Information on a common measurement report of APWPT and the DKE WG 731.0.8 (DIN/VDE)

A study of LTE interference potential with regard to PMSE operation[1]

Executive Summary

Previous compatibility work has used either signal generator modulation based on the ETSI standards or recorded signals from a single manufacturer, this set of tests consists of two parts:

1. Off air using working LTE base station and UE
2. Actual UE controlled by a R&S "base station emulator"

The results of using actual equipment add the next stage to the compatibility work and the overall findings are summarized below:

1) Actual LTE signals produce a range of transient products not present in the previous laboratory testing.
2) Using signals of 100%, 50% and idle mode are insufficient for compatibility testing.
3) Production of these transients is proportional to the change in number of resource blocks allocated in combination with the power control.
4) These combinations stimulate transients both in the duplex gap and the 862-870 MHz band
5) In the 3m scenario we measured harmful interference effects to wireless microphone receivers of up to 40dB loss of sensitivity.
6) To overcome this nominal 40dB of additional power for the radio microphone is required!!
7) These measurements bring into question the theoretical results from SE42 in CEPT Report 30.
8) It was found that the infinitely variable nature of resource block/power allocation makes finding the correct combination for compatibility testing between radio devices extremely difficult.

The results mean that

- **the use of the duplex gap for radio microphone is not feasible under the terms and conditions imposed by the current ETSI LTE standards.**
- **the 862-870 MHz band will become unusable for Hearing Aids, cordless audio, radio microphones, Tour guide systems conference interpretation systems, In Ear Monitors, baby alarms, social alarm RFID and other SRDs consisting of many millions of devices which will cause industry to receive a wave of complaints.**
- **the input paper to TG4 from September 2009 (TG4(09)304) was accurate in its predications.**

Considering our investigations are right and taking into account the results of our testing any further deployment of LTE equipment should be stopped until the issues identified are addressed.

[1] PMSE = Programme Making and Special Events / wireless tools for professional event production. This document deals exclusively with receivers of audio transmissions.

A study of LTE interference potential with regard to PMSE operation

1. Introduction

The LTE 791-821 MHz (base station – BS[2]) and 832-862 MHz (user end equipment – UE[3]) frequency ranges should be in place throughout Europe by 2013.[4] It is expected that the duplex gap in the 823-831 MHz range will be used for PMSE operation.

The 863-865 MHz frequency range, which is also used for PMSE as well as other applications (e.g. wireless headsets), has already been in intensive use for many years. The question is to what extent might the latter two frequency ranges be affected by LTE operation in the home environment or at special events.

When monitoring pilot wireless UHF internet access projects in 2009, Working Group 731.0.8 of the German Commission for Electrical, Electronic & Information Technologies of DIN and VDE (DKE) reported that, in addition to known UMTS and HSDPA interference scenarios, other types of interference can occur. In particular, so-called transmission transients (impulses of very short duration superimposed upon the transmission signal) have been noted as having a significant effect on PMSE operation. The question is, whether this type of interference can also occur with LTE and, if so, what effect it could have on PMSE.

Few representative studies have been undertaken in this area up to the present time. These studies assume low LTE interference potential. The following study suggests otherwise.

The current study - supported by Vodafone and the Technical University of Brunswick[5] - confirms the occurrence of this type of interference and makes a first attempt at its measurement. The study involves the monitoring of LTE and PMSE hardware typically found on the market operating in a real LTE cell, so it can therefore be assumed that it realistically simulates the practical scenario[6].

In addition, free field and laboratory test arrangements are described, which could be used to conduct further studies in the future. These laboratory test arrangements were used to evaluate various LTE and PMSE scenarios. It was possible to configure LTE end equipment to a range of different operating frequencies.

The question of why the UE interference demonstrated in this study was not observed and documented in previous studies has also been addressed. We suggest a possible reason for this and offer our recommendations for further studies.

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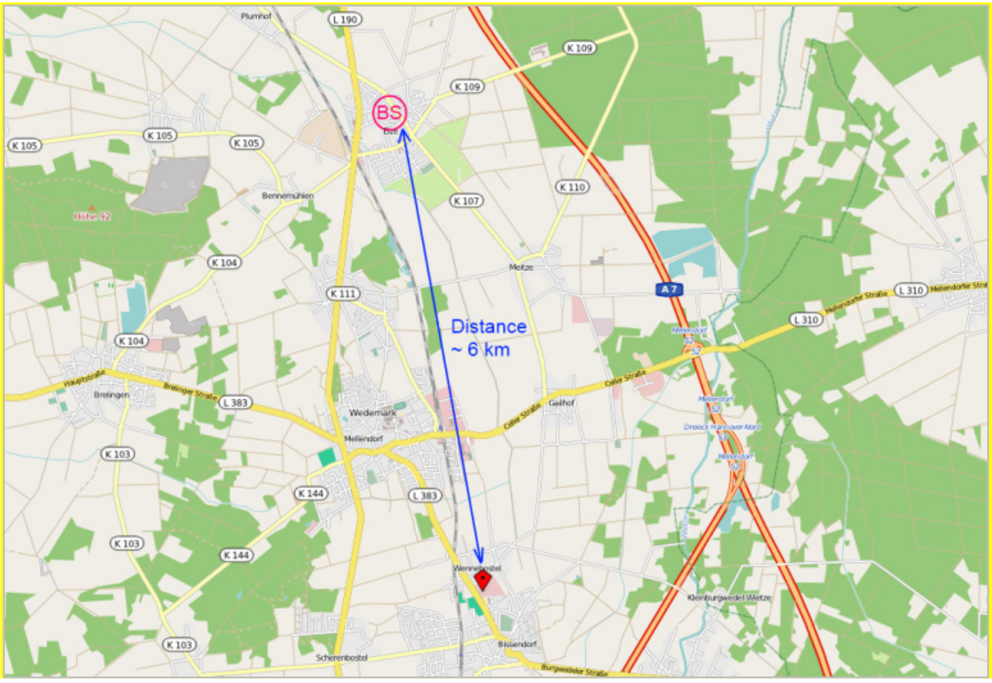
[2] Downlink frequencies
[3] Uplink frequencies
[4] In addition to 800 MHz, LTE is to be introduced at 1800 and 2600 MHz. LTE1800 and LTE2600 are not, however, considered in this document.
[5] Institute for Communications Engineering, Brunswick Technical University, Germany
[6] All tests based on the LTE800 uplink, i.e. on the signal transmitted by the LTE UE. The LTE base station downlink was not considered.

2. Observations of LTE – UE operation in a real LTE cell

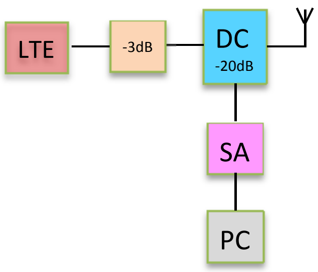
Vodafone operates LTE base stations in the Wedemark and in other regions of Germany:



Map: http://www.openstreetmap.de/karte.html

Two LTE routers and an LTE – USB stick were put into operation at a distance of some 6 km from the LTE base station (BS) and their transmission signals were monitored.

