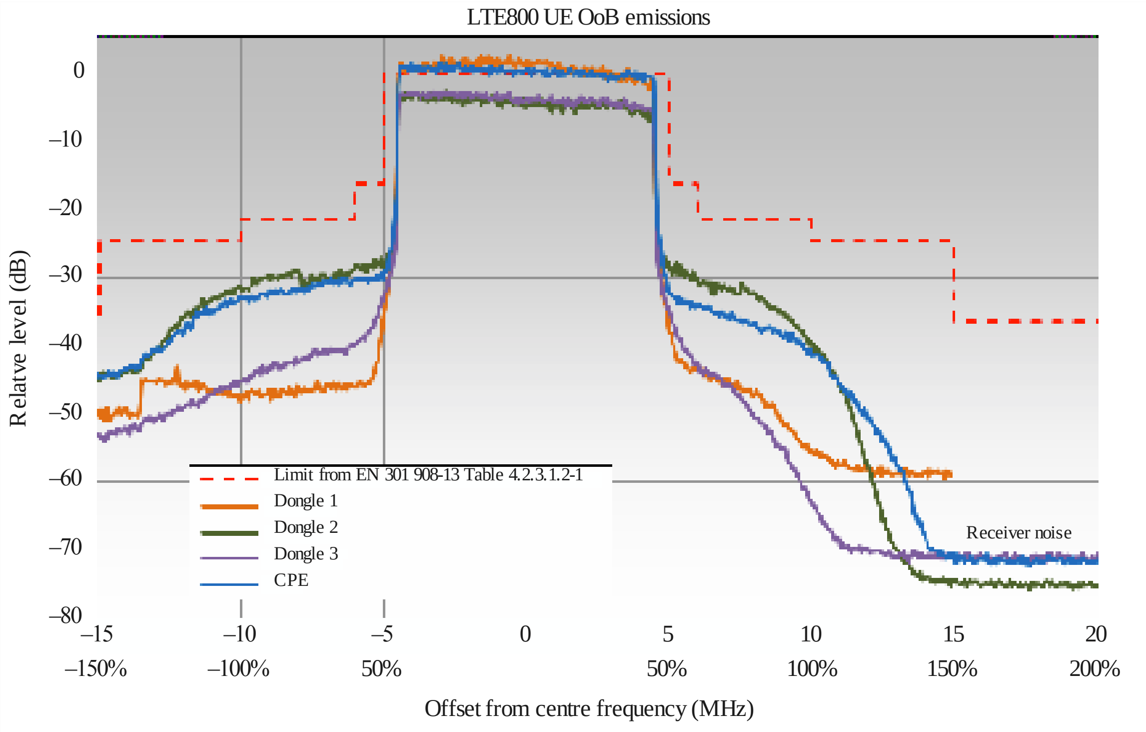
[2] Note: The “worst case” resource block allocation for LTE in terms of out-of-band and spurious emissions cannot be easily identified. In practice, this “worst case” configuration differs from a “full load” configuration with all available resource blocks being allocated in both the Base Station and User Equipment case. The reasons are as follows: In LTE there are very flexible resource block (RB) allocations possible, which can range from 1 to 100 for a single carrier. The positions of these resource blocks can also vary from 0 to 99, so that there are thousands of combinations. In case of carrier aggregation these thousands of combinations for the first carrier can be combined with the combinations of the second carrier resulting in even more combinations. While full allocation is in some cases the worst case as it results in a quite wide signal, there are also other cases where a medium number of resource blocks can result in higher OoB emissions. One other case is transmissions of a single resource block, since single RB transmissions have a very high power spectral density. Therefore intermodulation products between the transmitted resource block, the carrier frequency, and the image frequency can fall into the OoB frequency range and have significant amplitudes close to the limit. In carrier aggregation it is even possible that there is a single RB on each of the carriers. Then intermodulation products between the carriers falling out of band can be quite high, therefore in that case power reduction is required to fulfill the OoB and spurious emissions limits.

FIGURE 10

OoB measurements of four LTE800 UEs



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Observations from Fig. 10:

– The results show that all UEs outperform the OoB emission mask to varying degrees.

– All tested UEs demonstrated asymmetric emissions, with higher suppression above 862 MHz. This suggests the presence of (internal) filtering to address co-existence issues with systems in adjacent frequency bands.

System	**Figure**	**Comparison with:**	
		Rec. ITU-R SM.1541	**ETSI EN 301 908-13, Table 4.2.3.1.2-1**
LTE800 UEs	Figure 10	No information for OoB limits for this kind of application in this Rec.	The tested UEs outperform the OoB emission mask to varying degrees and demonstrated asymmetric emissions, with higher suppression above 862 MHz. This suggests the presence of (internal) filtering to address co-existence issues with systems in adjacent frequency bands.

5.2 Spurious emissions

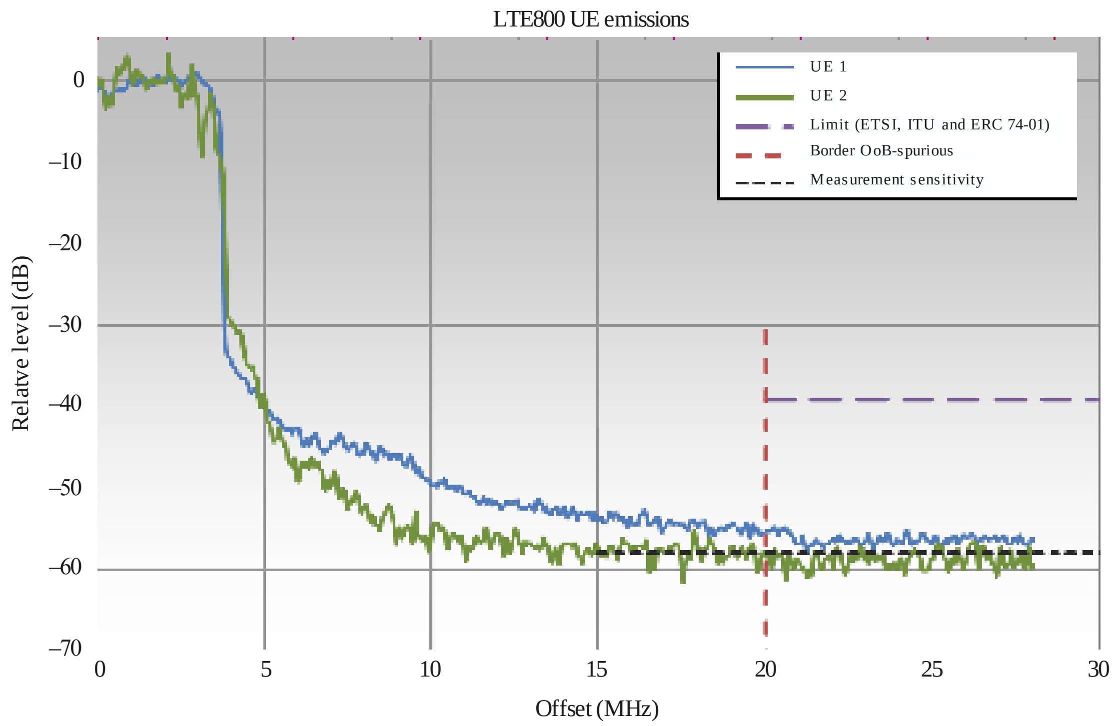
– Recommendations ITU-R SM.329 (Cat. B, land mobile service), Table 2.1 of ERC/REC 74-01 and the relevant ETSI standard EN 301 908-13 (Table 4.2.4.1.2-2) specify a spurious emissions limit of −36 dBm in 100 kHz reference bandwidth (measured conducted at the transmitter output). This limit has to be referenced to a total in-band power of 200 mW = 23 dBm in 10 MHz, which corresponds to an in-band spectral density of 23 dBm − $10\log_{10}(10\,000/100)$ = 3 dBm in 100 kHz bandwidth. The resulting relative attenuation of spurious emissions is then 3 dBm − (−36 dBm) = 39 dB.

– Note that ETSI EN 301 908-13 defines the OoB boundary for 10 MHz LTE signals to be at 20 MHz offset which is equal to 200% of the channel bandwidth (see Table 4.2.4.1.2-1 thereof).

Figure 11 shows measurements of two LTE800 UEs operating on 857 MHz in the offset range near the OoB boundary.

FIGURE 11

Emissions from two LTE800 UEs



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Observations from Fig. 11:

– It can be seen that both UEs outperform the limits from Table 2.1 of ERC/REC 74-01 by at least 20 dB in this configuration. The actual spurious emissions are lower than shown because of the limitation by the available measurement sensitivity;

– The fact that the UEs operated at the highest LTE800 channel where spurious emissions are further suppressed to protect adjacent services results in very high suppression of the spurious emissions, even below the measurement sensitivity. By examining the lower sidebands in Fig. 11 it can be seen that at the OoB boundary and even inside the LTE800 band, the spurious emissions are considerably lower than the limits.

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	ERC/Rec 74-01	ETSI
LTE800 UEs	Figure 11	Both UEs outperform the limits from Rec. ITU-R SM.329 (Cat. B, land mobile service), Table 2.1 of ERC/REC 74-01 and the relevant ETSI standard EN 301 908-13 (Table 4.2.4.1.2-2) by at least 20 dB in this configuration. The actual spurious emissions are lower than shown because of the limitation by the available measurement sensitivity.		

5.3 Harmonic emissions

Unwanted emissions at the second harmonic frequency of commercially available LTE800 UE have been measured as it falls within the receiver bandwidth of a radionavigation satellite service band. Because these unwanted emissions are always above 1 GHz, the limits from Cat. B, land mobile service of Recommendation ITU-R SM.329, Table 2.1 of ERC/REC 74-01 and ETSI EN 301 908-13 of −30 dBm in 1 MHz reference bandwidth apply. Recommendation ITU-R M.2071, applicable to IMT-Advanced UEs, also specifies the same limit. The total radiated power measured was 27 dBm in 10 MHz which results in an in-channel spectral density of 17 dBm/MHz. The required suppression of the harmonic frequencies would therefore be 17 dBm/MHz − (−30 dBm) = 47 dB.

The transmitter frequency was 858 MHz. Measurements have been performed radiated in a laboratory setup with a measurement bandwidth of 100 kHz. Figures 12 and 13 show the measured in-band signal and its second harmonic.

