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FREQUENCY MANAGEMENT WORKING GROUP

Assessment report on GSM-R current and future radio environment

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Executive summary

Due to the evolution of public land mobile network (PLMN) technologies, GSM-R radios in Europe will have to operate as specified in the presence of GSM, UMTS and LTE signals in the 900MHz frequency band. It has been demonstrated that particularly the introduction of UMTS or LTE in the 900MHz band will increase the level of interference on GSM-R receivers, over and above the interferences currently experienced due to GSM.

In order to successfully mitigate interferences due to receiver overloading, the GSM-R radios need to be improved with respect to their current, ETSI standards defined radio performance. To enable defining the necessary improvement, and as reference for network coordination, this report provides the UIC view of the *RF environment* that GSM-R receivers have to be able to operate in, in order to ensure full interoperability across all European GSM-R networks. This report itself does not define new technical specifications for the GSM-R radios.

The conclusion of this report is that all GSM-R radios must function as specified when subjected to the following, estimated, PLMN signal levels, measured at the train antenna connector[1]:

- -10dBm for 925-960MHz, cumulative maximum power per 5MHz with GSM-R signal level at -98dBm[2]

  The -98dBm is the minimum 95% coverage level required by the CCS TSI (2012/696/EU) / EIRENE specification [Ref 8].

This level should provide sufficient mitigation against overloading due to strong signals until ca. 2028, until which time the GSM-R system is expected to be operational.

The UIC expects that the above stated level ensures full interoperability for trains within the EU. Any national deviations need to ensure that interoperability is maintained.

It is the UIC's expectation that this estimated RF environment will be provided as input to the ETSI standardization work to improve the technical specifications for the professional mobile station over and above that defined in current TS102 933 v 1.2.1. This UIC report will also be provided as input to the ECC Project Team 54 to foster the work on a new ECC report addressing GSM-R interferences.

As a certain period of time is needed to implement GSM-R radios with improved performance in all trains within the EU, a transition period should be defined in which the maximum allowable PLMN carrier powers, predicted or measured at the railway tracks, should be limited. For this transition period, the UIC suggests that the RF environment will be limited to -35dBm for 925-960MHz, cumulative maximum power per 5MHz, with the GSM-R signal level at -98dBm.

In addition to mitigating interferences due to strong signal levels, also the interferences due to Out Of Band (OOB)[3] emissions have to be resolved in order to allow full coexistence between GSM-R and PLMNs using UMTS / LTE 900. This report demonstrates that current, so-called "realistic levels" [Ref 5] of OOB emissions would either block the use of the EIRENE minimum required coverage level (-98dBm), or would impose severe limitations on either the UMTS / LTE carrier power in the 925-930MHz frequency range, or on the proximity of PLMN transmitters to the railway tracks. Both are probably not acceptable to PLMNs. It should be noted that current 3GPP defined maximum OOB emission levels are even higher than these "realistic levels", thus potentially creating even more interferences on GSM-R.

As interferences due to OOB emissions can only to a very limited extend be mitigated by measures on the GSM-R network side, the UIC assumes that such interferences will be handled by harmonised EU

[1] This assumes a 0dBi train antenna at 4m height, 6dB cable loss (including aging) between antenna and receiver. Also unwanted emissions are assumed to be sufficiently low, i.e. lower than the so-called "realistic levels" [Ref 5].

[2] Note that situations with multiple broadband signals over the 925 – 960MHz frequency band shall be considered

[3] Unwanted emissions consist of Out Of Band and spurious emissions.

and national regulatory actions, for example by defining an adequate relation between OOB emission levels that the PLMNs may create at railway tracks, and GSM-R levels.

The UIC notes that, to ensure railway interoperability across Europe, harmonised levels for handling of strong signals are necessary, as well as the mitigation of OOB emissions. Interoperability in this context means that GSM-R radios in trains continue their correct functioning when crossing international borders, without any hardware or software changes.

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1 Introduction

Due to the evolution of public land mobile networks (PLMNs), GSM-R radios, which originally had been designed to work in a radio environment with only GSM signals in its neighbor frequency band, will have to operate as specified with any mix of GSM, UMTS and LTE neighbor signals, from one or multiple mobile networks. Several study reports, lab measurements and field experience, [Ref 1] to [Ref5], have demonstrated that particularly the introduction of UMTS or LTE in the 900MHz band will increase the level of interference on GSM-R receivers, over and above the interferences currently experienced due to GSM.

Interference to GSM-R is an issue relevant to both national and international railway operation. The focus of this document is to address the handling of interferences for international railway operation, i.e. what is needed to ensure full interoperability, thus enabling trains to cross multiple country borders whilst using GSM-R, without changing anything to the train radio equipment. However, the document is equally valid for national railway operation.

There are three potential interference mechanisms, i.e. interference due to Out Of Band (OOB)emissions, interference due to blocking and/or interference due to intermodulation (IM).

The interferences caused by blocking and/or intermodulation, which are caused by strong PLMN signals received by GSM-R radio's can be mitigated by improving the performance of GSM-R receivers, or by limiting the PLMN emission levels. As however no harmonized limits exist in the EU for PLMN emission levels, interferences due to blocking and/or intermodulation will primarily have to be solved by the GSM-R radios.

The other interference mechanism, i.e. the OOB emissions from PLMNs, can only to a very limited extend be mitigated by measures in the GSM-R network. Instead, the level of such OOB emissions should be limited at the PLMNs.

In order to determine the RF environment / signal level in which the receiver shall still meet the performance quality criteria originally defined in the ETSI TS 100 910 "Radio transmission and reception" (3GPP TS 05.05) [Ref 6], several data sources have been used in this report. At first, the currently known emission limits in EU countries are listed. As next input, data of actual interference cases from the UIC interference database is used.

Subsequently, an extrapolation to the future situation is made. Currently it is expected that GSM-R networks will be in operation until at least 2028. As the implementation of any solution in order to provide adequate interference protection until the GSM-R end-of life is expensive and time consuming, there is a need for a one-shot upgrade of the GSM-R radios. For this, the RF environment scenarios should include the anticipated growth and evolution of the 900MHz PLMNs until that time. This results in rather high levels of anticipated PLMN signal levels at the railway tracks. To create this view, input information has been used from current railway experiences and available knowledge, as well as from the GSMA.

The resulting RF environment estimation should be used as input to updates of the ETSI TS 102 933 "GSM-R improved receiver parameters" [Ref 7], the EIRENE System Requirements Specifications [Ref 8], and possibly to the creation of a stand-alone filter solution specification document (e.g. as a UIC FFFIS or IRS).

As a consequence of the approach taken for this report, no specific technical specification, solution or implementation for mitigating the blocking and/or intermodulation type interferences, is prescribed. Thus, industry and railway operators can themselves determine their preferred technical solution. The concept of a so called “black-box-radio” is introduced, to be used for both cabradios and EDORs, being the technical radio implementation that operates as specified, i.e. meets its functional performance, in the defined radio environment.