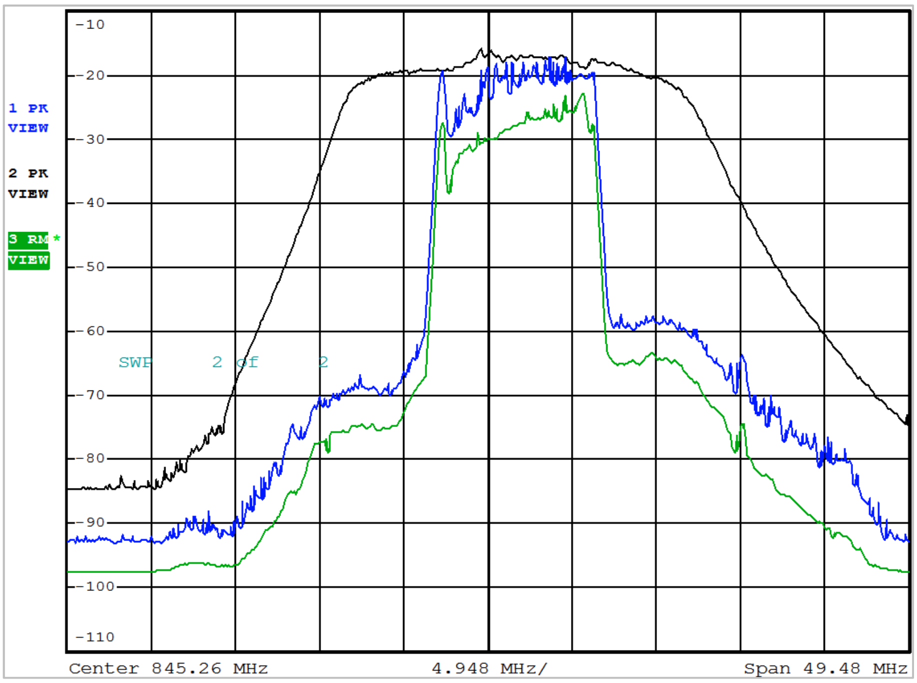
3. Test arrangement for monitoring LTE end equipment operation



DC	:	Antenna coupler
-3dB	:	Attenuator
SA	:	Spectrum analyser
LTE	:	LTE end device (UE)
PC	:	PC for spectrum recording

a. Illustration showing antenna coupler connected to an LTE router

b. First print of the LTE signal[7] at normal measuring equipment settings



Data level approx. 40 dB below that of the source signal

Key to graph:

- Trace 1: Detector = Max Peak, RBW = 300 kHz (blue)
- Trace 2: Detector = Max Peak, RBW=10 MHz (black)
- Trace 3: Detector = RMS, RBW = 300 kHz (green).
  Trace 3 is offset by a typical crest factor of 7-10 dB when compared to Trace 2
- Maximum output level is reduced by approx. 40 dB due to pre-scaling and antenna coupling attenuation.

The absence of transmission transients at normal measuring equipment settings was reported in 2009. However, high levels of interference are clearly perceptible in microphone receivers. The interference, which is present at the outputs of the microphone receivers affected, is perceptible as a loud crackling and is superimposed upon the useful, information-carrying signal.

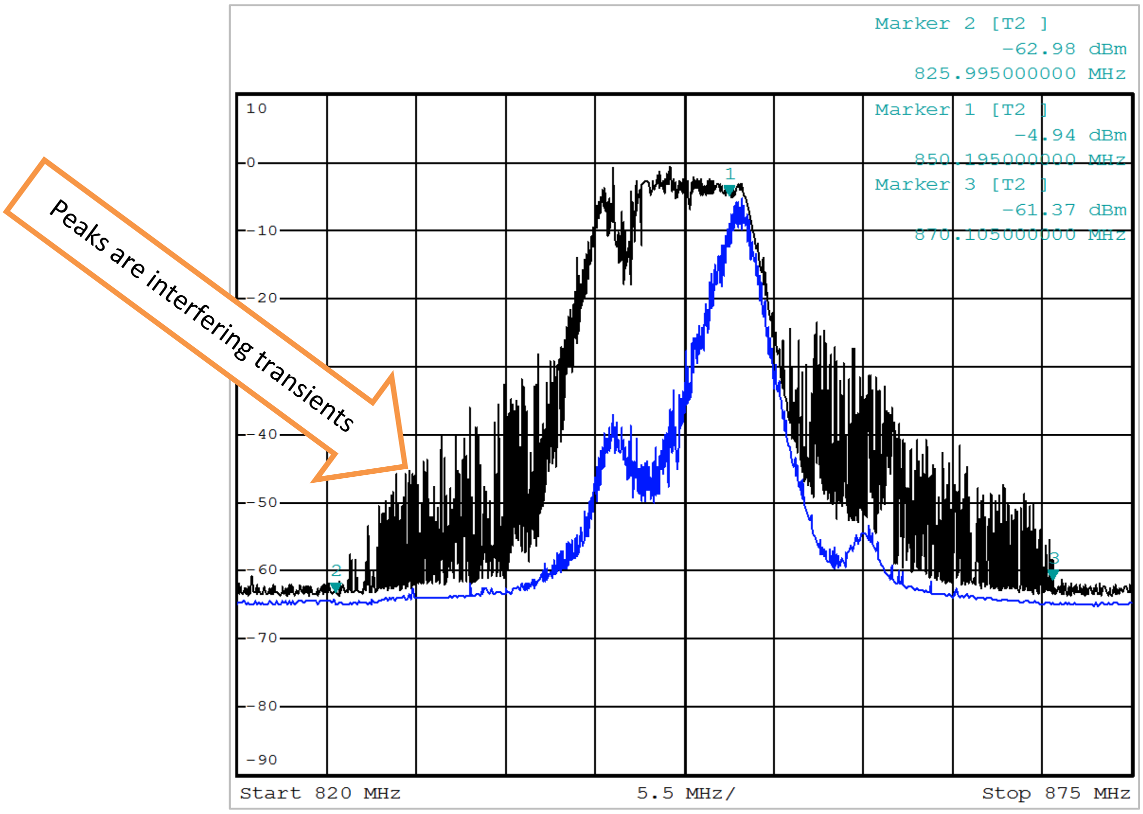
c. Suggestions for altering equipment settings

The LTE transients observed are narrow impulses. At default measuring equipment settings (typical spectrum analyser set-up), these are either difficult to detect or completely imperceptible. This suggests that the “sweep time” should be significantly increased.

In the following examples, the “sweep time” was increased by a factor of 5. High bandwidth and a “Max Hold” trace setting were used when measuring transient amplitude. Since the results are frequency-related, the picture is improved at lower bandwidths.

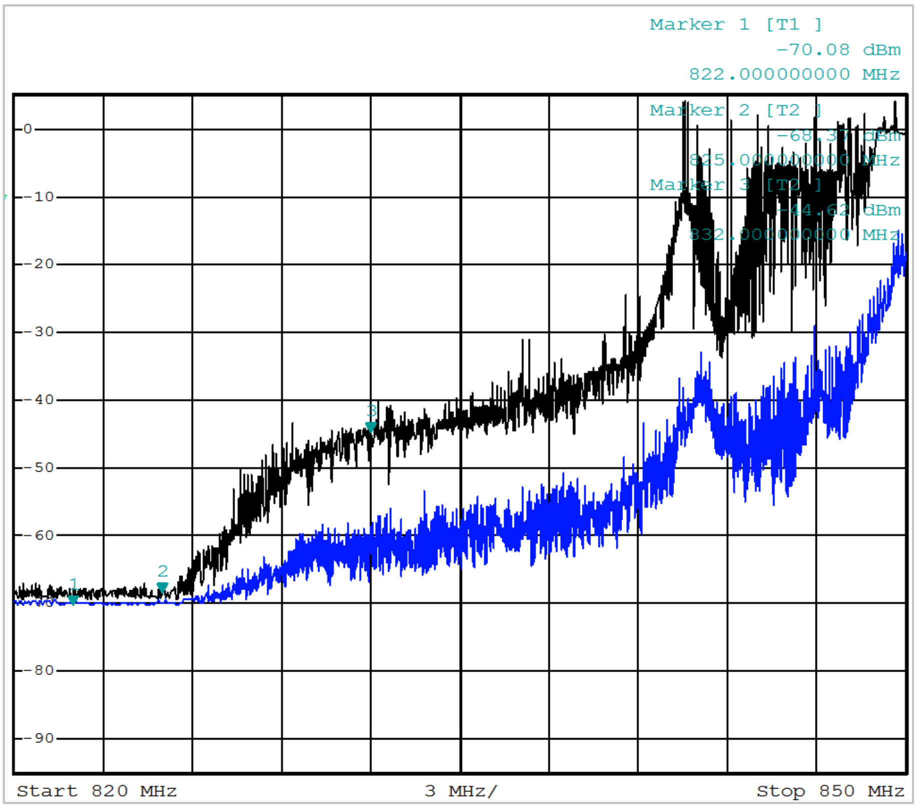
[7] LTE uplink at 847 MHz

d. Using modified measuring equipment settings to show the presence of signal transients