FIGURE 12

In-band emissions from an LTE800 UE

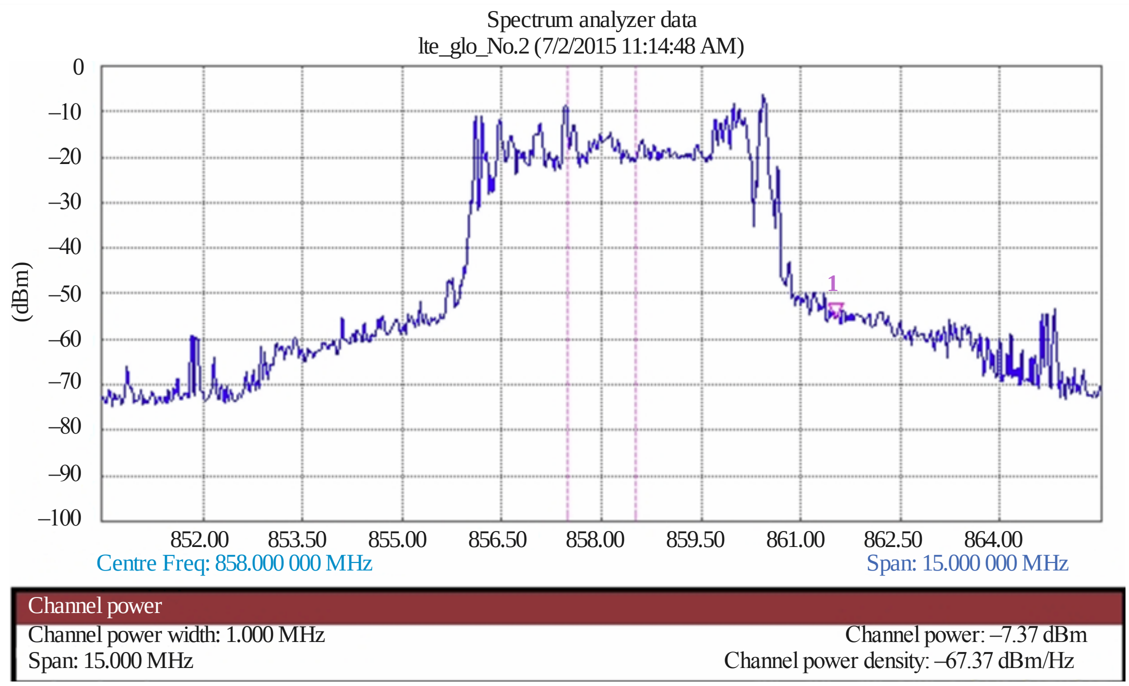

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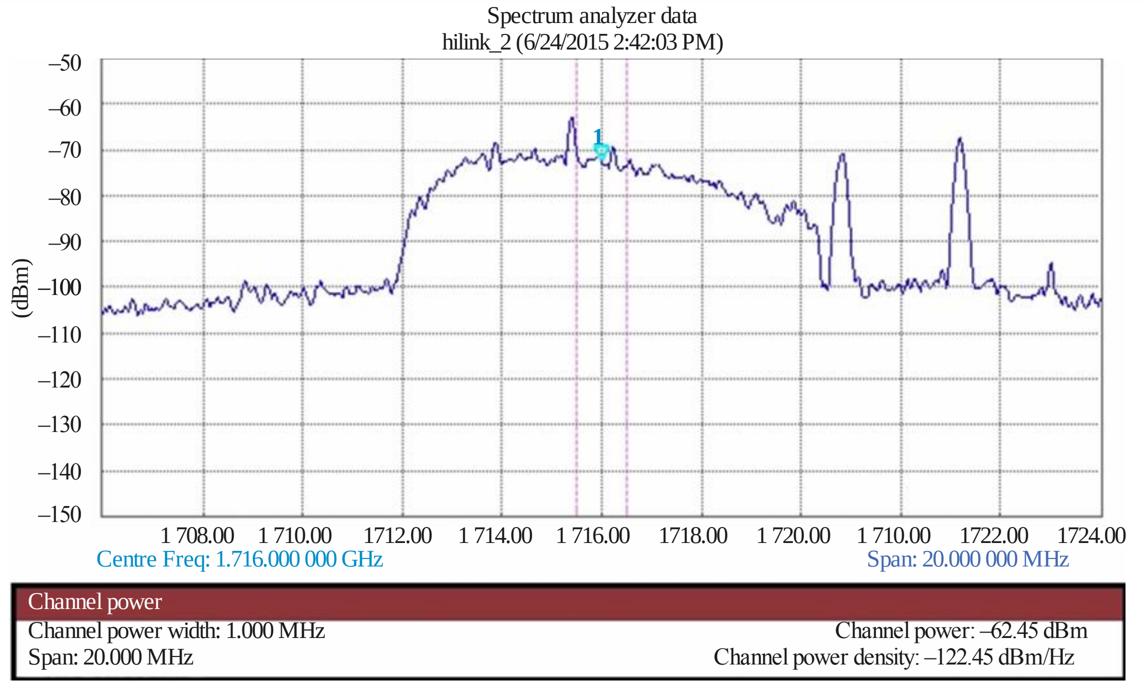
FIGURE 13

Emissions from an LTE800 UE at the second harmonic frequency



Report SM.2421-13

The link budget for these measurements was as shown in Table 3:

TABLE 3

Link budget

Parameter	Main emission	Second harmonic emission
Frequency	858 MHz	1716 MHz
Measured Power	−7.35 dBm/MHz	−62.45 dBm/MHz
Antenna gain	7.8 dB	7.5 dB
Cable attenuation	1.2 dB	1.5 dB
Free space attenuation	31.2 dB	37.14 dB
Radiated power	17.23 dBm/MHz	−31.31 dBm/MHz

The suppression of the second harmonic for the measured UE is estimated as 17.23 dBm/MHz − (–31.31 dBm/MHz) = 48.54 dB.

Observation:

– The unwanted emission of the measured UE at the second harmonic frequency is approximately 1.5 dB below the limit.

6 LTE 2300 User Equipment

In some European countries LTE is also used in the 2.3 GHz range. The system is principally the same as LTE800 with the exception that typically channels are 20 MHz wide. The relevant RF parameters are:

Frequency range:	2 300 MHz - 2 400 MHz
Modulation:	SC-FDMA
Bandwidth:	180 kHz to 20 MHz
Transmitter power:	up to 23 dBm (200 mW) Tx output and e.i.r.p.
Tx output filter:	None
OoB domain ends at:	35 MHz offset from the centre frequency (see ETSI EN 301 908-13, Table 4.2.4.1.2-1).

Figure 14 below shows the results of lab measurements on the unwanted emissions of two different LTE UEs operating in a 20 MHz channel of the 2.3 GHz LTE TDD band from 2 370-2 390 MHz. Measurements were recorded as RMS power in a 10 kHz resolution bandwidth, with each UE set to transmit at maximum power (23 dBm) and using 16QAM modulation.

For reasons similar to those discussed in § 5, the measurements are based on two equipment samples and worst case performance may considerably deviate from the results shown due to the inherent dynamic behaviour of the 3GPP LTE systems. Also, the LTE configuration used (i.e. the number of resource blocks, where are resource blocks located in time/frequency, etc.) is not always specified.

The graph in Fig. 14 is normalised to the in-channel power spectral density in a 10 kHz bandwidth.

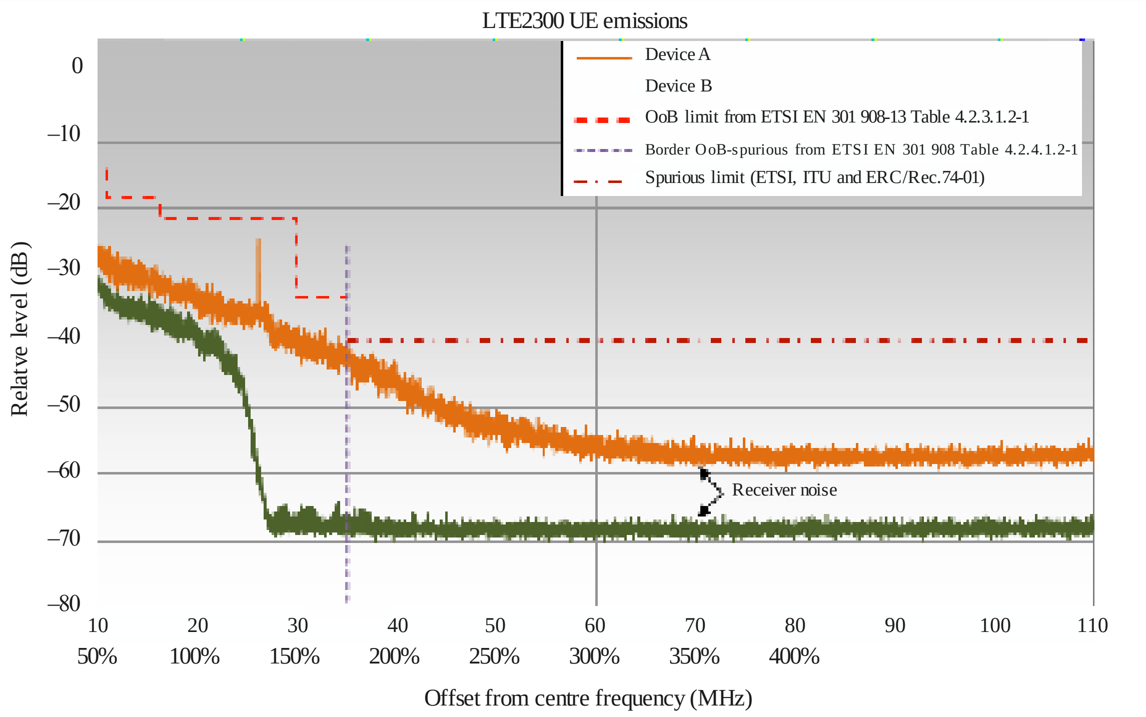
Recommendation ITU-R SM.1541 does not contain OoB emission limits for this system, therefore the spectrum mask from the relevant standard, ETSI EN 301 908-13 (Table 4.2.3.1.2-1), converted into a 10 kHz bandwidth and compared to the in-channel power spectral density, is shown in Fig. 14.

The relevant ETSI standard EN 301 908-13 (Table 4.2.4.1.2-2), Recommendation ITU-R SM.329 (Cat. B for land mobile systems) and ERC/REC 74-01 (Table 2.1) provide a spurious emissions limit of −30 dBm in 1 MHz bandwidth. Since this value applies to the transmitter output, the regulatory limit has to be referenced to a total in-band power of 200 mW = 23 dBm in 20 MHz, which corresponds to an in-band spectral density of $23 \text{ dBm} - 10\log_{10}(20/1) = 10 \text{ dBm}$ in 1 MHz bandwidth. The resulting relative attenuation of spurious emissions is then 10 dBm − (−30 dBm) = 40 dB.

Note that ETSI EN 301 908-13 (Table 4.2.4.1.2-1) defines the OoB boundary for 20 MHz LTE signals to be at 35 MHz offset which is equal to 175% of the channel bandwidth.

FIGURE 14

Unwanted emission measurements of 2 LTE 2.3 GHz UEs
(RMS power, resolution bandwidth = 10 kHz)



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Observations from Fig. 14:

– There is a noticeable difference in the measured emission profile between the two devices. Device A has a linear roll-off with the exception of a spike within the OoB domain, and only just meets the spurious emission limit immediately beyond the boundary. Device B shows significantly better performance, with much sharper roll-off in the OoB domain;

– The spurious emissions for higher frequency offsets outperform the limit by as much as 30 dB. It should be noted however that measurements in the spurious domain are limited by the dynamic range of the measurement equipment. The unwanted emissions from the devices could therefore be even lower than shown in Fig. 14.

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	**ERC/Rec 74-01**	**ETSI**
LTE2300 UEs	Figure 14	The spurious emissions for higher frequency offsets outperform the limit by as much as 30 dB. It should be noted however that measurements in the spurious domain are limited by the dynamic range of the measurement equipment. The unwanted emissions from the devices could therefore be even lower than shown in Fig. 14.		

7 GSM900 Base station

The relevant RF parameters of the GSM900 base stations are:

Frequency range: 925 MHz – 960 MHz

Modulation: GMSK

Occupied Bandwidth: 250 kHz

Channel spacing: 200 kHz

OoB domain ends at: 500 kHz offset from the centre frequency (250% rule, using channel spacing (Note 1))

Transmitter power: up to 46 dBm Tx output (typical)

Tx output filter: None.

NOTE 1 – 500 kHz offset to the start of the spurious domain has typically been used in compatibility studies. In GSM specifications ETSI EN 302 408 V8.0.1 section 4.3.3.1 and EN 301 502 V12.1.1 section 4.2.5.1.3 and Table 4.2.5.1, the spurious emissions are defined starting 1.8 MHz from the carrier centre inside a transmit band and from 2 MHz offset from the band edge outside the transmit band.

Although no external output filters are applied, the transmitters usually have some internal filtering to limit unwanted emissions in adjacent bands and to protect their own uplink receiver band (880-915 MHz).