Interferences due to blocking and/or intermodulation can be mitigated by two principal technical approaches: to improve the linearity of the receiver to enable handling of strong signals, or to avoid these strong signals getting into the receiver by using a filter functionality.

This implies that the black-box-radio can for example be implemented by adding an external RF filter to existing GSM-R radios, or by designing new GSM-R radios with an improved resistance to interference.

It should be noted that, in case the intermodulation and/or blocking type interference are solved by this black-box-radio, the OOB emission problem must still be solved on the PLMN side.

1.1 Document structure

Chapter 4 of this report provides information on functionality and quality criteria. Chapter 5 describes the relevant interference mechanisms. Then, in chapter 6 the radio environment is analysed in which this improved radio should be able to operate. Chapter 7 derives the maximum RF levels to be handled by GSM-R receivers, and finishes with the conclusions of this report.

1.2 Definitions

In order to support the understanding of this report, the following definitions have been used:

- Power levels.
  All power levels are defined as RMS values, measured in the necessary channel bandwidth and at the maximum output power of the base station transmitter, using for UMTS a test signal defined as Test Model 1.1, as defined in ETSI TS 125.141, clause 6.1.1.1, and for LTE test model 1-1 as defined in ETSI TS 136 141 clause 6.1.1.1. As the measurements reported e.g. by UIC [Ref1] and BNetzA [Ref 5] have also been based on RMS values, the peak to average ratio of UMTS and LTE signals has implicitly been taken into account in the effects of these signals on the GSM-R receivers. Therefore, RMS power levels do not need to be corrected for peak to average ratios.
- Out Of Band emissions.
  Source: 3GPP TS 37.104 “Multi-Standard Radio (MSR) Base Station (BS) radio transmission and reception”. Unwanted emissions consist of out-of-band emissions and spurious emissions. Out of band emissions are the part of unwanted emissions immediately outside the channel bandwidth resulting from the modulation process and non-linearity in the transmitter but excluding spurious emissions. Spurious emissions are emissions which are caused by unwanted transmitter effects such as harmonics emission, parasitic emission, intermodulation products and frequency conversion products, but exclude out of band emissions. The out-of-band emissions requirement for the BS transmitter is specified in terms of an Operating band unwanted emissions requirement that defines limits for emissions in the downlink operating band plus the frequency ranges 10 MHz above and 10 MHz below the band. Emissions outside of this frequency range are limited by a spurious emissions requirement.

  Note: based on this, the spurious emissions from UMTS or LTE signals in the 900MHz band are considered to fall outside of the GSM-R spectrum.
- Blocking of narrowband (GSM, GSM-R) signals; blocking is a condition inside the receiver in which a second signal causes the signal of interest to be suppressed
- Blocking of wideband (UMTS, LTE) signals: in a system with nonlinearities, single or multiple wideband signals create multiple intermodulation products due to the multiplicity of frequency components within the UMTS or LTE carrier. As this effect is already existing for a single wideband carrier, it is tested using a blocking test set-up, and hence is called a blocking effect.

- Intermodulation of narrowband (GSM, GSM-R) signals: this is the amplitude modulation of signals containing two or more different frequencies in a non-linear receiver . This interaction between each frequency component will create additional signals inside the receiver.

2 Functionality and quality criteria

All GSM-R radios, i.e. cabradios, ETCS Data Only Radios (EDORs) and handhelds, have to meet the functional and technical requirements as defined in the EIRENE FRS and SRS. Essentially, ETSI TS100 910 [Ref 6] defines the technical and performance specifications for the GSM-R radios. Additionally, Quality of Service (QoS) requirements specific for ETCS data communication have been defined in the UNISIG Subset 093 [Ref 10].

The functional and performance requirements for GSM-R are not changed by the introduction of PLMN induced interferences. It is the UIC's view that degradation of GSM-R availability or QoS due to interferences is not acceptable. As result, the test methods, philosophy and test limits for the black-box-radio remain the same as those defined in chapter 14 of the ETSI TS 100 607-1 "Mobile Station (MS) conformance specification" (3GPP TS 11.10-1 – [Ref 11]) and paragraph 8.2 of the ETSI TS 100 911 "Radio subsystem link control" (3GPP TS 05.08 – [Ref 12]).

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3 Interference mechanisms

3.1 Blocking and intermodulation

Strong wideband signals (UMTS, LTE) from PLMNs generate intermodulation products inside GSM-R Mobile Station (MS) receivers, covering the entire GSM-R band and therefore increasing the probability of interfering with the serving channel of a GSM-R MS. This has been shown in UIC report O-8725 [Ref 1] and other reports. Also, public GSM base station signals still play a significant role in intermodulation and/or blocking type interference. The high spectral density of a GSM signal in combination with wideband UMTS / LTE signals result in a high probability of interference on GSM-R. The current generation of approved, ETSI compliant GSM-R receivers cannot handle strong signals from PLMNs operating in nearby frequency bands.

In real world deployments, several strong PLMN signals are to be expected in the 925-960MHz band, resulting in high composite receive powers, and a high probability of blocking and/or intermodulation products falling in the GSM-R band. UIC report O-8725 [Ref 1] shows that increasing the frequency separation between the GSM-R and interfering signals only results in a limited reduction of the interference.

In order to enable interoperability of conventional and high-speed trains across Europe, it is essential to determine a set of performance criteria for the GSM-R radio. For this, it is necessary to determine the anticipated future radio environment that it will be subjected to. This environment is defined by the spectral distribution and cumulative RF power caused by the PLMN's wanted emissions in the 925 – 960MHz band, plus the OOB emission falling in the (E-)GSM-R band.

Furthermore, due to physical and practical constraints, there is a limit to the total interfering power that any receiver can handle. This could place an upper limit on the achievable performance of the GSM-R radio, or, vice versa, identify the need for a European harmonized maximum level for the PLMN's emissions along tracksides.

As alternative to improving the performance of the GSM-R radios, one could consider to increase the GSM-R signal levels in order to overcome the interferences as a single sided, railways only, solution. However, as the major interference mechanism is a 3rd order intermodulation effect, as shown in UIC report O-8725 [Ref 1], the Bundesnetzagentur (BNetzA) report [Ref 5] and other reports, the necessary improvement on the GSM-R side would be impractically high. It is to be noted that increasing GSM-R signal levels would lead to smaller radio cells, resulting in increased number of handovers and thus reducing the overall GSM-R system performance. Vice versa, if the PLMNs would reduce their transmission levels by only 1dB, this would correspond to a 3dB reduction of GSM-R interference levels.

3.2 OOB emissions

OOB emissions from PLMN carriers can only to a very limited extend be mitigated by the GSM-R network. However, they have a direct relation with the required strong signal handling capability of the receiver at low GSM-R signal levels. Therefore, it is necessary to understand their impact on the overall performance of a GSM-R system.

OOB emission is that part of the PLMN downlink signal that is emitted into the GSM-R band (918-925MHz). The effect of OOB emissions is that they raise the effective noise floor of the GSM-R radio. This directly translates to a reduction in the carrier to interference ratio (C/I) of the GSM-R radio[4].