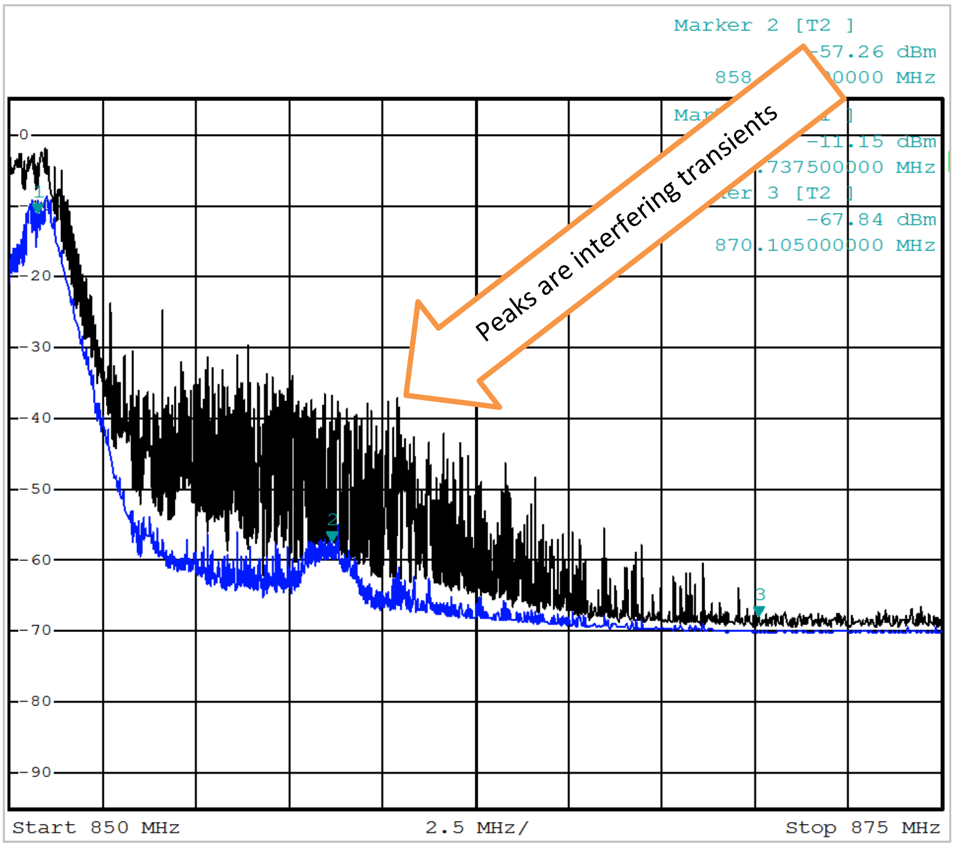
All signals reduced by approx. 23 dB due to measuring arrangements used

e. Measurement in the duplex gap frequency range



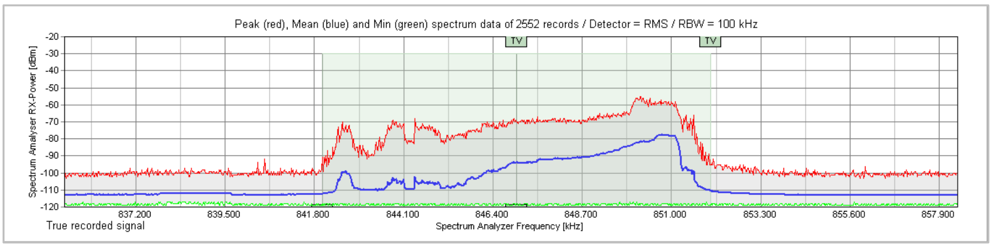
All signals reduced by approx. 23 dB due to measuring arrangements used

f. Measurement in the 863-875 MHz frequency range



All signals reduced by approx. 23 dB due to measuring arrangements used

4. LTE UE recording over greater distances



Although the measuring station was decoupled by some 80 dB (corresponding to a free space distance of 270 m), it can be seen that the LTE UE generates transmissions outside its operating window (shown grey-green on graph).

a. LTE end equipment monitoring

- 2 x B1000-VT (taken from different production series) - LTE Router
- 1 x GT83740 – LTE USB Stick

b. Summary of free field observations

The presence of transmission transients was confirmed at changed measuring equipment settings when monitoring end devices operating under real conditions and even in LTE operation. Prior to further analysis, the first test arrangement needed to be confirmed under laboratory test conditions.

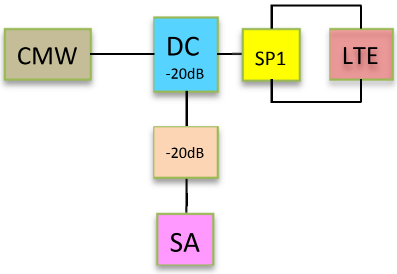
5. Laboratory measurements

Two different measuring arrangements were employed when carrying out the laboratory tests:

- additional tests on the real operation of LTE end equipment and on the occurrence of transmission transients were carried out using a simplified arrangement;
- a study of the effects on the PMSE receivers of two different manufactures was carried out using extended laboratory test arrangements.

A Type CMW500 (Rohde & Schwarz Wideband Radio Communication Tester) base station simulator was used for testing in both cases. This made it possible to exert a more specific influence on the operation of the LTE end equipment.

6. Laboratory arrangement for monitoring LTE end equipment operation



CMW	:	Base station simulation
DC	:	Antenna coupler
-20dB	:	Attenuator
SA	:	Spectrum analyser
SP1	:	-3dB coupler
LTE	:	LTE end device with 2 antenna ports

Note:

- The splitter (SP) should be chosen to give the highest possible values of port decoupling. Where this is not the case, intermodulation can be generated by the inactive LTE output. In our tests, we ensured a decoupling value of > 25 dB.
- This is ignored in practice if two antennas are used for the LTE end device. In all probability, therefore, transmitter intermodulation is the rule rather than the exception.