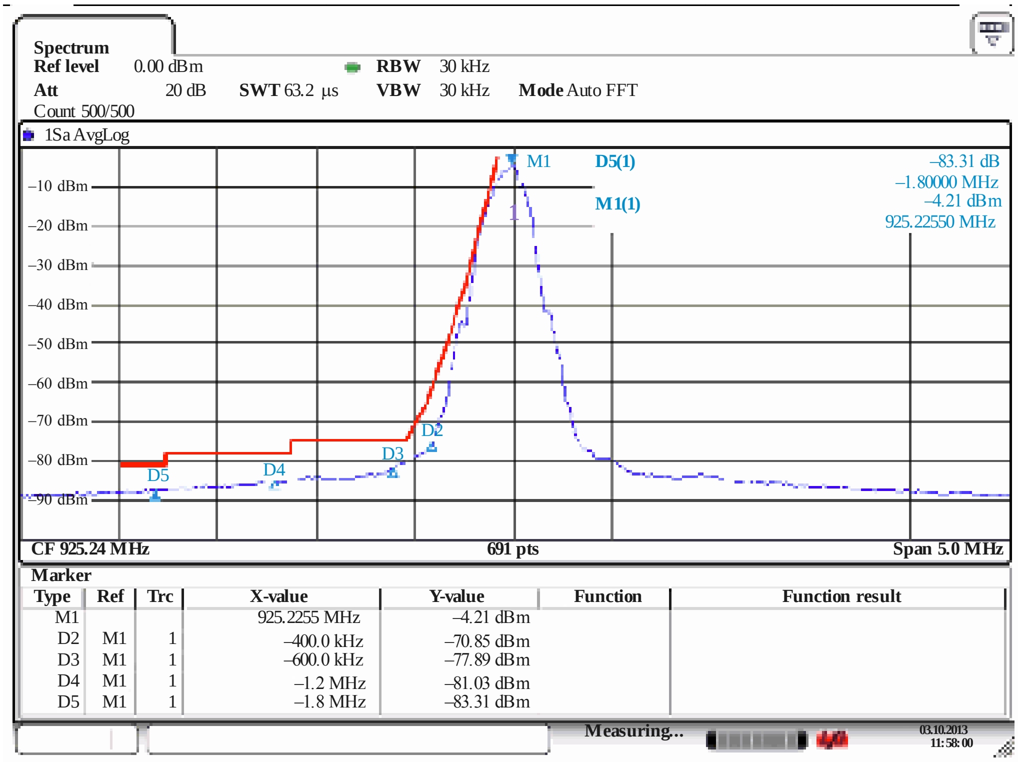
7.1 Out-of-band emissions

Recommendation ITU-R SM.1541 does not contain specific OoB limits for GSM. The relevant standard ETSI TS 145 005 does not separate requirements for OoB and spurious emissions. However, ETSI TS 145 005 section 4.2.1 “Spectrum due to modulation and wide band noise” thereof defines a spectrum mask in section 4.2.1.3, Table in a2 that may be used as a reference. This reference mask is presented in Fig. 15 as a red line.

The measured base station was set to the lowest possible operating channel (#975), which corresponds to a downlink centre frequency of 925.2 MHz. The spectrum analyser was set to a 30 kHz resolution bandwidth, using a RMS detector and displaying a max-hold trace.

FIGURE 15

Measurement result of GSM900 base station test



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Observations from Fig. 15:

- Over the full range the level of unwanted emissions is below the ETSI limit and particularly at 400 kHz offset outperforms the emission mask by approximately 10 dB.

System	Figure	Comparison with:	
		Rec. ITU-R SM.1541	**ETSI TS 145 005**
GSM900	Figure 16	No information for OoB limits for this kind of application in this Rec.	Over the full range, the level of unwanted emissions is below the ETSI limit and particularly at 400 kHz offset outperforms the emission mask by approximately 10 dB.

7.2 Spurious emissions

The measurements were done at the transmitter output of a common GSM base station on the so-called "C1" frequency (930.6 MHz) carrying the broadcast channel (BCCH). Although GSM is a TDMA system and normally transmits in bursts, the C1 frequency is continuously transmitted with full power. Therefore, external triggering was not necessary to measure the RMS level.

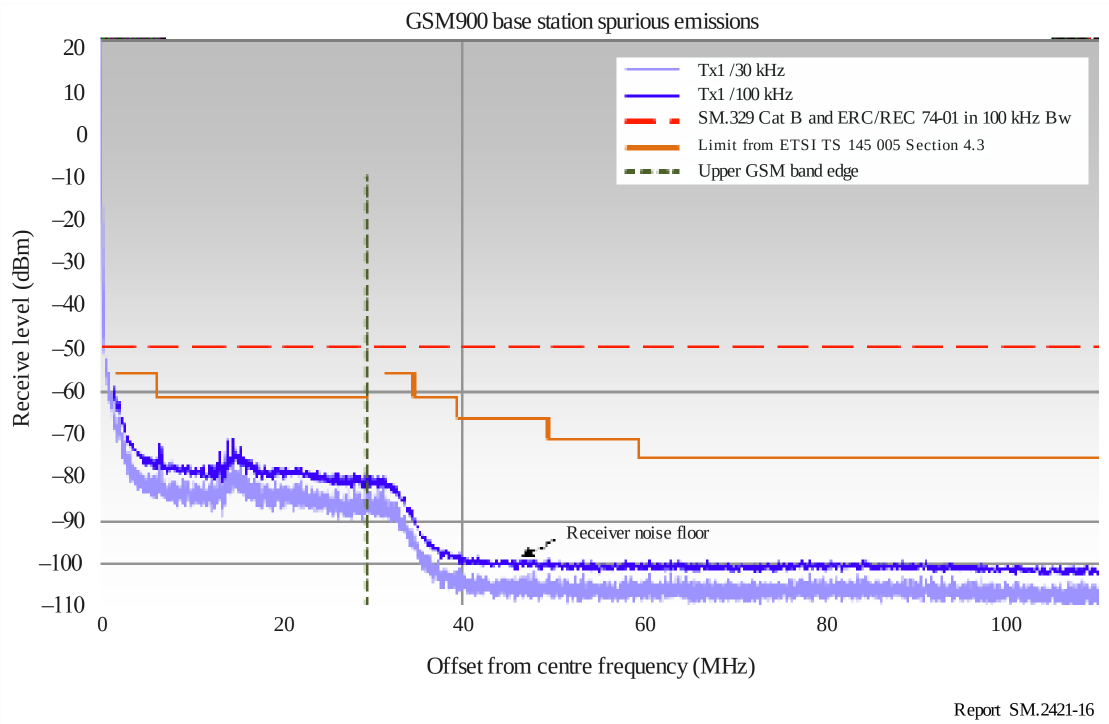
ERC/REC 74-01 and Recommendation ITU-R SM.329 0specify a spurious emission limit of −36 dBm in 100 kHz bandwidth for Category B, land mobile systems, base stations. In this case the transmitter output power was 42 dBm in a 200 kHz channel bandwidth, therefore this limit will correspond to a relative attenuation of the spurious emissions of

42 dBm − (−36 dBm + 10*$\log_{10}$(200/100)) = 75 dB. The in-channel receive level of the measured base station was +20 dBm in 30 kHz measurement bandwidth which corresponds to +25 dBm in a 100 kHz reference bandwidth. The limit from Recommendation ITU-R SM.329 and ERC/REC 74-01 is therefore at +25 dBm − 75 dB = −50 dBm in the diagram.

ETSI TS 145 005 has rather complicated limits for spurious emissions, specified separately inside and outside the assigned GSM band. However, the resulting values are much more stringent than the general values from the ITU Recommendation. The upper band edge of the GSM downlink band is 960 MHz. With a transmit frequency of the measured base station of 930.6 MHz, the boundary is at an offset of 29.4 MHz.

FIGURE 16

GSM900 base station spurious emissions (upper frequency range)



Observations from Fig. 16:

– The actual spurious emissions above an offset of 40 MHz could be even lower than shown in the Figure due to the limited sensitivity limitation of the measurement receiver.

– Outside the assigned GSM band, the spurious limit for Category B, land mobile systems, base stations of Recommendation ITU-R SM.329 and ERC/REC 74-01 is outperformed by at least 30 dB.

– Especially outside the assigned GSM band, the level of unwanted emissions is more than 25 dB below the ETSI limit in [16] because of the internal filtering to protect adjacent services.

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	ERC/Rec 74-01	ETSI
GSM900 base station	Figure 16	Outside the assigned GSM band, the spurious limit for Category B, land mobile systems, base stations of Recommendation ITU-R SM.329 and ERC/REC 74-01 is outperformed by at least 30 dB.		Especially outside the assigned GSM band, the level of unwanted emissions is more than 25 dB below the ETSI TS 145 005 limit because of the internal filtering to protect adjacent services.

The 2nd harmonic could not be seen above the noise floor of the measurement receiver which means that it was below –100 dBm (receiving equipment level in 100 kHz), corresponding to less than −90 dBm (transmit level in 100 kHz bandwidth). Emissions were measured but not recorded above the 2nd harmonic, because already no emissions were found above the noise floor above 110 MHz offset.

8 DECT

The Digital Enhanced Cordless Telecommunications (DECT) standard is commonly used by many personal communication systems. It is a TDMA system, so both fixed and portable parts transmit in bursts. The parameters of the measured systems are:

Tx frequency: 1 897.344 MHz

Modulation: 2-FSK

Radiated power: 250 mW = 24 dBm (average burst)

Occupied bandwidth: 1.15 MHz

Spurious domain starts at: 2.875 MHz offset

Burst duration: 90 µs or 368 µs

Burst repetition: 10 ms

Measurement bandwidth: 100 kHz.

The measurements were performed radiated (off air) because the equipment usually has no external antenna connectors. The measured levels are RMS during the bursts only (average-burst level). External triggering was used to synchronise the measurement with the transmitted bursts (see Annex 1 for a description of the measurement setup).

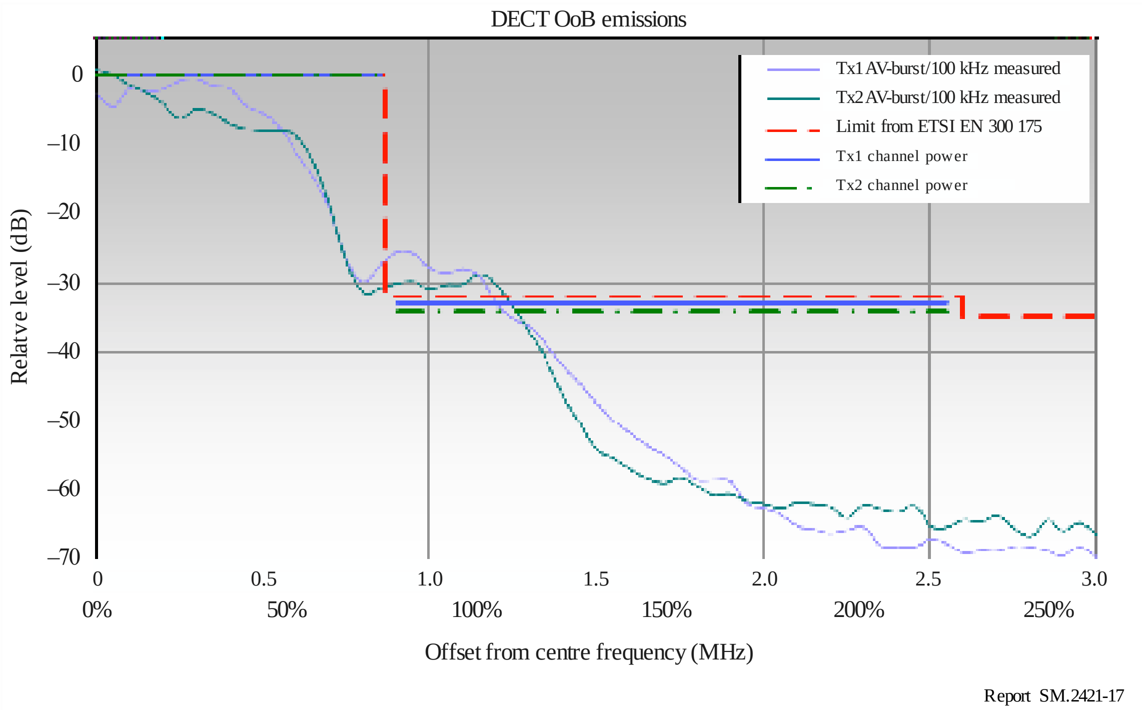
8.1 Out-of-band emissions

Two DECT handsets of different manufacturers were measured with a resolution bandwidth of 100 kHz. The resulting OoB spectra are shown as “Tx1 AV-burst/100kHz” and “Tx2 AV-burst/100kHz” in Fig. 17.