[4] Interference components that need to be considered for C/I are the receiver noise figure, unwanted emissions (i.e. Out Of Band emissions), adjacent channel emissions as well as GSM-R's own co-channel emissions

In 3GPP standards [Ref 13] and [Ref 14] the maximum level of OOB emissions have been defined for UMTS respectively LTE carriers. However these levels are rather high, and significantly higher than for GSM carriers. Current UMTS equipment in the field has been shown to have a ca 10 dB or more improved performance. That is the so-called “realistic” level as used in the BNetzA measurements [Ref 5].

For the EIRENE [Ref 8] defined minimum coverage level of -98dBm, this “realistic” OOB emissions level is still too high, as shown in Annex 2. Annex 2 also derives the maximum allowable levels of OOB emissions, received at the railway track, for several GSM-R signal levels.

The UIC assumes that interferences due to OOB emissions will be handled by harmonised EU and national regulatory actions e.g. by defining an adequate relation between OOB emissions that the PLMNs may create at railway tracks, and GSM-R levels.

For the purpose of this report, it has been assumed that the level of OOB emissions is reduced to such a low level that it will allow operation of the GSM-R network at the EIRENE defined minimum coverage level of -98dBm[5]. The effect of this is that for low GSM-R signal levels, the OOB emissions are not a dominant factor for the performance of the receiver. These lower levels of OOB emissions may be achieved by using improved PLMN UMTS/LTE transmitters, or by using improved/additional filtering at those PLMN base station transmitters.

4 Radio environment analysis

This chapter will first provide an overview of currently known maximum allowed power levels of PLMNs, at railway tracks, as currently defined by spectrum regulators in European countries.

Subsequently, actual interference cases, predominantly from GSM networks, with the current generation GSM-R radios, from the UIC interference database will be used to demonstrate the actual signal levels. Also, a view on future developments is given.

These elements are then combined into a maximum anticipated RF environment in which the GSM-R receivers shall operate as specified.

4.1 Licensed RF power levels

The following table (Table 1) shows the maximum RF power levels above the rail tracks, due to public operator base stations, that currently have been defined by national regulators. At this moment, only 2 countries have defined such maximum RF power levels. The purpose of this proactive approach is to protect the high quality of their GSM-R systems.

For all other EU countries, only limits have been defined for the total emitted power from a public operator base station, or, where no such limits have been defined, by health & safety limits. Note that in these cases at rail tracks RF power levels significantly higher than listed in the following table are theoretically possible.

[5] Assuming a -98dBm GSM-R level (this equals to a power level of -104dBm at the receiver input connector), a receiver noise figure of 8dB, a C/I requirement of 9dB, and 6dB loss between antenna and receiver input connector (including a margin for e.g. aging), the maximum total interference level at the train antenna, allowing a 1dB desensitization, is -113dBm/200kHz.

Country	Description	Regulatory power limit at rail track 925-930MHz	Regulatory power limit at rail track 930-960MHz	Remarks
Sweden	For each public operator's UMTS/LTE carrier.	-33dBm /5MHz EIRP	-23dBm /5MHz EIRP -33dBm EIRP/5MHz at ERTMS tracks	Until June 30, 2015
	For each public operator's UMTS/LTE carrier.	-5dBm /5MHz EIRP	0dBm /5MHz EIRP	After June 30, 2015
	Maximum unwanted emissions	-107dBm / 200kHz, or -95dBm @ 6 months' notice	-107dBm or -98dBm @ 6 months' notice	Notification for higher levels possible
Finland	Per carrier only for UMTS	-23dBm /5MHz EIRP	-23dBm /5MHz EIRP	Valid until end 2015
	Maximum unwanted emissions	-107dBm / 200kHz or ensuring 14 dB C/I for GSM-R signal	-107dBm / 200kHz or ensuring 14 dB C/I for GSM-R signal	Valid until end 2015

Table 1 – Country specific regulatory limits

In addition to the above table 1, in one EU country it recently has been agreed between the PLMNs and the GSM-R operator, to use a Common Pilot Channel (CPICH) level of -31dBm, as the starting point for mutual cooperation.

4.2 Interferences in UIC database

The following section describes a statistical analysis of the interference cases described in the UIC database. Although the UIC database at this moment contains more than 660 interference cases, the analysis was conducted on 194 cases, due to GSM carriers, as only for this subset sufficient details were available. The number of UMTS900 interference cases is increasing but these are not yet sufficient to allow a statistical analysis.

The following figure indicates the distribution over the countries of the included interference cases (showing only those cases where information on actual radiated power levels is available).

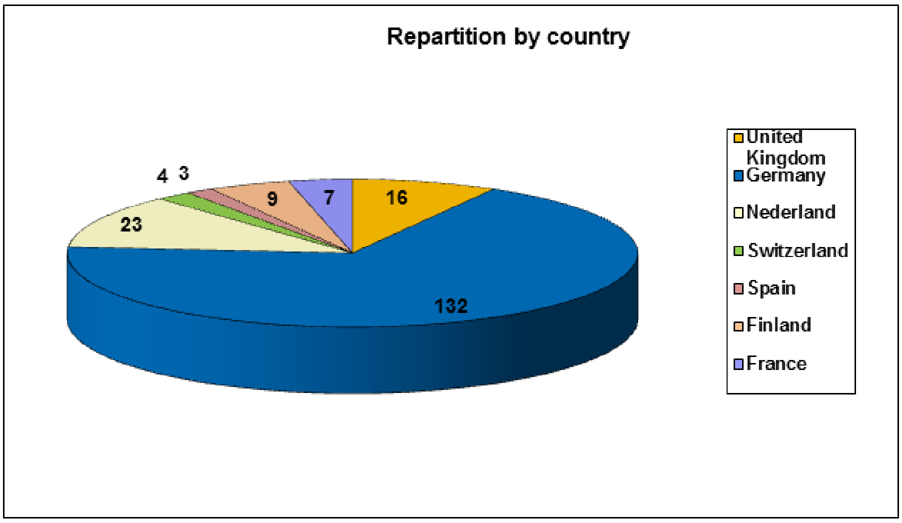

Figure 1 – distribution by country of the number of the GSM interference cases

The following figure (Figure 2) represents an example distribution by level for GSM and GSM-R signals, plus a few UMTS levels for actual (French and Finnish) cases of GSM-R interferences.