a. Preliminary LTE operating mode observations

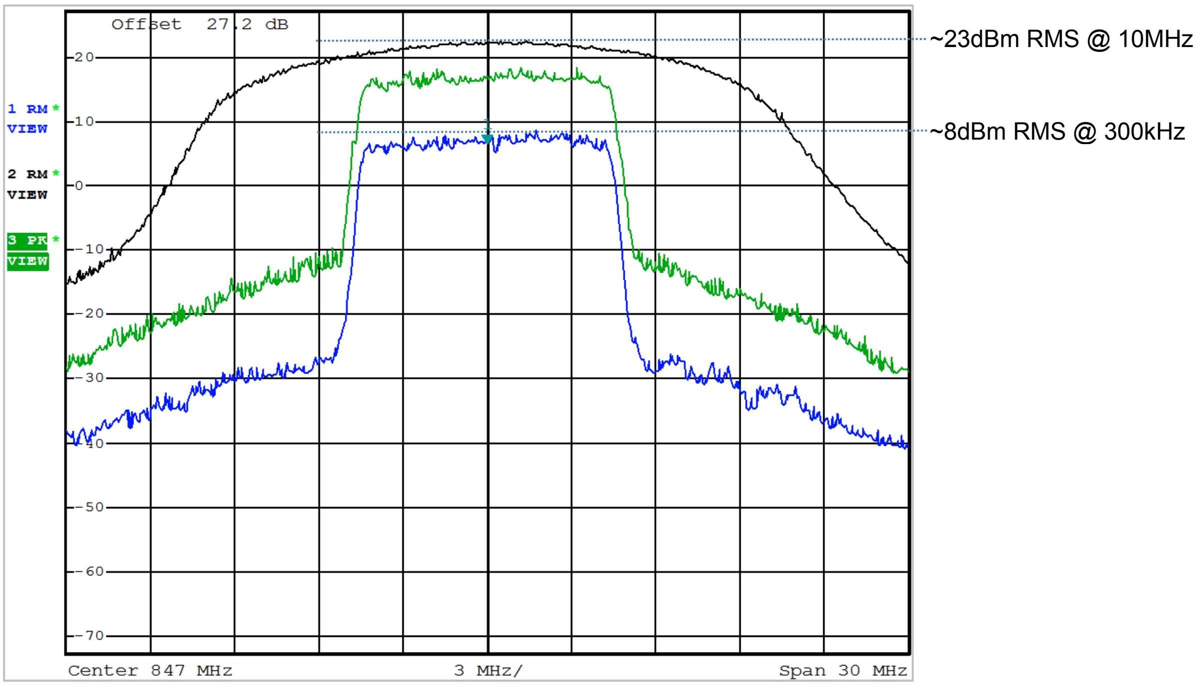
It was clear from the laboratory tests that the LTE external channel spectrum is affected by at least the following parameters:

- LTE centre frequency (837, 847 or 857 MHz)
- LTE output power
- Type of resource allocation in the 10 MHz operating channel
- Output power control

For the special case, in which resources are fully or continually allocated to the LTE UE by the base station and the LTE UE is operating at constant output power, no transients could be detected. **Limiting operation in this way might have led to the different conclusions reached in other test reports.**

In real operation, however, where resource blocks are dynamically allocated to the LTE UE and where the LTE UE continually adjusts to transmitter power, transients occur. **This is the usual case and it should be taken into consideration in all future tests.**

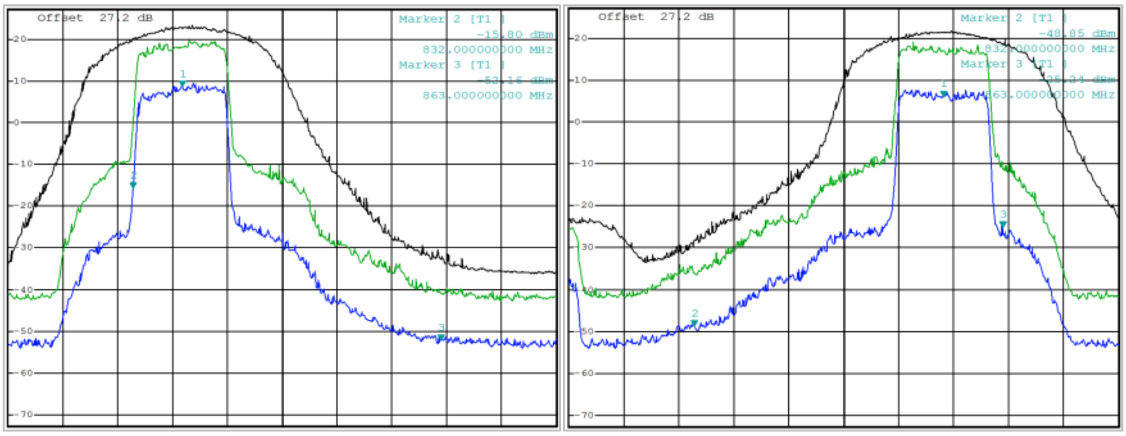
b. LTE signal at constant power and full resource allocation



he values shown correspond to the source level

- Trace 1 (schwarz): RBW = 10MHz, Sweep = 2.5ms, Detector = RMS
- Trace 2 (grün): RBW = 300kHz, Sweep = 2s, Detector = MaxPeak
- Trace 3 (blau): RBW = 300kHz, Sweep = 2.5ms, Detector = RMS

c. Changes in LTE signal at various centre frequency values

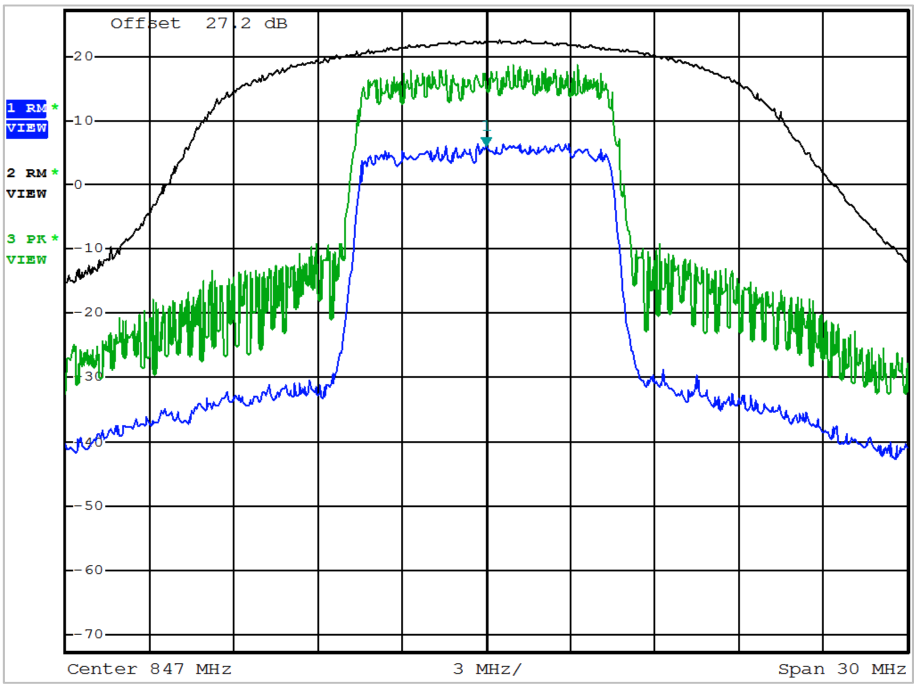


The values shown correspond to the source level

In practice, monitoring of LTE UE operation in real LTE cells has shown that LTE output power and resource allocation change continually.

No further tests were therefore conducted using the static mode of operation.