Recommendation ITU-R SM.1541 does not contain an annex specifying limits for DECT OoB emissions, therefore the mask from the applicable standard ETSI EN 300 175-2 (§ 5.5.1 Table 1) was taken as a reference. The OoB limits are defined in power levels over the whole channel bandwidth for both the 0 dB reference and the OoB emissions, so no bandwidth conversion was required. To have a direct comparison with the limits, the measured spectral densities were integrated over a bandwidth of 1.15 MHz for the used channel and adjacent channel. The results are shown in Fig. 17 as horizontal lines ("Tx1 channel power" and "Tx2 channel power"). The level axis of the Figure is normalised to the 0 dB reference line of the total in-channel power.

FIGURE 17

DECT OoB emissions (upper frequency range)



Observations from Fig. 17:

– It can be seen that the OoB levels of both measured DECT devices do not fulfil the requirements from the ETSI standard in the offset range around 1 MHz.

– As only modulation-related emissions can be seen in the OoB domain, it can be assumed that all DECT devices will have almost the same OoB spectrum in which case it seems that there is a considerable margin between the OoB emissions limit and the actual OoB emissions, especially in the range of the neighbouring channel with 2 MHz offset.

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	ERC/Rec 74-01	ETSI
DECT	Figure 17			The OoB levels of both measured DECT devices do not fulfil the requirements from the ETSI standard 0 in the offset range around 1 MHz. As only modulation-related emissions can be seen in the OoB domain, it can be assumed that all DECT devices will have almost the same OoB spectrum in which case it seems that there is a considerable margin between the OoB emissions limit and the actual OoB emissions, especially in the range of the neighbouring channel with 2 MHz offset.

8.2 Spurious emissions

For the DECT service, Recommendation ITU-R SM.329 (Cat B0, land mobile service) and ERC/REC 74-01 specify a spurious emission limit of −30 dBm in a 1 MHz reference bandwidth. With a transmitted power of 24 dBm, this limit corresponds to a relative attenuation of the spurious emissions of 24 dBm − (−30 dBm) = 54 dB.

The equivalent measured in-channel receive level in 1 MHz was −12 dBm. The level axis in Fig. 18 can therefore be converted to reflect radiated power in 1 MHz bandwidth by adding 36 dB to account for the losses in the set-up. In Fig. 18, the line for the necessary suppression of spurious emissions of 54 dB lies at −12 dBm − 54 dB = −66 dBm.

Section 5.5.4 of ETSI EN 300 175-2 specifies a spurious emissions limit of 1 µW = −30 dBm above the designated DECT band. The reference bandwidths for this level are between 30 kHz and 3 MHz, resulting in a decreasing limit when referenced to the 1 MHz bandwidth of Fig. 18. The measured devices were forced to a transmit frequency of 1897.344 MHz which is the highest DECT channel in Europe. The designated DECT band ends at 1900 MHz which corresponds to an offset of 2.656 MHz.

Because DECT devices transmit in bursts, the unwanted emissions were only measured during a burst, using a triggered spectrum analyser. For details on the measurement setup, see Annex 1, § 3, Setup Type 3.

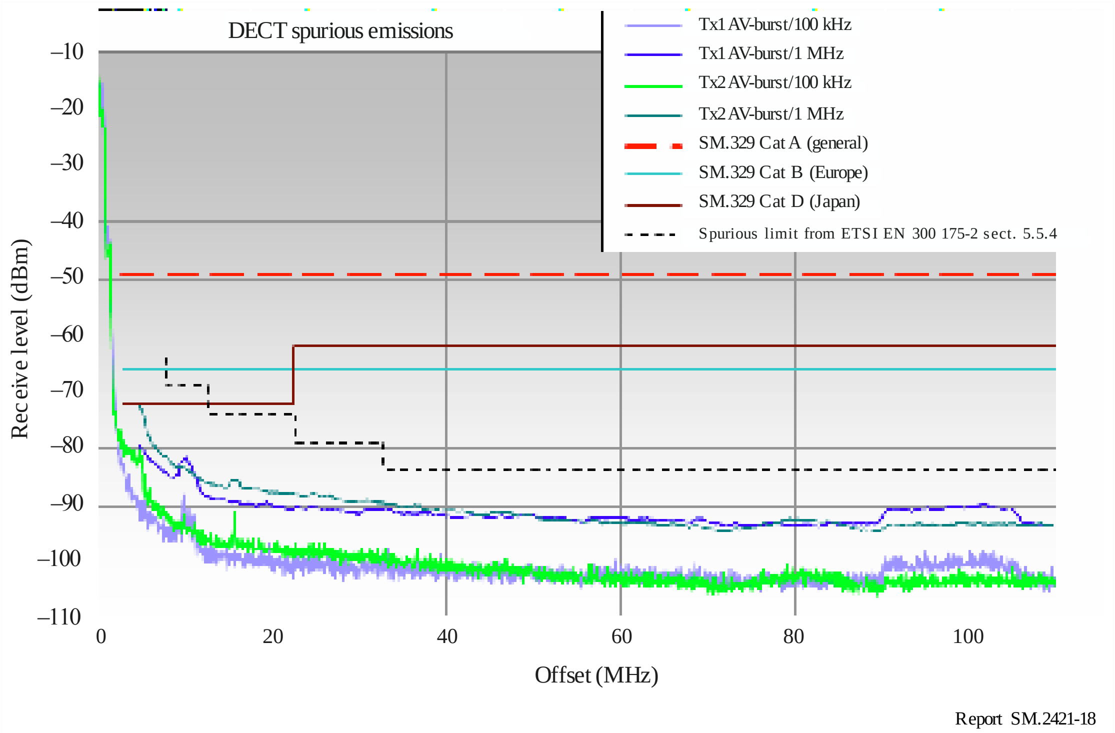
A floating window was applied on the levels measured in 100 kHz to integrate the levels to the reference bandwidth of 1 MHz. The resulting spectrum lines shown in dark blue and dark green have to be compared to the limits in Fig. 18.

To compare the measured levels with the limit from the ETSI standard EN 300 175-2 v2.6.1 that is defined as a peak power level, a reduction of 13 dB[3] was applied in the calculation of the limit in Fig. 18 to account for the difference between average and peak levels for noise-like signals.

[3] This is an empirically derived figure. It applies to noise-like signals when measured with a peak and with an RMS detector.

FIGURE 18

DECT spurious emissions (upper frequency range)



The harmonics were measured separately; the results are given in Table 4:

TABLE 4

Harmonic levels of measured DECT base stations

	Tx1			Tx2		
	Frequency	**Level/1 MHz**	**Attenuation**	**Frequency**	**Level/1 MHz**	**Attenuation**
Fundamental	1881.6 MHz	−6.0 dBm	0.0 dBc	1890.4 MHz	−8.0 dBm	0.0 dBc
2nd harmonic	3763.2 MHz	−80.0 dBm	74.0 dBc	3780.8 MHz	−77.0 dBm	69.0 dBc
3rd harmonic	5644.8 MHz	−79.0 dBm	73.0 dBc	5671.2 MHz	−85.0 dBm	77.0 dBc
4th harmonic	7526.4 MHz	< −88 dBm	> 82 dBc	7561.6 MHz	< −88 dBm	> 80 dBc

Observations from Fig. 17 and Fig. 18:

– The results show that the spurious emission limits of Recommendation ITU-R SM.329 and ERC/REC 74-01 are met with a large margin. For higher offsets, the spurious emissions are typically 30 dB below this limit;

– As with the other digital systems, the most critical offset is at the boundary between the OoB and spurious domain where Tx1 meets the requirements of Cat. B with a margin of 5 dB;

– The spurious emission limits from ETSI EN 300 175-2 are met with a margin of typically 10 dB;

– All harmonic emissions of the measured devices are well below the spurious emission limits.

9 UMTS 2100 base stations

This 3G cellular mobile system uses W-CDMA spread spectrum technique to manage multiple accesses. It is widely used in Europe and worldwide as the successor to GSM. The parameters of the UMTS system are:

Frequency range: 2 110-2 170 MHz (FDD downlink Band I)

Modulation: QPSK

Bandwidth: 5 MHz (channel)

Tx external filter: none

Spurious domain starts at: 12.5 MHz offset (250% rule).

Although no additional filtering was applied at the transmitter output, some internal filtering must be assumed to protect the base station's own receive band and possibly also adjacent services.

9.1 Out-of band emissions

The following measurements of OoB emissions were conducted at the transmitter output. The relevant RF parameters of the measured station were:

Tx frequency: 2 152 MHz (centre)

Tx power: 3 W / 35 dBm (RMS at transmitter output)

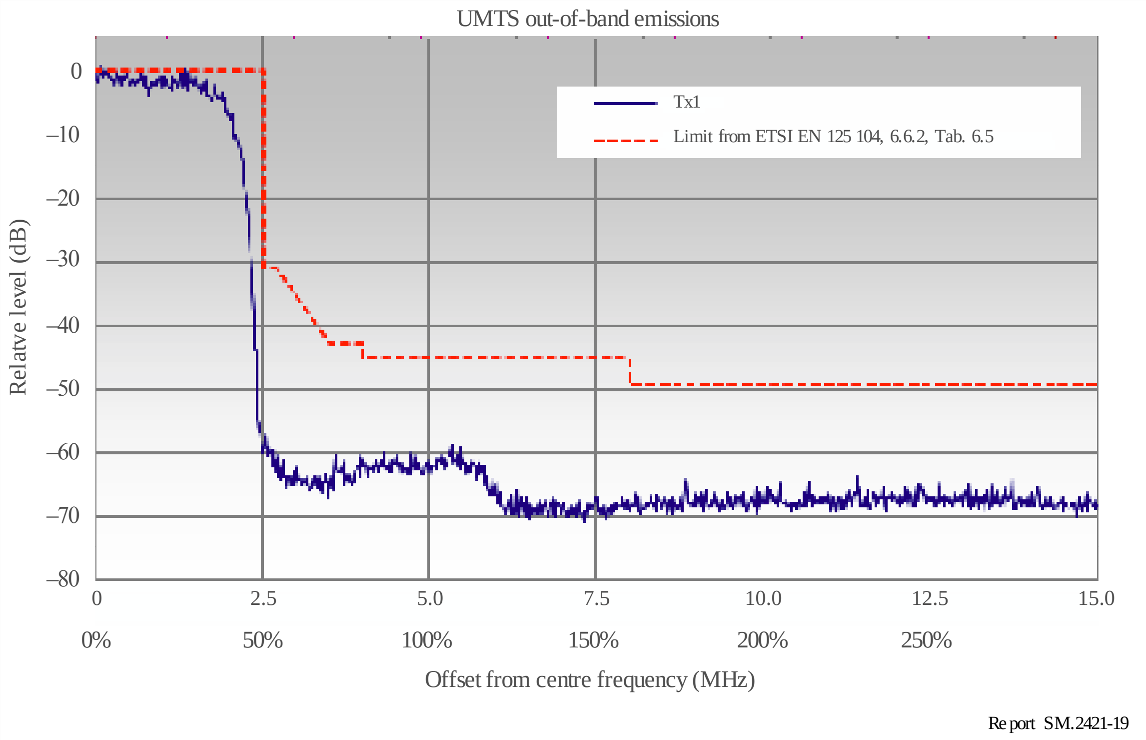
Measurement bandwidth: 4 kHz.

The measured spectrum in Fig. 19 below shows relative levels in dB normalised to the maximum power spectral density in the measurement bandwidth of 4 kHz.

Recommendation ITU-R SM.1541 does not provide limits for W-CDMA systems. Therefore, the limits defined in ETSI TS 125 104, Chapter 6.6.2.1, Table 6.5 are shown. Because they are given in reference bandwidths between 30 kHz and 1 MHz, the limit in the following Figure has been derived after bandwidth correction and normalised to the measured in-channel power spectral density.