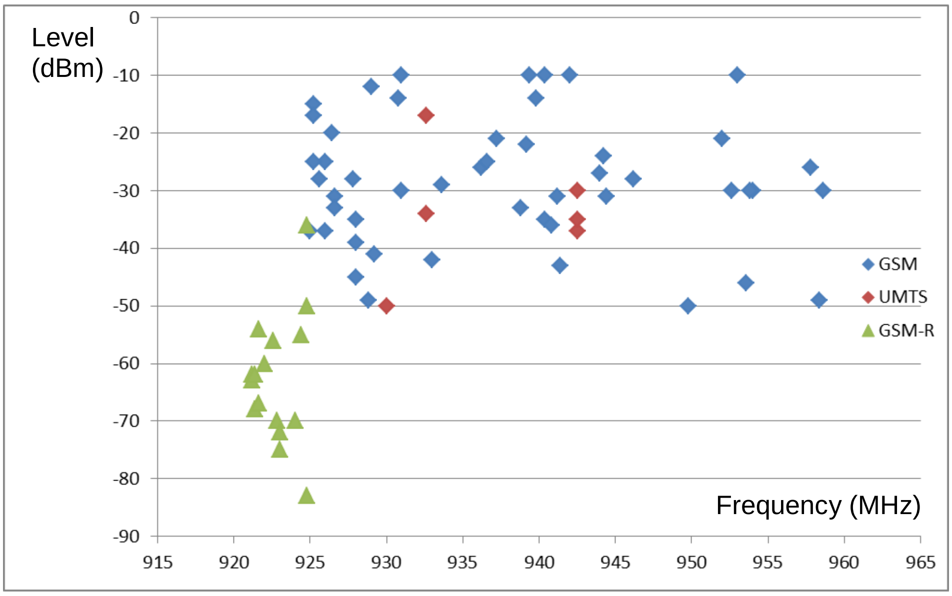

Figure 2 – distribution of interference cases with GSM-R and GSM / UMTS levels (in dBm)

Notes:

1. The GSM-R values shown in figure 2 are well above the minimum EIRENE levels, normally resulting in good GSM-R performance, fulfilling the GSM-R mission. The difference between the GSM-R and PLMN power levels can be explained by the different business targets between rail and public network operators.
2. The figure 2 represents only a small number of GSM-R interference cases where the frequency of interferers was included in the UIC database (total of 16 interfered cases). This figure gives some indication about the difference of levels between GSM-R signals and GSM or UMTS signals from PLMNs. One single interference case can involve multiple interferers (represented in blue and red colors on the figure).
3. As the UIC database is based on field measurements, it is likely that the recorded levels are measured as average values, and only strictly valid at that particular time and position of measurement. Specifically for TCH carriers, they may be lower than the maximum emitted powers that may have caused the actual interference situation. Due to the varying traffic load, GSM carrier levels can vary with some dB, and thus the actual EIRP from the GSM interferers could in fact be higher than what has been recorded in the UIC database. UMTS signal levels too are traffic dependent and normally show larger variations.
4. The shown levels are not representative for the actual GSM-R network coverage design level, but only show the level at the reported interference location. Note that most of the current networks have been designed on the -98dBm / 95% minimum EIRENE coverage level
5. The current database does not contain any information on the frequency separation between the GSM-R carrier and the GSM interferer

For the following graph (Figure 3) showing the distribution of GSM interferer levels, out of the UIC data base,194 cases have been used where detailed measurement data is available.

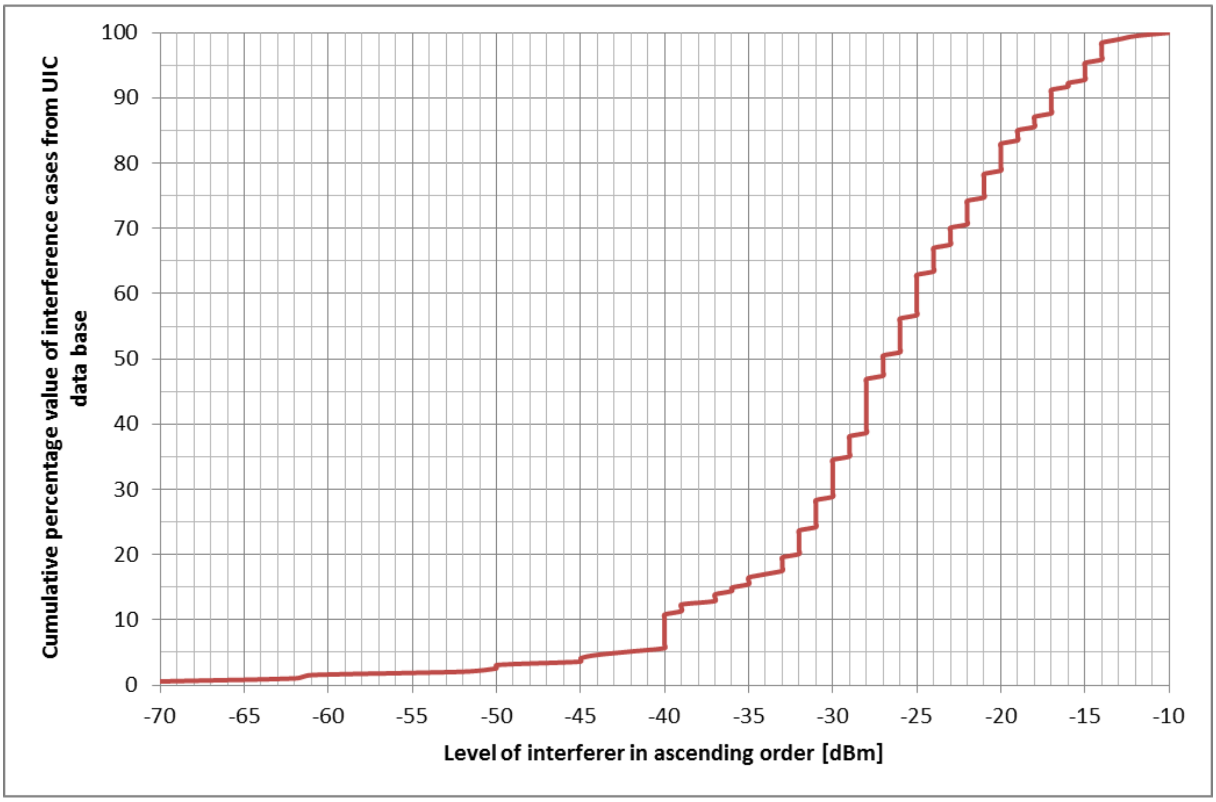

Figure 3 – distribution of GSM interferer levels

The following table (Table 4) for the GSM-R signals and the PLMN GSM interferer signals shows the average power levels, plus their 5% and 95% percentiles (note that these numbers are not directly correlated):

	GSM-R level (dBm)
Average	-73,4
Cut 95%	-53,0
Cut 5%	-91,0

	GSM Interferer level (dBm)
Average	-27,4
Cut 95%	-14,8
Cut 5%	-42,5

Table 4 – distribution of GSM-R and GSM levels

Cut value at 5% means that 5% of the interferer level samples are below a level of -42,5 dBm, or 5% of the GSM-R level samples are below -91 dBm.

Cut value at 95% means that 95% of the interferer level samples are below a level of -14,8 dBm, or, vice versa, 5% of interferer level samples are higher than -14,8 dBm. 95% of the GSM-R level samples are below -53 dBm.

The average difference of level samples between GSM-R and interferer level is typically 46 dB ((-73.4 dBm) – (-27.4 dBm)).

In addition to the above data on GSM interferers, the following table (Table 5) provides some info on UMTS900 interferences reported by one specific country until now.