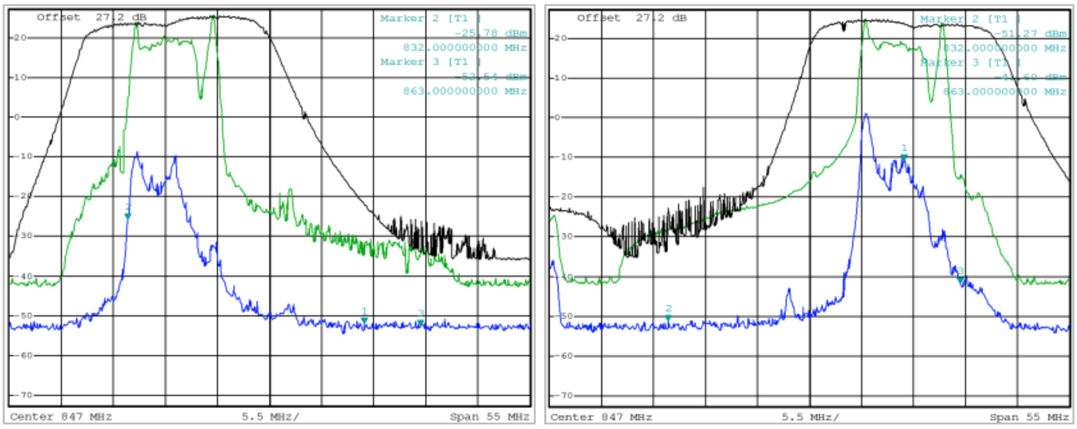
d. LTE signal under cyclically-changing output power



The values shown correspond to the source level

Additional interference products emerge under continually changing output power conditions.

e. LTE signal under cyclically-changing output power and resource allocation

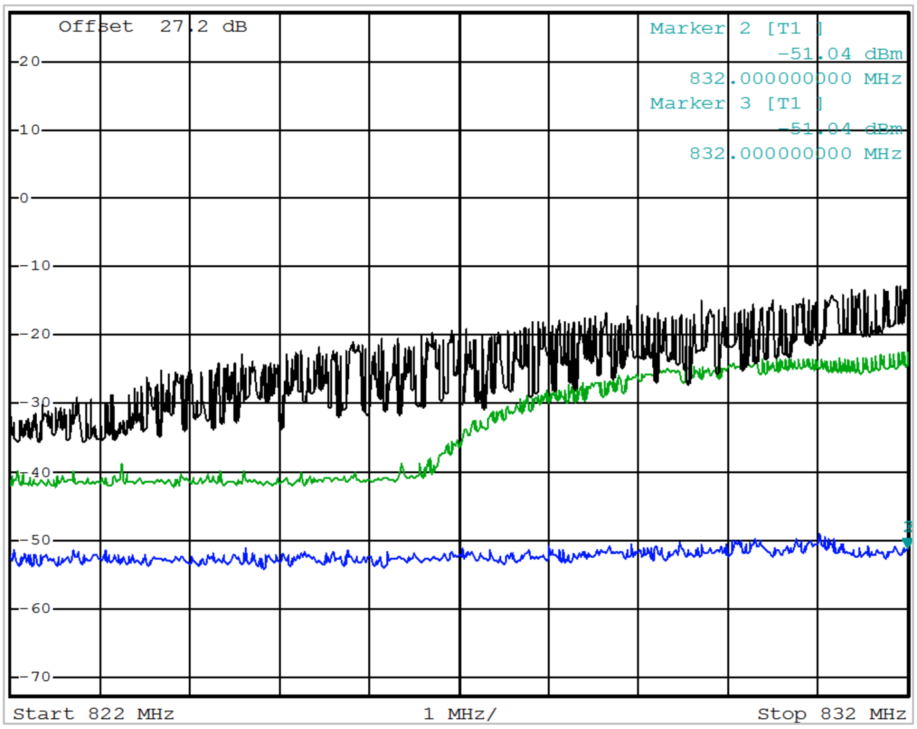


The values shown correspond to the source level

Note:

- Due to the long “sweep time”, the blue trace (here set to average) departs significantly from that of the green (peak value).
- It can be clearly seen that transmission transients occur in this mode of operation.

f. The effect of duplex gap at an LTE frequency of 847 MHz

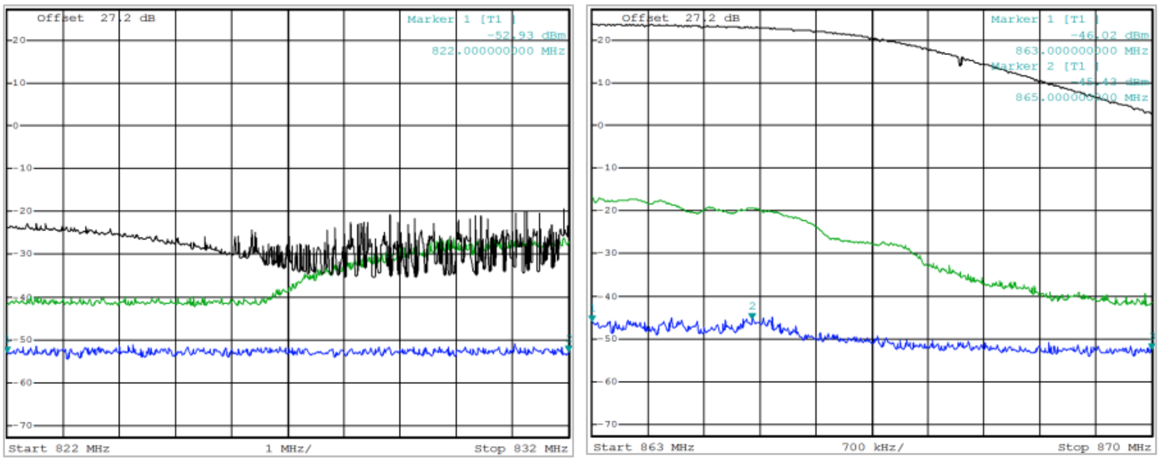


The values shown correspond to the source level

The 823-831 MHz LTE duplex gap is affected by significant levels of interference. At LTE UE and PMSE separation distances of 3m, interference levels of more than -25 dBm in a 200 kHz PMSE channel have to be reckoned with.

The high proportion of impulses – evident due to the low RMS amplitude – is significant.

g. The effects of 863-870 MHz at LTE frequencies of 837 and 857 MHz

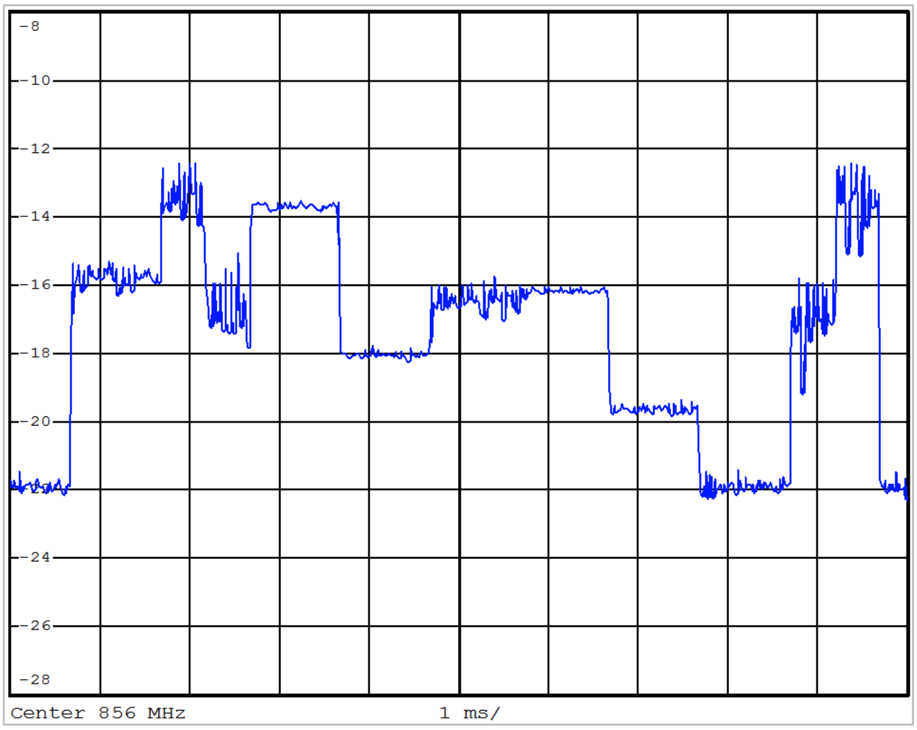


The values shown correspond to the source level

h. Laboratory test LTE signals in the time domain

Based on the laboratory test findings, a representative LTE signal was devised and studied in the time domain at different resolutions.