FIGURE 19

OoB emissions from a UMTS base station



Observations from Fig. 19:

– The results show that the limit from the relevant ETSI standard TS 125 104 is easily met. The OoB emissions are at least 15 dB below the mask.

– The unwanted emissions due to modulation already disappear in the broadband noise from the amplifier at offsets around 125% of the channel width.

System	Figure	Comparison with:	
		Rec. ITU-R SM.1541	**ETSI TS 125 104, Chapter 6.6.2.1, Table 6.5**
UMTS base station	Figure 19	No information for OoB limits for this kind of application in this Recommendation.	The OoB emissions are at least 15 dB below the mask. The unwanted emissions due to modulation already disappear in the broadband noise from the amplifier at offsets around 125% of the channel width.

9.2 Spurious emissions

Rec. ITU-R SM.329 Cat B (Europe) for Land mobile service (base stations), Table 6.9 of ETSI TS 125 104 and Table 2.1 of ERC/REC 74-01 specify a maximum spurious emissions level of −30 dBm/MHz. Section 6.6.3 of the ETSI standard [18] defines the applicability of the spurious emissions limit for offsets more than 12.5 MHz below the first carrier frequency used in the UMTS band or more than 12.5 MHz above the last carrier frequency used.

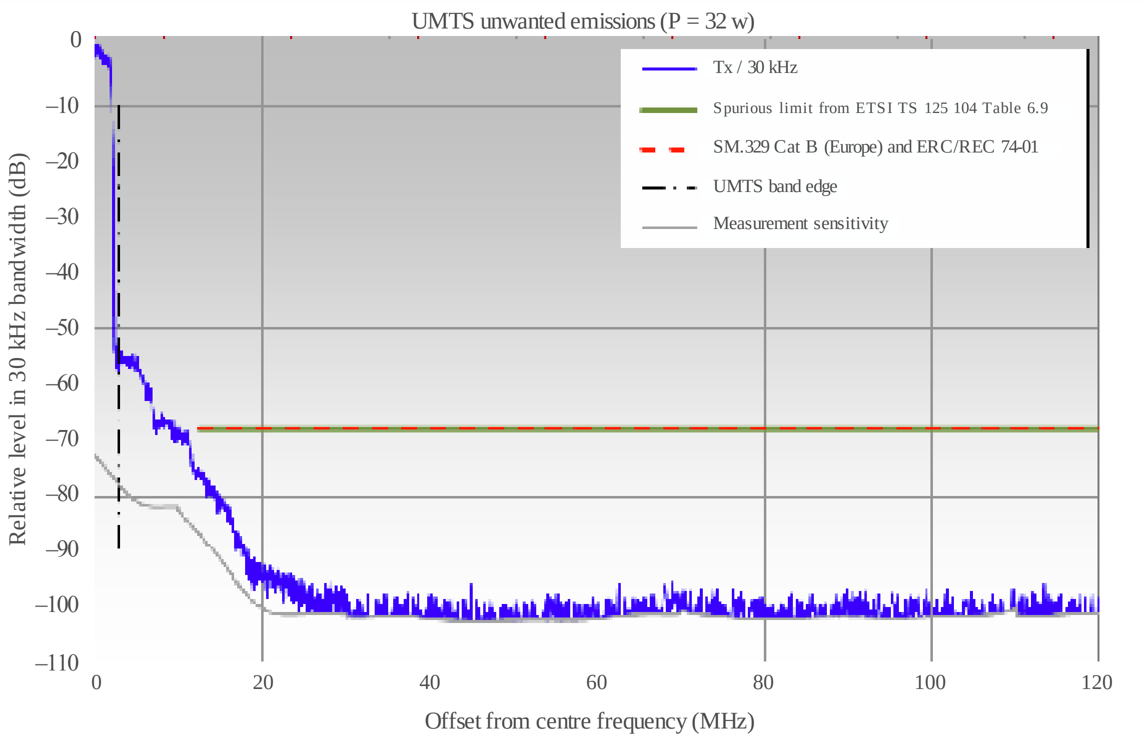
Figure 20 shows a radiated measurement of a UMTS base station operating on the highest channel in the UMTS band I. The relevant RF parameters are:

Tx frequency:	2 167.2 MHz (centre frequency)
Tx power:	32 W / 45.1 dBm (RMS at transmitter output)
Bandwidth:	5 MHz (channel)
Measurement bandwidth:	30 kHz.

In Fig. 20, the levels are normalised to the in-channel power spectral density in 30 kHz bandwidth. The limit of −30 dBm is defined in a 1 MHz bandwidth. The conversion to the UMTS bandwidth of 5 MHz is $10*\log_{10}(5) = 7$ dB. With this correction and normalisation to in-channel power spectral density, the limit is shown at −30 dBm − (45.1 dBm-7 dB) = −68 dB in the Figure.

FIGURE 20

Spurious emissions from a UMTS base station



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Observations from Fig. 20:

– Although transmitting on the highest channel and thereby presenting the most critical case for complying with spurious emission limits, the measured station outperforms these limits by approximately 10 dB even at the start of the spurious domain.

– For offsets higher than 20 MHz, the limits are outperformed by at least 30 dB. The actual spurious emissions for these offsets are even lower than shown. The limitation is the measurement sensitivity.

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	ERC/Rec 74-01	ETSI
UMTS base station	Figure 20	Although transmitting on the highest channel and thereby presenting the most critical case for complying with spurious emission limits, the measured station outperforms these limits by approximately 10 dB even at the start of the spurious domain. For offsets higher than 20 MHz, the limits are outperformed by at least 30 dB. The actual spurious emissions for these offsets are even lower than shown. The limitation is the measurement sensitivity.		

10 RLAN devices in the 2.4 GHz band

RLAN or WLAN devices are used in large numbers all over the world. The service conforms to the IEEE 802.11 standard [28]. Depending on the variant of this standard, a frequency in the ranges around 2.4 GHz or 5.6 GHz is used. The parameters are:

Modulation: QPSK or OFDM

Max. radiated power: 100 mW = 20 dBm (average burst)

Bandwidth: around 16 MHz

OoB domain ends at: 40 MHz offset (250% rule)

Burst duration: variable, depending on traffic, example: 100 µs

Burst repetition: variable, depending on traffic, example 100 ms.

10.1 Out of band emissions

Measurements were made on three different WLAN devices:

Tx1: RLAN access point, operating in 802.11g mode (OFDM), measured radiated

Tx2: RLAN router, operating in 802.11b mode (DSSS), measured at the Tx output

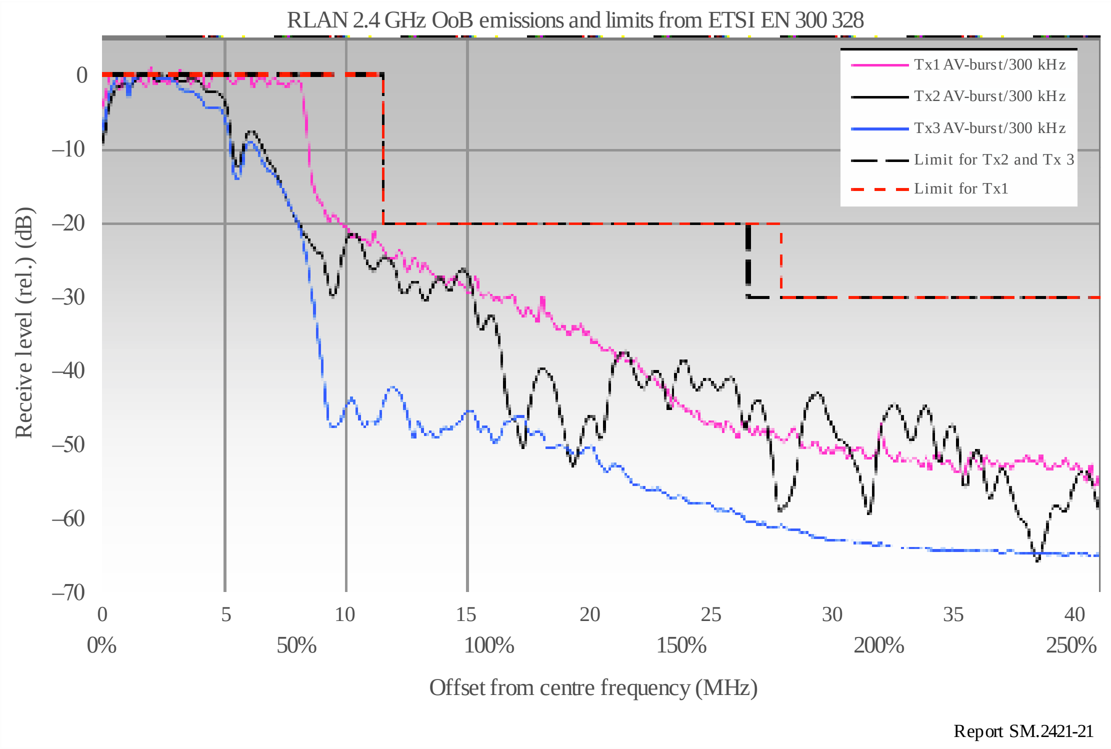
Tx3: Smartphone with RLAN capability, operating in 802.11b mode (DSSS), measured radiated.

Since Recommendation ITU-R SM.1541 does not contain an annex specifying limits for SRD OoB emissions, the mask was taken from the applicable Standard ETSI EN 300 328 V1.9.1 [19], Section 4.3.2.8.3. The definition of the OoB emission limits outside the allocated band depend on the occupied bandwidth which was 16.5 MHz for Tx1 and 15 MHz for Tx2 and Tx3. During the measurement, all three transmitters were operating on the highest channel in the band with a centre frequency of 2 472 MHz. The limit from the band edge (2 480 MHz) and 2480 + OBW is −10 dBm/MHz and between 2 480 + OBW and 2 480 + 2*OBW it is −20 dBm/MHz (see an illustration of this phenomenon in Fig. 21).

The levels in Fig. 21 show relative values in dB and are normalised so that 0 dB corresponds to the maximum in-channel power spectral density in the measurement bandwidth of 300 kHz. The limits are also normalised to 300 kHz bandwidth to allow a direct comparison.

FIGURE 21

RLAN OoB emissions



Observations from Fig. 21:

– All three measured devices meet the OoB limits from ETSI EN 300 328. At 250% offset, the OoB emissions are typically more than 20 dB below the limit.

System	Figure	Comparison with:	
		Rec. ITU-R SM.1541	**ETSI EN 300 328**
RLAN	Figure 21	No information for OoB limits for this kind of application in this Rec.	At 250% offset, the OoB emissions are typically more than 20 dB below the limit.

10.2 Spurious emissions

For RLAN systems, Table 2.1, reference number 2.1.2 of ERC/REC 74-01 and Recommendation ITU-R SM.329 specify a spurious emissions limit of −30 dBm in a 1 MHz bandwidth for Europe (Cat B).