GSM-R Carrier level dBm/200kHz	GSM Carrier level dBm/200kHz	UMTS 1st Carrier level dBm/5MHz	UMTS 2nd Carrier level dBm/5MHz
-18	-20	-20	-30
-36		-17	
-50		-34	
-60		-37	
-67		-35	
-70	-28	-28	-41
-70		-30	
-71	-61	-30	-47
-72		-50	
-75	-25	-25	-50
-75	-30	-30	-30
-78	-28	-28	
-79		-15	
-79	-36	-32	
-80	-35	-35	-35
-80	-50	-39	-40
-85	-35	-26	-40

Table 5 – UMTS and GSM interferer levels in one EU country

It is expected that in most cases the existing GSM900 base station locations will be reused for UMTS / LTE900. This is possible as the link budgets for GSM, UMTS or LTE are very similar. If anything, it is to be expected that for UMTS or LTE higher transmit powers will be used in the future in order to support the higher data rates expected by the mobile network's customers.

4.3 Future view on PLMN RF power levels

In view of the general mobile market trend of ever increasing mobile data volumes, with e.g. Cisco predicting a 66% increase year on year, one should expect that mobile networks need to significantly increase their data traffic capacity.

For this report, based on general market and technology information, and input from the GSMA, the following effects on the PLMN RF levels are assumed:

- The ever increasing usage of mobile Internet and other mobile applications translates to higher data rates, which can be achieved by moving from the currently used 16QAM to 64QAM or perhaps even 128QAM modulation schemes. These higher modulation schemes need increasing signal to noise ratios, resulting in higher wanted emission levels from the PLMNs. The following graph suggests that to step from 16QAM to 64QAM to 128QAM the signal to noise ratio needs to be increased by ca 6dB per step. Information from the GSMA suggests that 64QAM is likely to be deployed for UMTS or LTE, but 128QAM not.

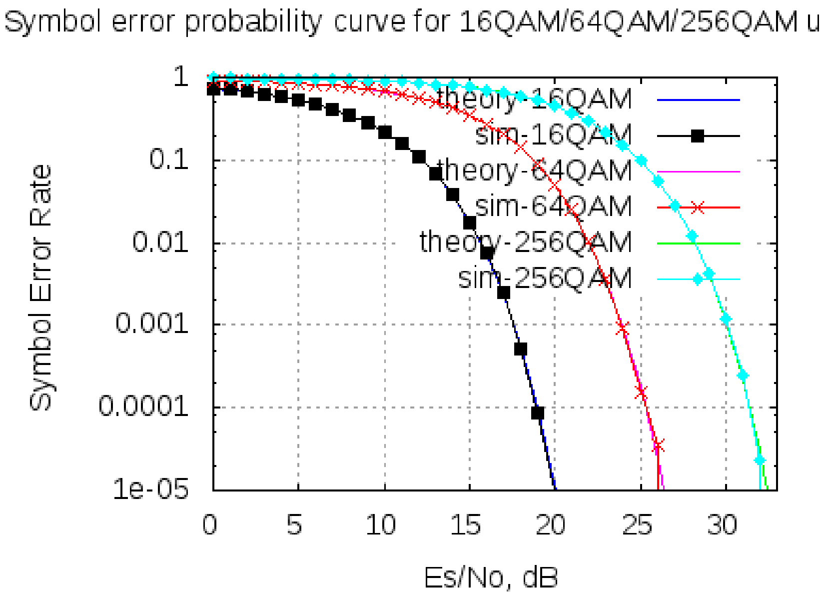

Fig 4 – Necessary C/I for different modulation schemes

- Modern multi standard base stations are capable of transmitting at higher power levels (e.g. +46 or even +49dBm/5MHz) than previous GSM versions (+43dBm/200kHz). Also so-called remote radio heads can be used, which avoid the feeder losses between the base station transmitter and antennas. These can enable a 3dB or more increase of radiated power, thus allowing the above described power increases for higher modulation schemes, and potentially resulting in higher signal levels at rail tracks then currently experienced,

- Also wider bandwidths (2x5MHz dual cell for UMTS, or 10 and perhaps even 15MHz carriers for LTE) can be introduced to support increasing traffic needs. A 2x5MHz dual cell can be implemented at the same radiated power levels as a 1x5MHz cell due to the high available output power of modern multi carrier/standards base stations. In other words, EIRP levels are not expected to be reduced when using wider carrier bandwidths

- Higher data rates can also be gained from the introduction of UMTS or LTE MIMO technology. Using 2x2 MIMO would result in a 3dB higher EIRP level, and using a 4x2 or 4x4 scheme would even result in a 6dB increase, compared to today's SISO power levels. Note that when using MIMO, also the OOB emission levels increase by 3 respectively 6dB. Information from the GSMA suggests that for UMTS no MIMO is expected to be deployed, and for LTE 2x2MIMO will be the standard. Higher MIMO schemes are said to be unlikely due to e.g. limitations in the physical antennas.

For the 900MHz band the above described mechanisms are highly likely to be used by the public operators, due to the good wide area and indoor coverage characteristics at this frequency band.
It is felt unlikely that all possible power increases will actually be used in realistic deployment scenarios, e.g. also due to the potential of self-interference in the operator's own network or to other public operators' networks. Therefore, a somewhat restrained total view is taken on the total effect on the anticipated MNO EIRP levels that need to be taken into account for a longer term view:

- Assume only 2x2MIMO usage for LTE, resulting in a 3dB EIRP increase
- Assume that for increasing from 16QAM to 64QAM 2x2 MIMO is used plus a 3dB power increase, which is easily available from the modern multi carrier/standard base stations. This results in a total increase of 6dB over currently experienced EIRP levels.

4.4 RF scenarios for cabradio

As further input to derive the maximum RF environment that the black-box radio will be subjected to, a number of actual interference scenarios, reported in the UIC interference database, are described in Annex 1.

4.5 RF scenarios for Handhelds

Similar as for cabradios and EDORs, GSM-R handhelds will be subjected to an RF environment with strong signals from GSM, UMTS and/or LTE emitters, and thus are prone to interferences. As handhelds are used for example in shunting areas, good performance of these mobile terminals is equally important as that of the cabradios.

The differences between handhelds and cabradios, for example due to the integrated antenna versus a train rooftop antenna, and the effects of strong UMTS / LTE900 signals, should be considered by ETSI when modifying the ETSI specification documents.

5 Conclusions on RF environment to be handled

5.1 Estimation of maximum PLMN RF levels to be handled

The purpose of this document is to provide the UIC view on the RF environment that **interoperable trains** will encounter in Europe until the GSM-R end of life, i.e. until ca. 2028. In this RF environment the black-box radio (used as cabradio or EDOR) must be able to operate as specified. It should be based on a realistic estimation of the PLMN carrier levels that can be expected. This however is not necessarily the absolute worst case situation that a GSM-R radio can encounter in the various EU countries. Note that all following signal levels are defined relative to a 0dBi antenna at 4m height.