At 501 point resolution – no LTE transients are detectable:



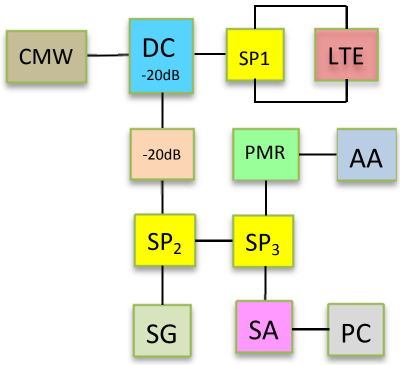
This suggests that LTE interference impulses emerge during the change to different resource allocations. It could be clearly demonstrated in the laboratory tests that this type of interference is brought about by the combination of changing resource allocation and changing power.

i. Summary of LTE signal recordings in the laboratory tests

The LTE signal is subject to a complex interaction of different operating parameters. A simplified evaluation of interference potential – which was possible in the case of UTMS signals[8] - is therefore ruled out.
Depending on the LTE and PMSE frequencies used, interference products of up to -18 dBm (Peak @ 300 kHz RBW) could be observed at the test distance of 3m.
In the next chapter, we examine what effect this type of interference has on PMSE receiver operation.

[8] UMTS comprises simplified speech and data. The DKE Working Group 731.0.8 tested an HSDPA data link under laboratory conditions and reported on transmission transients. For further information, see Page 11 of the report: http://www.apwpt.org/downloads/dke_bericht_pilotversuch_baldern_final.pdf

7. Laboratory arrangement for studying the effect of interference on PMSE receivers



CMW	:	Base station simulation
DC	:	Antenna coupler
-20dB	:	Attenuator
SA	:	Spectrum analyser
SP1-3	:	-3dB coupler
LTE	:	LTE end device with 2 antenna ports
PMR	:	PMSE receiver
AA	:	Audio analyser
PC	:	PC for spectrum recording
SG	:	FM signal generator

Notes:

- For the purposes of testing, a distance of 3m was maintained between the LTE router and PMSE receiver. This would correspond, for example, to a home environment, company presentation, club or smaller-scale performing arts scenario.
- No A-weighting filters were installed between the PMR audio output and the audio analyser (AA), since this would have caused the sharp impulses to die away too quickly.

a. **Note on interconnection of the LTE UE antenna ports:** the splitter (SP) should be chosen to give the highest possible port decoupling value. Where this is not the case, intermodulation can be generated by the inactive LTE output. In our example, we ensured a minimum decoupling value of 20 dB. In practice, this is ignored when using two neighbouring antennas at the LTE end device. This suggests that transmitter intermodulation is more often the rule rather than the exception.

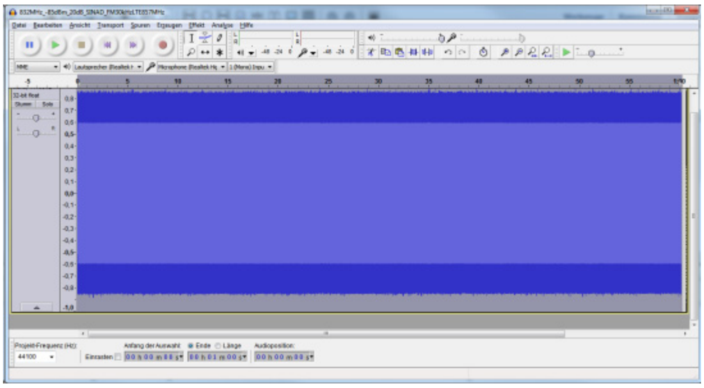
b. **Note on LTE operational control using the CMW500**

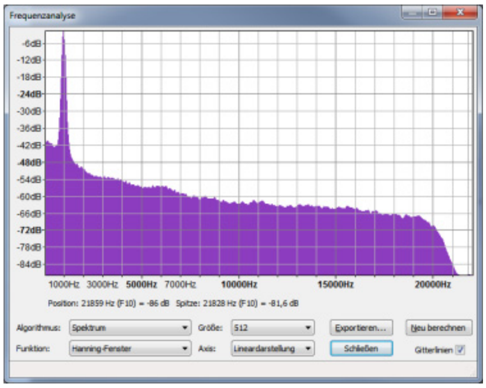
On the basis of the laboratory test findings and to ensure interaction of the various operational parameters, the CMW500 base station simulator was configured so that the LTE UE operating conditions were both realistic and representative. The LTE signal generated was used to study the effects on various PMSE receivers. Due to programming complexities, it was not possible to fully simulate free field monitoring. The subjective laboratory test prints show reduced levels of interference when compared with free field conditions. It is likely, therefore, that higher levels of interference would have to be reckoned with in practice.

c. **Effects of LTE transients on audio reproduction**

A reference value of 20 SINAD was used to evaluate receiver output signal effects. The FM generator was set with a 1 kHz tone to a modulation value of +/- 30 KHz. The PMSE frequency lies within the duplex gap at 832 MHz with the LTE UE operating at 857 MHz. At these favourable frequencies, the test arrangement was capable of achieving 20 dB SINAD at the receiver input (EM3732) at -94 dBm.

The diagram shows a 68s recording of the audio signal[9]:

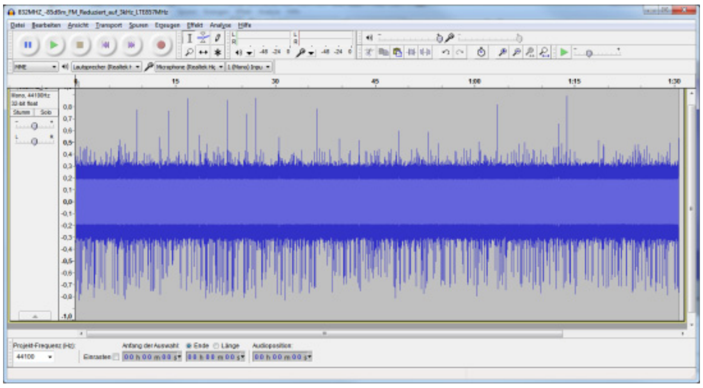


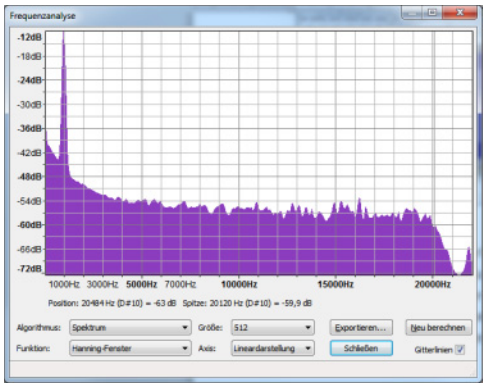


At maximum modulation, the effect of the LTE signal is barely detectable, either in the time domain or in the spectrum. Crackling is audible, however, when wearing the headset.

Clearly, the test modulation does not represent a typical transmission case. In a further test, therefore, the degree of modulation was reduced from +/- 30 kHz (maximum volume) to +/- 3 KHz (-20 dB).