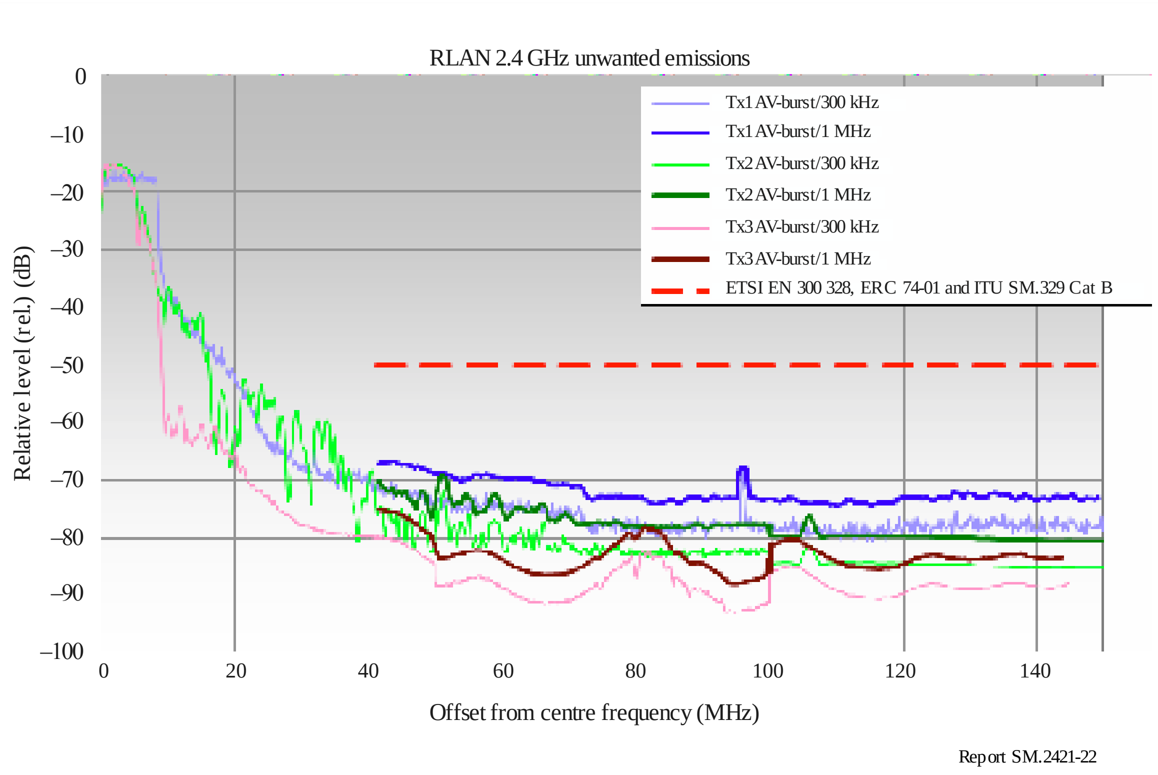
ETSI EN 300 328, section 4.3.1.10.3, Table 1 specifies a spurious emission level for transmitters of wideband emissions of −30 dBm in 1 MHz for the frequency range 1 GHz to 12.75 GHz.

The measurements were made on the same three RLAN devices as OoB emission measurements in Fig. 21, and with a measurement bandwidth of 300 kHz. For direct comparison with the limits, a floating 1 MHz integration window was applied to convert the measured values into the reference bandwidth of 1 MHz. Since Fig. 22 is normalised to the total in-channel power of 20 dBm, the limit of −30 dBm from Recommendation ITU-R SM.329 and ETSI EN 300 328 corresponds to a relative level of −50 dB.

The levels shown in the graph can directly be converted into radiated levels in a 1 MHz bandwidth by adding 20 dB.

FIGURE 22

RLAN spurious emissions



Observations:

– Even the more stringent limits from Recommendation ITU-R SM.329 are met with a margin of typically 20 to 30 dB.

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	**ERC/Rec 74-01**	**ETSI**
RLAN	Figure 22	The limits are met with a margin of typically 20 to 30 dB.		

11 WIMAX 3.6 GHz UE

WiMAX is a system for broadband wireless access. The respective WiMAX band has the following RF characteristics:

Frequency range: 3 600-3 800 MHz

Modulation: OFDM

Bandwidth: 10 MHz (channel).

11.1 Spurious emissions

The spurious emission limit for UE/BS in the land mobile service in accordance with Table 2.1 of ERC/REC. 74-01 is −30 dBm/MHz. The same limit is defined in Recommendation ITU-R SM.329

for frequencies above 1 GHz. Section 4.2.4 of EN 301 908-21 defines the transmitter spurious emission limits for OFDMA TDD WMAN (Mobile WiMAX) FDD User Equipment.

Figure 23 shows a spurious emission measurement of a production line of WiMAX terminals in the adjacent radar band, conducted directly at the transmitter output. The following RF parameters are relevant for this measurement:

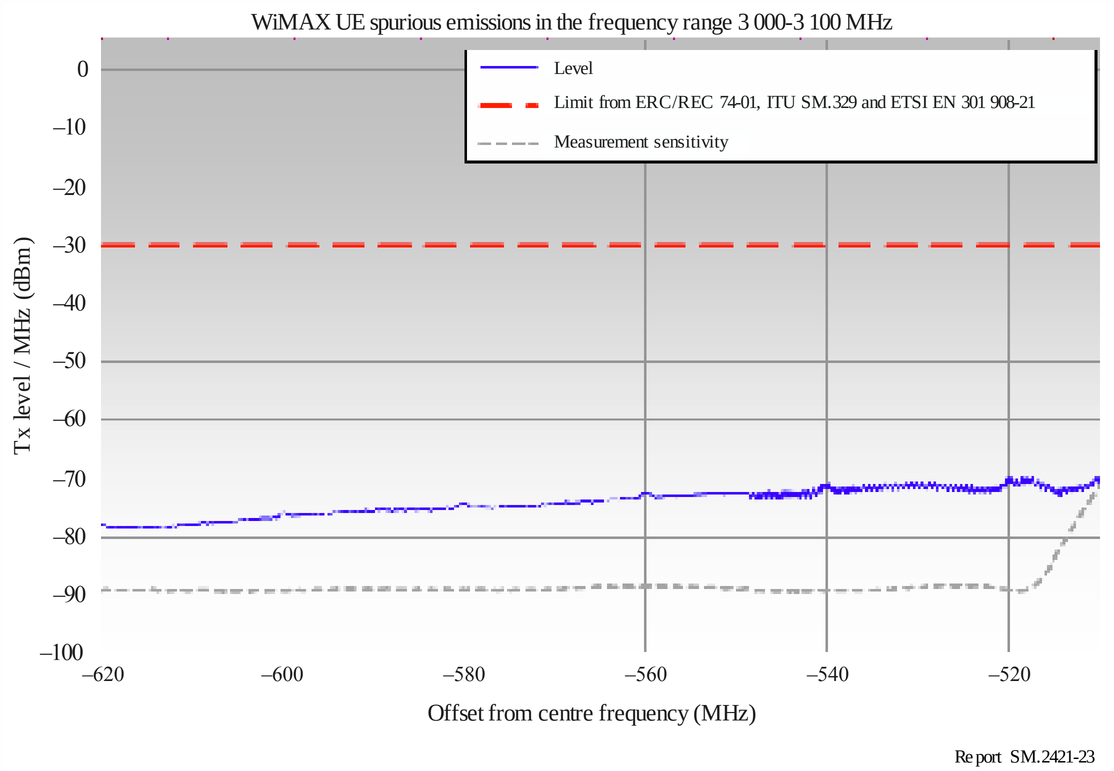
Tx frequency:	3 620 MHz (lowest usable uplink channel)
Tx power:	27 dBm / 500 mW (transmitter output)
Tx external filter:	none
Spurious domain starts at:	25 MHz offset (250% rule)
Measurement bandwidth:	1 MHz.

Although no additional filtering was applied at the transmitter output, some internal filtering must be assumed to protect the own downlink receive band and adjacent services.

Because the measurement and reference bandwidth are equal, no bandwidth conversion is required.

FIGURE 23

UE 3.6 GHz WiMAX - Emissions in radar frequency band



Observations from Fig. 23:

– Although the measurement covers only a small frequency range at a very high offset, it can be seen that the limits are outperformed with a margin of at least 40 dB.

– Even at very high frequency offsets, the level of the spurious emissions is frequency-dependent and tends to fall with higher offsets.

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	ERC/Rec 74-01	ETSI
WiMax 3.6 GHz UE	Figure 23	Although the measurement covers only a small frequency range at a very high offset, it can be seen that the limits are outperformed with a margin of at least 40 dB.		

12 25 GHz Point-to-Point Links

These point-to-point systems are commonly used to connect base stations of the public mobile service (e.g. GSM, UMTS, LTE). Depending on the required data rate, different bandwidths up to 50 MHz are assigned. The common characteristics for this equipment are e.g.:

Frequency range: 25.1-26.5 GHz

Modulation: QPSK or QAM

Bandwidth: 3.5 MHz - 50 MHz (channel)

Tx power: −10 dBm − 24 dBm (transmitter output).

Although no external filters are applied, internal filtering can be assumed to protect the own receiver for the signal from the opposite link station.

12.1 Out-of-band emissions

Figure 24 shows a conducted measurement of unwanted emissions from a 25 GHz Point-to-Point link device. The relevant RF parameters are:

Centre frequency: 25.157 GHz

Modulation: 64 QAM

Bandwidth: 40 MHz (channel)

Tx power: 17 dBm (transmitter output)

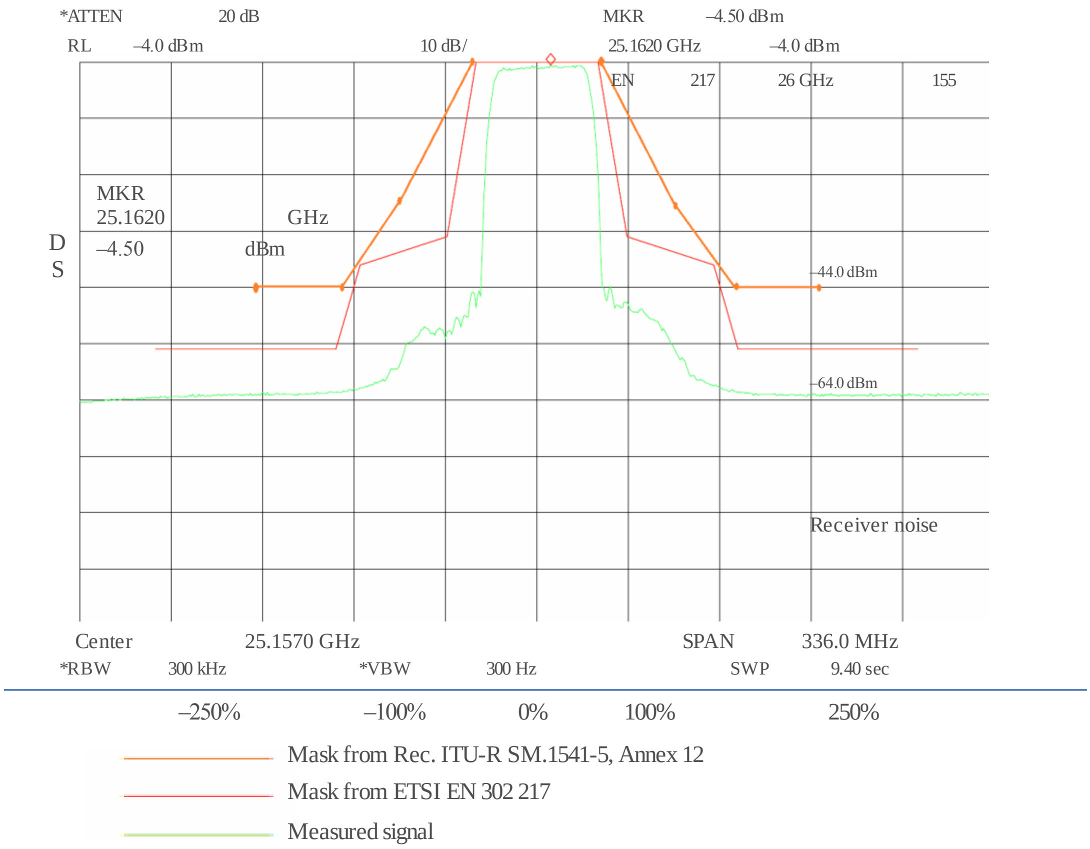
Tx external filter: None

Measurement bandwidth: 300 kHz.

The levels in Fig. 24 are normalised to the maximum in-channel power spectral density in a 300 kHz bandwidth. The generic FS OoB emission limits are taken from ITU-R SM.1541-5, Annex 12 and the specific limits for this system from section 4.2.4.2.1 of ETSI EN 302 217-2-2 and converted into relative levels in 300 kHz.

FIGURE 24

25 GHz Point-to-Point link unwanted emissions



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The measurements for offsets of more than ±75 MHz are limited by the sensitivity of the receiver. In fact, the unwanted emissions in these offset ranges are even higher than shown.