To arrive at the maximum RF environment that the GSM-R black-box radio must be able to operate in as specified, the following considerations are taken into account:

- From the UIC interference database, the average level of current PLMN interfering GSM signals creating interferences is ca. -27dBm. It also shows that 5% of all GSM interference cases exceed a level of ca. -15dBm. As the UIC database contains data measured in the field, the actual interferer power level causing the interference incident may possibly be some dB higher, due to for example traffic patterns. Note that the actual GSM-R signal levels differ for the various interference cases.
- It is assumed that the black-box radio will use some RF filter function, which will ensure that UMTS / LTE signals above 930MHz will not create intermodulation products in the GSM-R band. When such filter function would not be used, the receiver will be subject to the total power of all signals received in the 925-960MHz band, resulting in a worst case increase, assuming no further frequency selectivity, of 8,45dB (for 7 interferers each 5MHz wide) compared to the case of a single 5MHz wide UMTS/LTE interferer.
- Actual (GSM) interference cases show worst case field measured RF levels up to -6dBm, which, similar as for the UIC database information, may be lower than the power level actually causing the interference incident.
- The future view suggests that today's power levels can be increased by in total 6dB (for MIMO combined with increased transmitting power to allow a higher modulation order (as enabled by the RF power available in modern base station transmitters).
- It is to be noted that some national regulators indicate that levels higher than perhaps -10dBm are unrealistic.
- The Swedish regulator has defined a maximum signal level at railways of -5dBm for 925-930MHz, and 0dBm for 930-960MHz (all cumulative per 5MHz).

By taking the above mentioned 5% interferer level of ca. -15dBm, and adding to that the anticipated future increase of 6dB, the maximum future interferer level can be estimated to be around -10dBm, assuming a 5MHz UMTS or LTE carrier.

The maximum interferer target level needs to be defined based on the EIRENE minimum coverage level of -98dBm. This plus the above then suggests that the RF environment that the black-box radio (relative to a 0dBi antenna at 4m height) must operate in, is:

- -10dBm for 925-960MHz, cumulative maximum power per 5MHz with GSM-R signal level at -98dBm.

Note that the amount of interference that can be handled by a receiver increases for increasing GSM-R wanted signal levels (as shown by the test results in [Ref 1] and [Ref 5]). Therefore, the above defined -10dBm interferer level would increase to for example ca. -6dBm at a GSM-R signal level of -86dBm.

The -10dBm value was discussed, verified and confirmed by the ETSI working group TG EGSM-R, which is defining the update to the ETSI TS102 933 (Railway Telecommunications; GSM-R improved receiver parameters). It reflects the currently achievable performance for GSM-R state of the art technology.

As also explained in paragraph 5.3, for this document it has been assumed that the level of OOB emissions is reduced to a low level that will allow operation of the GSM-R network at -98dBm.

The UIC expects that the above defined level ensures full interoperability for trains within the EU. Any national deviations need to ensure that interoperability is maintained.

As a certain period of time is needed to implement GSM-R radios with improved performance in all trains within the EU, a transition period is needed in which the maximum allowable PLMN carrier powers, predicted or measured at the railway tracks, should be limited, For this transition period, the UIC suggests that the RF environment will be limited to -35dBm for 925-960MHz, cumulative maximum power per 5MHz, with the GSM-R signal level at -98dBm.

The value of -35 dBm given in this report for the transition period is directly linked to the EIRENE minimum coverage level of -98dBm and based on national and international experiences. This value is used in UK as the trigger to start the coordination/ cooperation between GSM-R and PLMN, It is also derived from the Red-M report “Analysis of Field Testing Results of Mobile Operator GSM & UMTS Interference on Network Rail GSM-R Mobiles Laboratory Test Report (Redacted)”[Ref15], as shown in Fig 5 below.

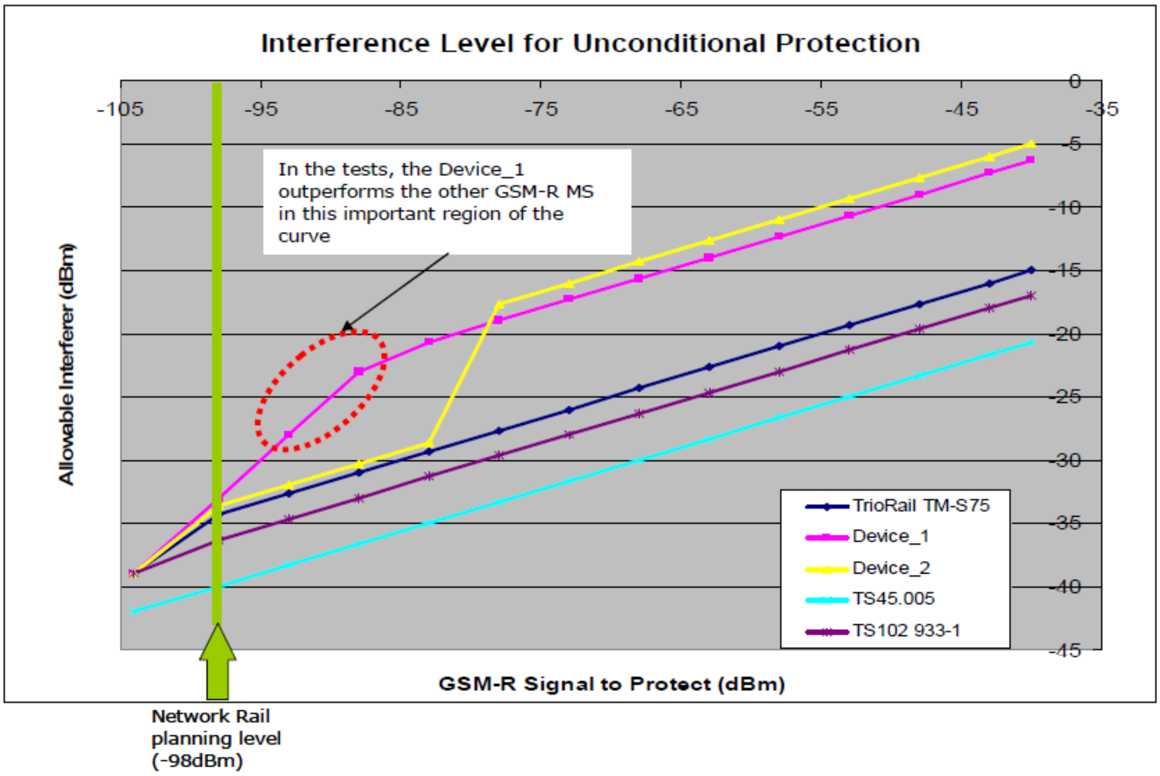

Fig 5 – Transition period interferer level

5.2 Conclusions

In order to enable handling of strong signals by interoperable GSM-R radios, this document introduces the concept of a black-box-radio, and estimates the maximum RF levels in which this has to operate as specified. The black-box-radio is to be used for cabradio and EDOR, and can be implemented as a combination of an existing GSM-R radio plus an external filter, or as an improved receiver which could include e.g. internal filter functionality and/or improved linearity. The detailed technical specification of the black-box-radio is left to an ETSI standard (improved version of ETSI TS 102 933 [Ref 7]. Additionally, a detailed specification for an external filter will be provided in a separate UIC document FFFIS or IRS (to be determined).