The following diagram shows a 90s recording of the changed audio signal:





At these more favourable PMSE – LTE frequencies, significant levels of interference (crackling) were detectable in the time domain. The interference disappeared completely when the LTE UE was switched off. The interference is clearly detectable on the frequency analysis at the higher frequencies.

Note:

- It should be borne in mind that, in professional audio transmissions, dynamics are typically much higher than 20 dB. Consequently, LTE interference can be expected to be even more prominent.
- In this example, a rather favourable interference scenario has been presented. Later on other PMSE and LTE frequency pairs are presented which cause higher levels of PMSE interference.

[9] Recording and evaluation were carried out using “Audacity 2.0”.

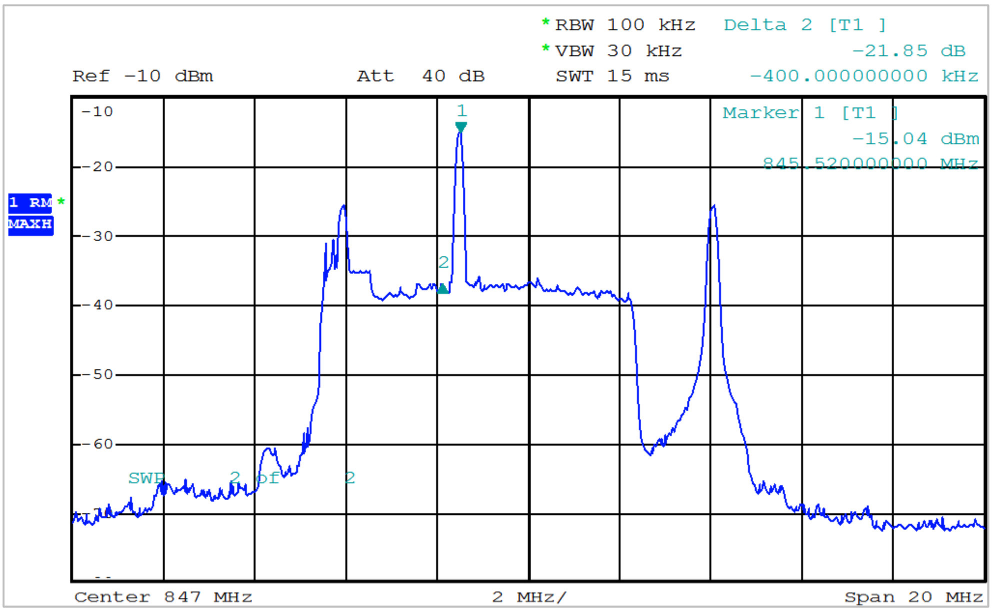
d. LTE measurement scenario for studying PMSE effects

The DKE Working Group 731.0.8 has been using indirect methods for determining PMSE interference since 2007. The PMSE receiver and a generator configured for typical modulation are tuned to the frequency range under consideration at constant interference levels. Depending on the level of interference, the generator must be set to a different HF output level, in order to achieve 20 dB SINAD at the PMSE receiver output.

Note:
The 20 dB SINAD measurement criterion does not represent professional audio quality. Production quality is dealt with in a later point (see Section h).

e. Determining the required C/I for PMSE analogue receivers

The following illustration shows the test LTE signal (^2) and a PMSE measuring signal (^1) at a measurement bandwidth of 100 kHz. To ensure the minimum necessary production quality, the useful carrier to interference ratio (C/I) can be determined from the difference between the LTE (^2) and PMSE (^1) signal strengths. Monitoring and control was achieved by means of a headset.



The required LTE signal level difference was determined at approx. 22 dB. This measurement confirms the initial hypothesis formulated by ETSI TG17WP3 of a minimal C/I of 20 dB for analogue PMSE use and refutes suggestions from other sources that lower C/I values can be used. It has to be expected that even higher protection levels would be required for digital PMSE operation.

Note:
The C/I values used for the following evaluation are based on a 20 dB SINAD and are approx. 7 dB lower compared to the C/I value for 30dBSINAD

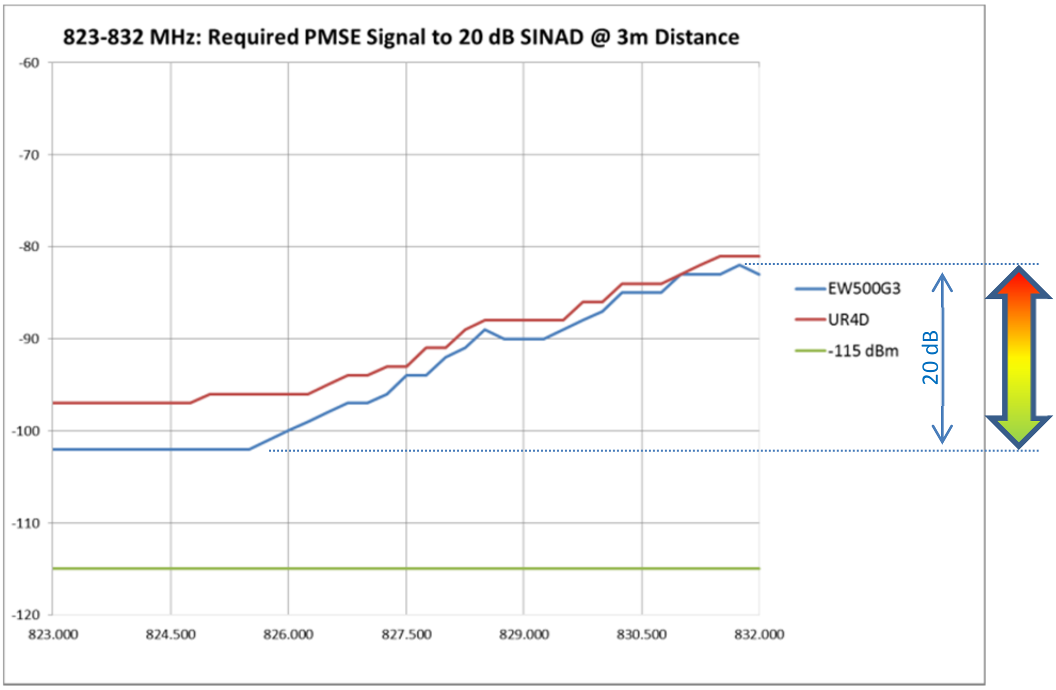
f. LTE effects in the duplex gap at 20 dB SINAD

i. Measurement 1

Two typical PMSE receivers were selected for determining the interference effects on PMSE of an LTE UE (847 MHz).

Note:

The receivers selected were products typical of those available on the market and comfortably met current ETSI standards (EN 300 422).