Observations from Fig. 24:

– The OoB generic FS safety net emission limits from Annex 12 of Rec. ITU-R SM.1541 are met with a margin of about 20 dB.

– The specific limit from the section 4.2.4.2.1 of ETSI EN 302 217-2-2 is met with a margin of at least 10 dB.

Regarding OoB emission characteristics and levels, these additional measurements show the same trend as the results presented in Fig. 24.

System	Figure	Comparison with:	
		Rec. ITU-R SM.1541	**ETSI EN 302 217-2-2, section 4.2.4.2.1**
25 GHz Point-to-Point link	Figure 24	The OoB generic FS safety net emission limits from Annex 12 of Rec. ITU-R SM.1541 are met with a margin of about 20 dB.	The specific limit is met with a margin of at least 10 dB.

12.2 Spurious emissions

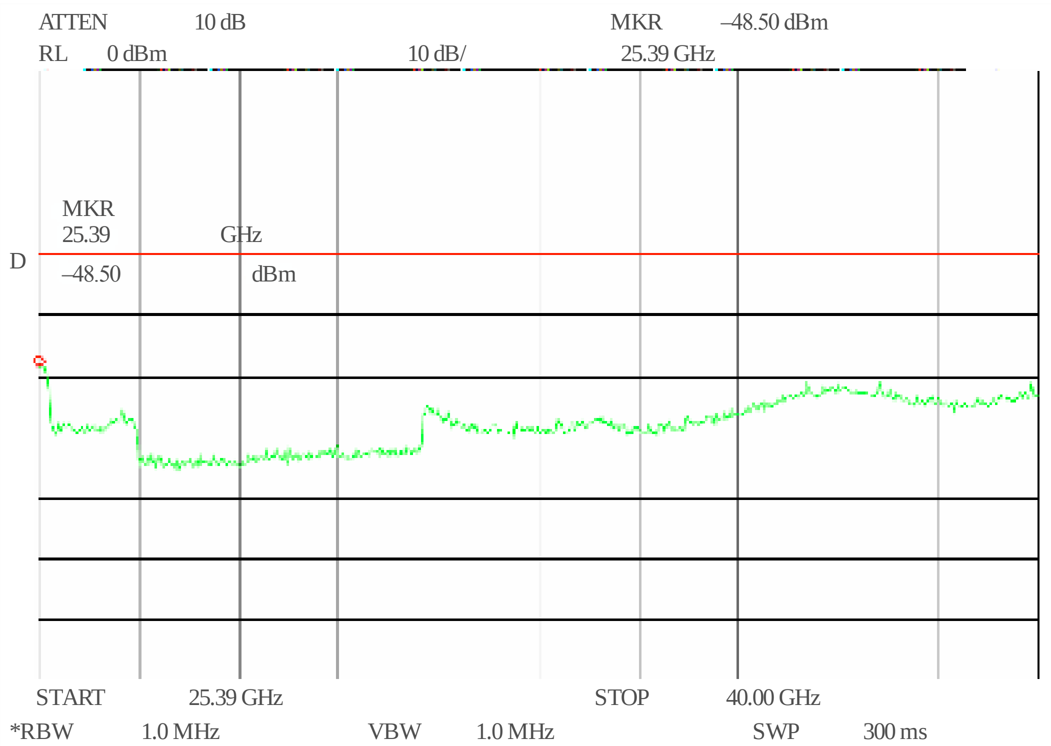
The limit for spurious emissions in ERC/REC 74-01 as well as in Recommendation ITU- R SM.329 (Cat B / Europe) is −30 dBm/MHz.

For the spurious emission limits, the relevant standard, ETSI EN 301 390 also refers in its section 4.1.1 to the limits given in ERC/REC 74-01.

Spurious emission measurements have been performed on a number of point-to-point devices in the 25 GHz range with different channel bandwidths. The following figure shows a typical example of the spurious emissions at the start of the spurious range which is usually most critical, up to 40 GHz. The same device as for the OoB domain above is presented. The measurement bandwidth was 1 MHz. The 0 dB level reference is the in-channel power spectral density in 1 MHz.

FIGURE 25

25 GHz Point to Point link spurious emissions



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Observations from Fig. 25:

– The spurious emission limit is met with a margin of more than 20 dB.

System	Figure	Comparison with:		
		Rec. ITU-R SM.329	**ERC/Rec 74-01**	**ETSI**
25 GHz point-to-point links	Figure 25	The spurious emission limit is met with a margin of more than 20 dB.		

Spurious measurements of the same equipment for other frequency ranges (e.g. 28 GHz, 32 GHz, 38 GHz in the measured range from 25.157 GHz to 40 GHz) have additionally shown that for wider frequency offsets the levels are even lower than physically expected.

Regarding OoB emission characteristics and levels, the additional measurements show the same trend as the result presented in Fig. 25.

13 Filtered and unfiltered systems

National and international frequency management often requires high suppression of unwanted emissions when allocating a frequency band for a specific service in order to prevent harmful interference to neighbouring radio services. In most cases these requirements can only be met if some sort of additional, physical filtering is applied in or after the final stage of the transmitter. In cases where such filters are deployed, the level of the unwanted emissions in the spurious domain is strongly frequency-dependant. In addition, their absolute level is often so low that it cannot be measured. In this case, the spurious emissions cannot cause harmful interference to other radiocommunication services and may therefore be neglected in compatibility/sharing studies.

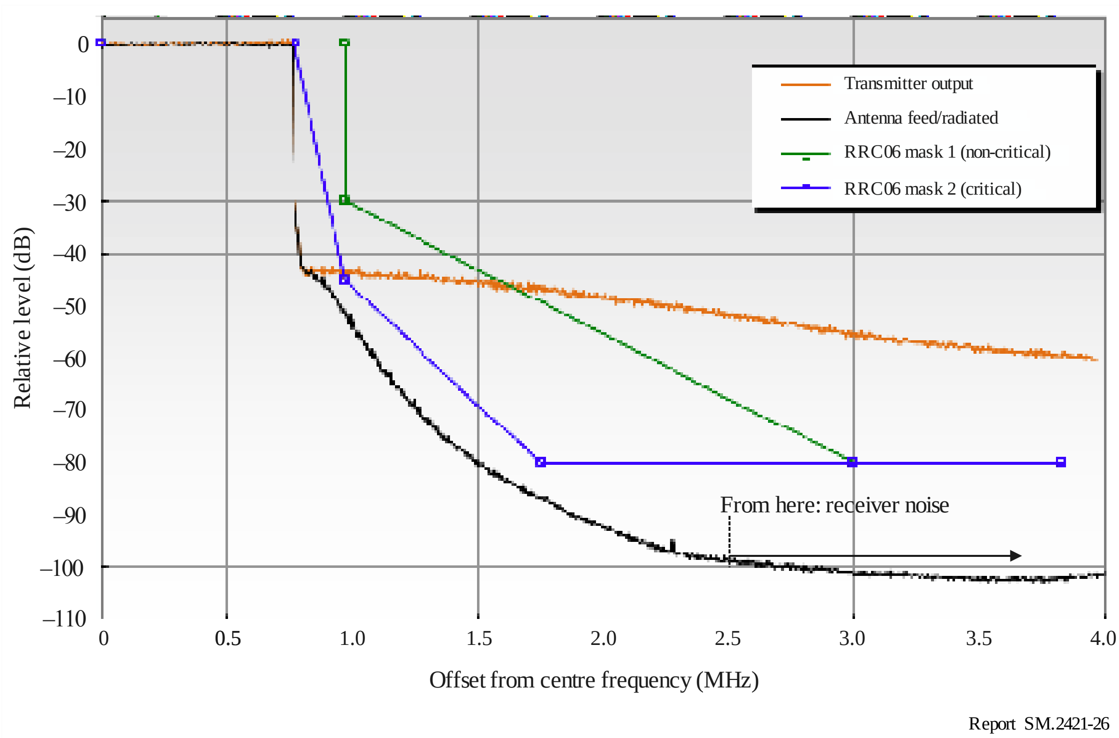
Some examples of systems that always apply filters at the transmitter output are DAB, LTE base stations, and DVB-T.

13.1 DAB

Figure 26 shows the measured unwanted emissions from a DAB transmitter directly at the transmitter output and after the additional filter at the antenna feed.

FIGURE 26

DAB unwanted emissions in the OoB domain



Observations from Fig. 26:

– The unfiltered spectrum cannot meet the GE-06 Mask 1 (non-critical) and GE-06 Mask 2 (critical), which are the OoB emission masks required in Europe.

– The filtered spectrum suppresses the unwanted emissions significantly even in the OoB domain.

– The unwanted emissions in the spurious domain are not measurable and are actually even lower than the noise level shown in Fig. 26.

13.2 LTE800 Base station

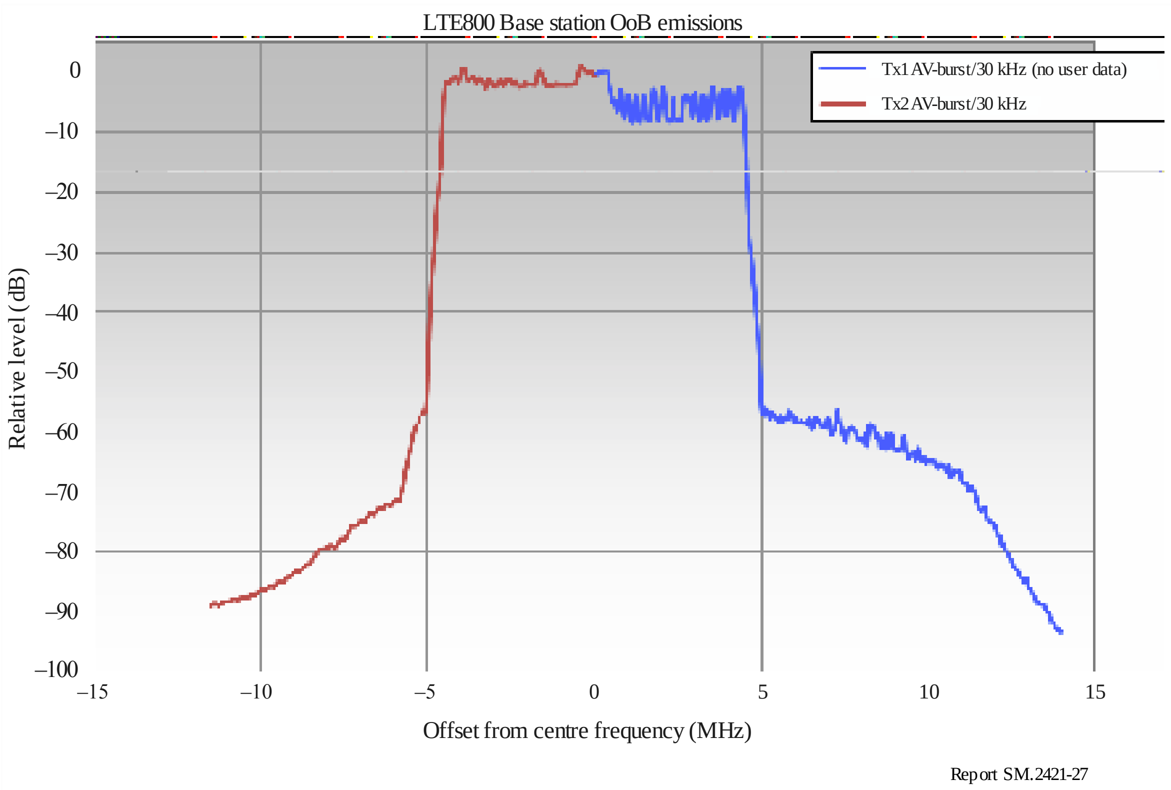
The requirements to supress emissions in adjacent bands may lead to “asymmetrical” OoB emissions because filters have to be applied to suppress emissions in only the lower or the upper adjacent frequency band.