The report defines the maximum RF environment for cabradios and EDORs as -10dBm cumulative per 5MHz, for 925-960MHz, with the GSM-R signal level at -98dBm.

When the handling of strong signals has been solved, the issue of OOB emissions remains. As these can only to a very limited extend be mitigated by measures on the GSM-R network side, it is assumed that interferences due to OOB emissions will be handled by harmonised EU and national regulatory actions e.g. by defining an adequate relation between OOB emissions that the PLMNs may create at railway tracks, and GSM-R levels.

References

Ref	Name	Source	Date
1	UIC O-8725, version 2.1	UIC	2013-06-29
2	Study on the impact of coexistence of GSM-R and UMTS / LTE in the 900 MHz band	Trafikverket / Afconsult	2011-10-15
3	Analysis of Field Testing Results of Mobile Operator GSM & UMTS Interference on Network Rail GSM-R Mobiles,	NetworkRail / Red-M	2012-03-29
4	UMTS900 – GSM-R interference measurements,	Ofcom / Red-M	2011-06-20
5	Measurement report compatibility measurements GSM/UMTS/LTE VS. GSM-R, Version 3.0, including Annex 6 to CG-GSM-R(13)024 October 2013	Bundesnetzagentur	2013-09-25
6	ETSI TS100 910 / 3GPP TS 05.05 V 8.20.0	ETSI / 3GPP	2005-11
7	ETSI TS 102 933-1 V1.2.1	ETSI / 3GPP	2011-12
8	EIRENE SRS v15.3.0	UIC	2012-05
9	CCS TSI (2012/88/EU, amended by 2012/696/EU)	EU	2012-11-06
10	UNISIG Subset 093 V2.3.0	UNISIG	2005-10
11	ETSI TS 100 607-1 / 3GPP TS 11.10-1 v8.3.0	ETSI / 3GPP	2001-09
12	ETSI TS 100 911 / 3GPP TS 45.008 v8.23.0	ETSI / 3GPP	2006-01
13	ETSI TS 125 104 / 3GPP TS 25.104 v10.0.0	ETSI / 3GPP	2011-01
14	ETSI TS 136 104 / 3GPP TS 36.104 v10.5.0	ETSI / 3GPP	2010-10
15	Analysis of Field Testing Results of Mobile Operator GSM & UMTS Interference on Network Rail GSM-R Mobiles Laboratory Test Report (Redacted)	Network Rail / Red-M	2012-3

Annex 1 Examples of interference cases.

	Distance of MNO site to railtrack (m)	Is near a railway station, level crossing or other safety related location	GSM-R level (dBm at 0dBi antenna)	GSM-R frequency (MHz)	Interferer antenna height above ground (m)	Number if MNOs radiating from the site	Number of sectors, and antenna direction relative to track	Interferer radiated power level (dBm EIRP)	calculated interferer level GSM (dBm/200kHz)	measured interferer level GSM (dBm/200kHz)	GSM interferer frequency	calculated interferer level (dBm/5MHz)	measured interferer level (dBm/5MHz)	UMTS interferer frequency (MHz)	Comments
Mäkkylä, Finland	40	railway station	-70	921,2	9	1	three sectors with one for the track			-12	927,4		-12	932,6	Regulator intervened to reduce UMTS to -23, GSM still at -12 still under discussion the regulator
Linnunlaulu, Finland	10	shuntin g yard	-68	921,4, 921,8 922,2	8	1	one sector and one antenna direction towards track			-6 per chan nel	942,0 940,4 946,8				Interference solved by move to 1800MHz; Finnish frequency regulatory view is that this high power level must be avoided
Pukinmäki, Finland	50	railway station	-37	921,6	20	3	three sectors and one for the track			-17 and -15	928,8 935,0		-13	932,6	still interference at high GSM-R level
Amsterdam RAI Netherlands	10	near railway station			10	1	3 sectors, 1 pointing directly at track	55		-11		-16			
Hardinxveld-Giesendam Netherlands	56	near railway station		923	12	1	3 sectors, 1 pointing directly at track			-16 and -14	930,4 and 933,8				Interference solved by PLMN change of frequency
Albertville France	50		-75	Ch 964, 973	20	2	three sectors and one for the track			-30 each	Ch 975, 981 987		-55	930	Dropped call due to IM3, probably due to GSM; built additional site

Annex 2 Derivation of OOB emission levels

Although this report focuses on handling of strong signals, once this interference aspect has been solved, still interferences due to OOB emissions may exist. Note that with any black-box radio solution, OOB emissions could remain the dominating issue for GSM-R networks at low GSM-R signal levels. Therefore it is important to address OOB emissions in this report, and identify means how to avoid interferences due to these.

The purpose of this annex is to demonstrate that, for GSM-R networks designed on the basis of the current EIRENE minimum coverage requirements, the OOB emissions from PLMN networks, received at railway tracks, have to be lower than the so-called realistic levels as used by BNetzA [Ref 5], and thus also significantly lower than the levels defined in the 3GPP specifications [Ref 13], [Ref 14]. Otherwise, significant limitations have to be placed on the PLMN carrier power received at railway tracks.

The EIRENE minimum coverage level (-98dBm[6]) is based on the situation where there are no external noise sources such as OOB emissions. This EIRENE minimum coverage includes 3 dB margin for cable loss, plus 3 dB margin for other effects, e.g. aging, and additional losses for splitters or filters,
To calculate the maximum allowable level of OOB emissions, the noise floor of the GSM-R radio has to be taken as a reference. Thermal noise level at 200 kHz bandwidth is -121 dBm, and if the noise figure of a cab radio is 8 dB (this is typical for currently deployed radios), then the noise floor of the receiver is -113 dBm. The OOB emissions add to this receiver noise floor, and if the negative effect (desensitization) of this is wanted to be not more than 1 dB, then the maximum OOB emission at the train antenna is maximum -113 dBm/200kHz.

The value of 1 dB as acceptable receiver desensitization is commonly used in standardization work. Furthermore in ETSI discussions on the Extended GSM-R band, the acceptable desensitization for an eUTRA base station in the presence of an ER-GSM base station has been defined at 0,8 dB (for further details see CG-GSM-R(13)005.
.
It should be noted that in these calculations only the effects of OOB emissions on the required C/I have been included. In real networks the total external interference power, cumulative over all contributors (such as multiple PLMNs, co-channel and adjacent channel signals) has to be taken into account This will result in maximum OOB emission levels having to be lower than shown in these calculations.

An alternative approach to demonstrate this issue is to calculate the maximum allowable PLMN carrier power level at the railway tracks, based on e.g. the EIRENE -98dBm minimum coverage and the BNetzA data [Ref 5] for the so-called realistic levels of OOB emissions relative to the PLMN carrier power.