Figure 27 shows OoB emissions from two different LTE800 base stations, both operating on the lowest LTE channel (796 MHz). The upper half comes from a transmitter in idle mode (Tx1), therefore the in-band power of the subcarriers are lower than from Tx2.

It can be seen that the OoB emissions close to the wanted channel are much lower in the lower sideband because a steep filter has to be applied in order to protect the immediately adjacent DVB-T band.

FIGURE 27

Asymmetrical OoB spectra from an LTE800 Base Station



14 Transient emissions in pulsed digital systems

Many TDMA systems produce so-called “transient” unwanted emissions. These are emissions that occur only for very short times during the switching on and off of the transmitter at the beginning and end of each burst. The same effect occurs in some OFDM systems during the changes of the transmitted symbols. Internal design of some TDMA systems also cause the final stage of the transmitter (power amplifier) to stay on continuously, while the bursts, including the on- and off-timing, are generated by the DSP in the baseband.

As a result, there are three different shapes of the unwanted emissions:

– Broadband amplifier noise that is continuously present.

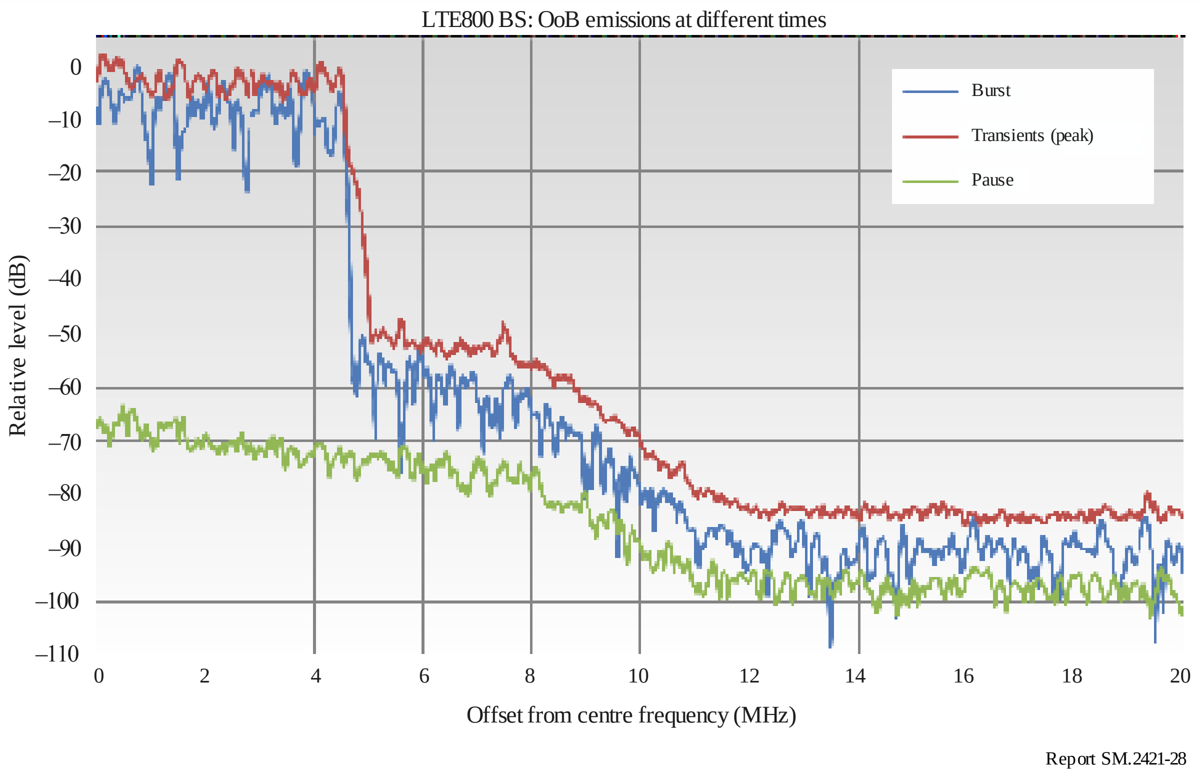
– Modulation dependant sideband emissions, present only during the burst.

– Transient emissions, present only during power ramping or symbol changes.

Figure 28 shows the OoB emissions recorded during a 10 ms frame of an LTE800 base station in all of the above mentioned phases.

FIGURE 28

LTE800 BS: OoB emissions at different times

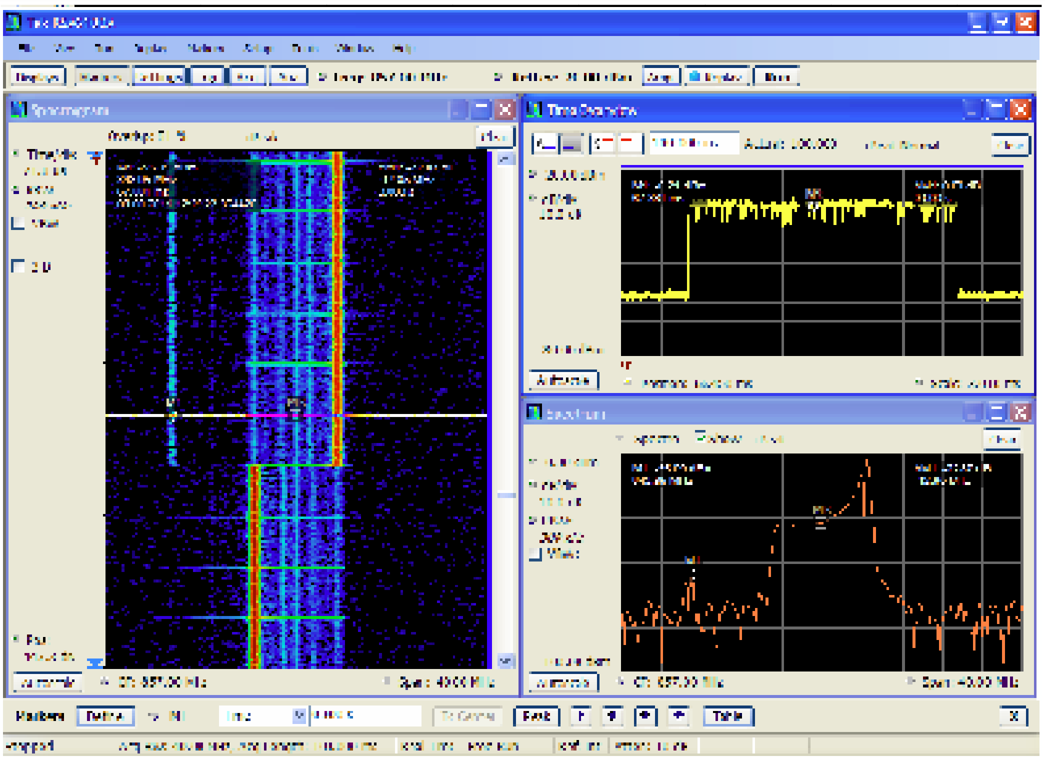


This example gives rise to the discussion whether one limit is enough to realistically represent the interference potential of a pulsed digital system, especially in the OoB domain.

Figure 29 shows the operation of an LTE800 UE device with a high time resolution. Only one resource block is allocated, so the used bandwidth is only 180 kHz. However, every 71 µs the transmitted symbol and the modulation of all used subcarriers change.

FIGURE 29

Spectrum, power versus time and momentary spectrum at the time marked with a line (with points M1 and MR) in the spectrogram of a randomly selected LTE800 UE, high time resolution



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Observation from Fig. 29:

– The OoB emission level rises significantly during the symbol changes (the red circle marks one symbol change).

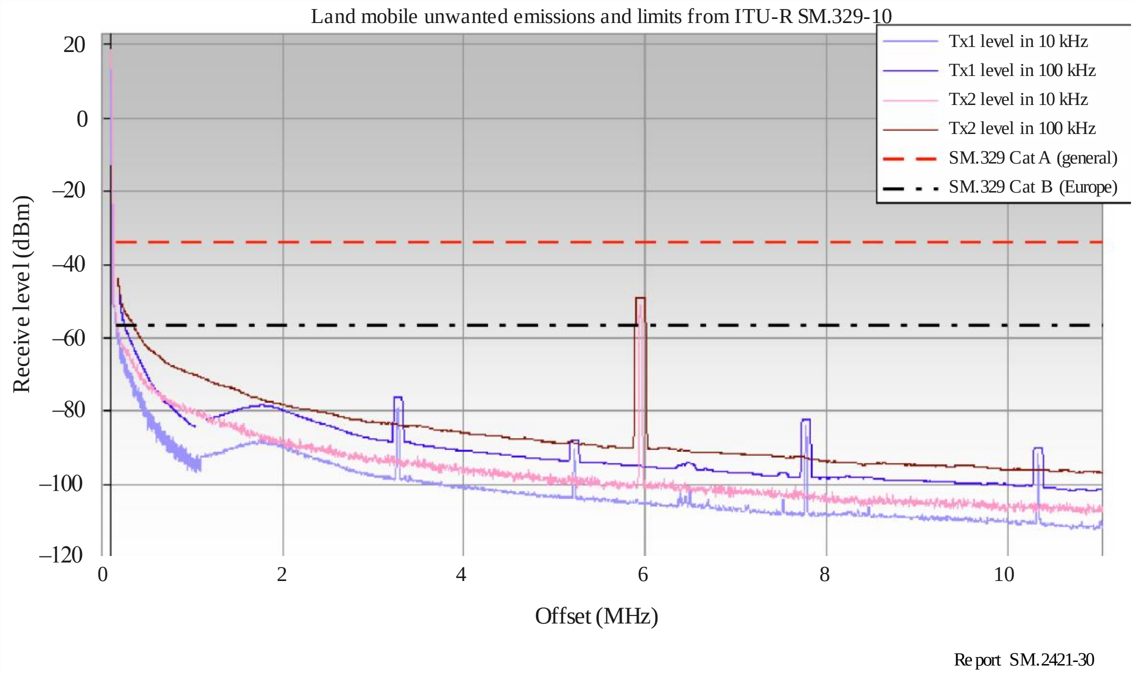
– When the OoB emissions are measured as peak levels, the resulting sideband spectrum will look like during the time of symbol changes. However, as seen in the spectrogram, these worst case emissions occur only for very short time ("transients") and possibly have a different interference potential than if they were present continuously.

15 Narrowband and wideband unwanted emissions

All output stages of transmitter amplifiers produce a certain amount of noise which can be seen as wideband unwanted emissions both in the OoB and spurious domain. In addition to that, analogue transmitters often produce narrowband emissions on single, distinct frequencies in the spurious domain that originate from the RF generation inside the transmitter with various mixing stages and intermediate frequencies. These "peaks" often have significantly higher levels than the wideband noise. Figure 30 shows a typical example of this performance with two different PMR transmitters:

FIGURE 30

Land Mobile spurious emissions from two different PMR transmitters (upper frequency range)



These peaks may be only single, unmodulated carriers. Their level will not change when measured with different bandwidths. Therefore, unwanted levels measured in a narrow bandwidth cannot simply be converted into a reference bandwidth of 100 kHz. In Fig. 30 the unwanted spectra measured with 10 kHz (light blue and light magenta) had to be converted into the reference bandwidth of 100 kHz by applying a sliding integration window (dark blue and brown).

It can be seen that this conversion raises the wideband noise levels by about 10 dB whereas the level of the peaks remain nearly the same.

Modern transmitters of digital systems always generate the RF spectrum digitally in the so-called “baseband”. After D/A conversion, the two baseband components are directly shifted into the RF frequency range by applying I/Q modulation. As a result, no distinct peaks occur in the spurious domain. All of the measurements presented in this document show that the spurious emissions are only wideband in nature. This is the main reason why the spurious emission levels of the measured digital systems are often far below the limits of Recommendation ITU-R SM.329 and ERC/REC 74-01 that accounted for the peaks of analogue systems. One advantage of this behaviour is that the spurious emissions of digital systems can usually be converted into different bandwidths by a constant correction of $10*\log_{10}(BW1/BW2)$.

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