This results in the following table:

GSM-R carrier dBm/200kHz	C/I dB	Resulting max cumulative OOB emissions at 0dBi antenna. dBm/200kHz	Max UMTS carrier level at 0dBi antenna. UMTS at 927,6MHz and GSM-R at 924.4 - 924.8MHz dBm/5MHz	Max UMTS carreir level at 0dBi antenna. UMTS >=932,6MHz and GSM-R <=924,6MHz dBm/5MHz
-98	9	-113	-47	-38
-85	9	-94	-28	-19
-72	9	-81	-15	-6
Notes:	1	All levels only applicable at rail track		
	2	Note that 1dB desensitization is valid only at the -98dBm GSM-R level		

Table 6 Max. carrier levels based on OOB emissions.

[6] Calculations in this report are all based on the EIRENE defined 95% minimum coverage probability. This may be related to a 50% probability value by use of a correction factor. However that correction factor depends on the actual propagation, fading and terrain aspects; it typically varies between ca. 10 and 13dB.

The above table also demonstrates the effect of frequency separation between the wanted GSM-R signal and the interfering UMTS/LTE carrier, based on the spectral power distribution used in the BNetzA measurement report [Ref5], as depicted below.

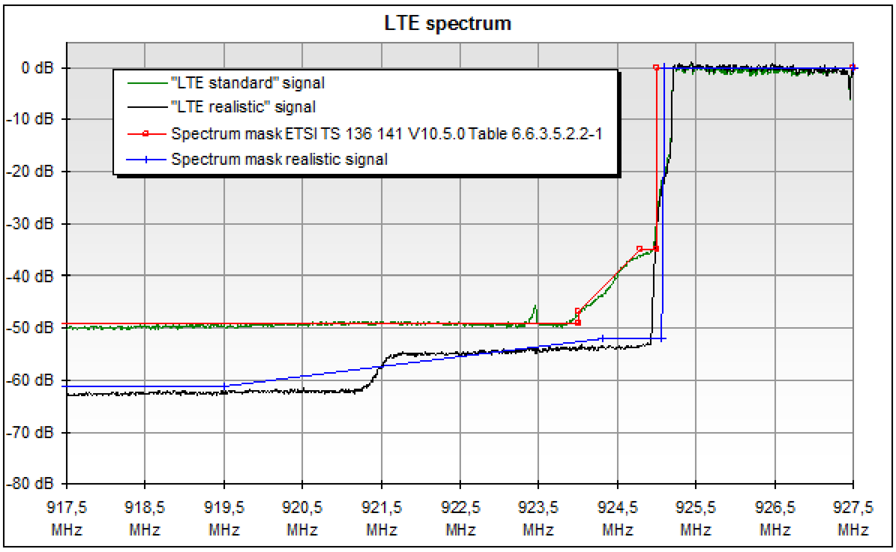

Fig 6 - Spectral power distribution

The following table provides the calculations used to create the above table,

EIRENE minimum coverage level is -98dBm at train antenna	signal level	-98 dBm	
Allowable reduction of receive sensitivity	desensitization	1 dB	
EIRENE defined cable loss	cable loss	3 dB	
EIRENE defined additional loss for other factors such as aging	other factors	3 dB	
C/I required for voice	C/I required	9 dB	
Total noise allowable at the radio module connector	allowable I total	-112 dBm	6,30957E-12 Watt
Noise factor of the currently deployed receiver types	noisefigure Rx	8 dB	
Receiver thermal noise floor for 200kHz bandwidth	noisefloor Rx	-113 dBm	5,01187E-12 Watt
Allowable interference level at the radio module connector	external InterferenceRx	-118,9 dBm	1,2977E-12 Watt
Allowable interference level at the train antenna	external Interference@antenna	-112,9 dBm/200kHz	
UMTS unwanted emission suppression ("realistic" level)	unwanted emission suppression	61 dBc	
Maximum UMTS carrier level at train antenna	max UMTS carrier level@antenna	-51,9 dBm/200kHz	
Maximum UMTS carrier level at train antenna	max UMTS carrier level@antenna	-37,9 dBm/5MHz	
Note 1: External interference = co-channel + adjacent channel + unwanted emissions			
Note 2: The train antenna is assumed to have 0dBi gain			

Table 7 - Max. carrier level calculation.

This table clearly shows that the “realistic” level of the OOB emissions is too high to be used with the -98dBm EIRENE minimum coverage level at any realistic and useful UMTS / LTE carrier level. Even for stronger GSM-R levels the OOB emissions are too high. As a consequence, the maximum OOB emissions of a UMTS or LTE carrier need to be reduced.

It is to be noted that, in case e.g. 2x2MIMO is deployed by the PLMNs, or with higher modulation schemes such as 64QAM, the OOB emission levels are expected to increase by the same ratio as the carrier power increase. Thus 2x2MIMO would result in 3dB increased carrier power plus a 3dB increase of the OOB emissions, and a combination of 2x2MIMO + 64QAM would result in 6dB increased carrier power plus a 6dB increase of the OOB emissions.

The above table clearly demonstrates that, in addition to improving the GSM-R receivers in order to enable handling of strong signals, also measures are necessary on the PLMN networks to define and handle the levels of OOB emissions..

There are two technical possibilities to reduce the interference effects of OOB emissions. Either the level of OOB emissions has to be reduced (e.g. by using filters) in the PLMN base stations, or
the wanted GSM-R signal level has to be increased. For each case an operational and economic evaluation of all impacts is necessary. In situations where a PLMN base station is far enough from a railway track there might be no need for mitigation measures. In practice however, public operators will

want to use their base stations close to railway tracks and then this OOB emissions issue has to be considered very carefully.

The results shown above can also be related as an example to the current Swedish situation. Note that the Swedish network is designed for a signal level higher than the EIRENE minimum requirement. A public mobile operator is allowed by the Swedish regulator to create a signal level of -5 dBm / 5MHz within 925 – 930MHz, measured at a 0 dBi train antenna at the railway track. It is also allowed for that operator to cause -95 dBm / 200kHz OOB emission in the GSM-R band. If the composite effect for other 900 MHz Swedish operators is not taken into account, we can derive that with 9 dB C/I the minimum level at the antenna for the wanted GSM-R carrier in this case is -86 dBm.

Vice versa, when starting at the allowed -5dBm / 5MHz carrier level at the railway track, in order to achieve the -95dBm /200kHz OOB emission level, the OOB emissions must be 90dB below the UMTS carrier, measured over its nominal bandwidth. The BNetzA report [Ref 5] has shown that for the so called realistic OOB emission levels, the difference between OOB emissions seen in a 200 kHz bandwidth and the UMTS/LTE carrier is about 65dB for a UMTS carrier at 927,6 MHz. This implies that the Swedish limits can only be achieved if the UMTS base station applies an extra attenuation of the OOB emissions of ca. 25dB.

This annex demonstrates that there is a strong need for a clear definition of OOB emission levels versus GSM-R levels; essentially some balance between these parameters needs to be defined.

It is the UIC's view that, in order to maintain the EIRENE defined minimum GSM-R coverage level, the allowed level of OOB emissions needs to be handled by harmonised EU or national regulatory actions, for example by defining an adequate relation between OOB emissions that the PLMNs may create at railway tracks, and GSM-R levels. Note that Sweden and Finland already have defined specific maxim values for this, as listed in Table 1.