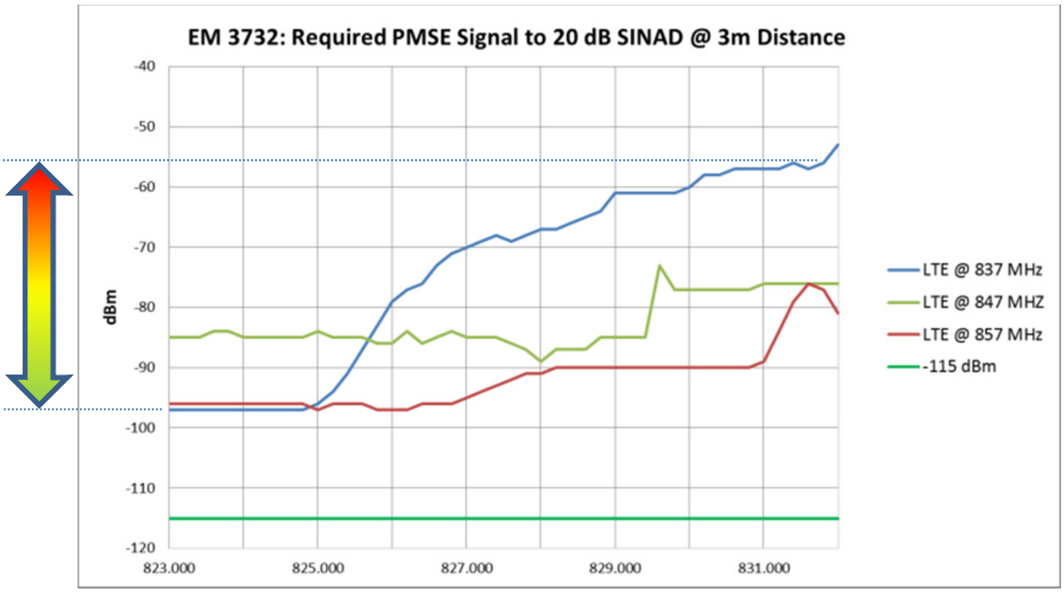


Although the LTE centre frequency of 847 MHz does not represent the most unfavourable case, reductions in PMSE transmission quality at up to 20 dB were observed. Reductions in quality below 827 MHz were less apparent in the UR4D receiver. This is due, however, to the reduced sensitivity of this particular receiver. LTE effects in the upper range of the duplex gap were identical in both receivers.

Practical effects:
In order to compensate for LTE interference, the distance between the LTE UE and the PMSE receiver must be increased from 3m to 30m. Where that is not possible, significant levels of interference must be reckoned with.

i. Measurement 2

The LTE UE centre frequency effects were studied using a different receiver. The category of equipment used is normally associated with the high levels of quality required during event production:



Using this receiver, reductions in PMSE transmission quality above 40 dB were observed at an LTE centre frequency of 837 MHz.
With the LTE UE configured to 847 MHz, the PMSE receiver was affected with interference levels of approx. 20 dB.
With the LTE UE operating at 857 MHz, interference levels of approx. 10 dB were encountered in the duplex gap above 831 MHz.

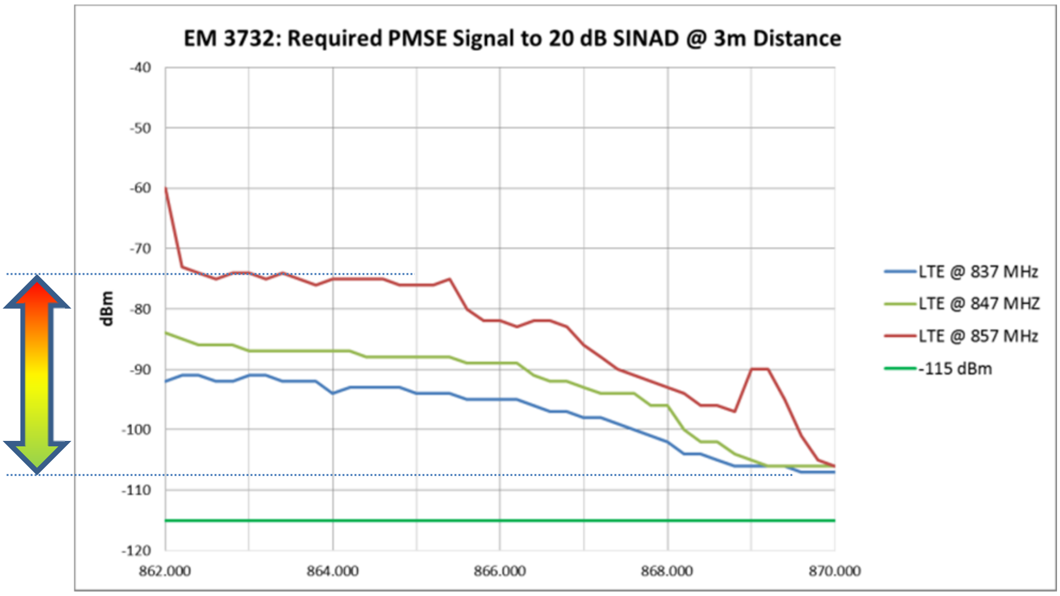
Note:
The broadband interference profile of the LTE UE lay unexpectedly at the 847 MHz centre frequency setting. Tests carried out with a second LTE device of the same series, but with different production date and a different firmware version, showed identical results.

Practical effects:

- Use of a neighbouring PMSE operating in the duplex gap in combination with an LTE UE at 837 MHz is not recommended.
- In order to compensate for LTE interference at 847 and 857 MHz, the separation distance between the LTE UE and the PMSE receiver must be increased from 3m to 30m.

g. LTE effects in the 863 – 870 MHz range at 20 dB SINAD

The following graph shows the effect of LTE UE operating frequency:



PMSE transmission quality in this PMSE receiver is frequency dependent and was reduced at levels up to 32 dB.

Practical effects:

- Use of a neighbouring PMSE operating in combination with an LTE UE at 857 MHz is not recommended.
- In order to compensate for LTE interference at 837 and 847 MHz, the separation distance between the LTE UE and the PMSE must be increased from 3m to 30m.

h. Relating the results to minimum professional production quality requirements

Although the test parameters are suitable for laboratory measurement, they are clearly different to those required for practical PMSE quality transmissions. In order to allow for the higher demands of a real production environment, different PMSE receivers were used to investigate the required useful signal strength for minimum production quality at 20 dB SINAD.
Depending on the LTE / PMSE frequency combination employed, an additional useful signal increase of 4 to 17 dB was investigated:

- 4 dB at LTE spurious transmission with no transmission transients = noise
- 17 dB at LTE spurious transmission with strong transmission transients = crackling

i. Probable combined effects

The DKE Working Group 731.0.8 tests describe an interference scenario involving an LTE- UE and a given microphone transmission distance. In this simplified scenario, a significant interaction is readily observable where two neighbouring frequencies are used. Where additional LTE end equipment is deployed (e.g. where the participants use LTE devices or the audience brings devices of a similar type to the event), the interference scenario created becomes significantly more complex. This is also the case, where additional PMSE devices are in operation at the same time. These scenarios are not the subject of this study and further research in this area is highly recommended.

8. Conclusions

The use of neighbouring spectrum for PMSE and LTE user equipment is not a currently recommended operating scenario. This study has established that, in practice, LTE user equipment can cause significant levels of interference to PMSE.
We urgently advise the following:

- further research to confirm the interference effects observed from live signals and to describe them in greater detail;
- Reconsideration of test conditions and certification requirements for LTE end user equipment;
- joint efforts to provide the next generation of LTE end equipment with significantly reduced transmission transients.

Until these issues have been addressed, we advise against the simultaneous use of PMSE and LTE end equipment operating on neighbouring frequencies. The risks to live productions using the only harmonised European band for radio microphones are difficult to estimate at the present time. We therefore advise the exercise of considerable caution.

9. Acknowledgments

We would like to thank:

- Mr Peter Schlegel of the Institute for Communications Engineering, Technical University of Brunswick for his invaluable advice on LTE and CMW500 issues.
- Dr Thomas Zwemke of Vodafone GmbH Northern Region for the provision of LTE equipment and practical support with laboratory testing.
- Professor Fischer, Chair of Technical Electronics at the Friedrich-Alexander University, Erlangen – Nuremburg, for the invaluable discussions on transmitter amplification and linearization.

10. Further Information: info@apwpt.org

11. Appendices

- Illustrations

Appendix 1: Illustrations

1) LTE hardware tested

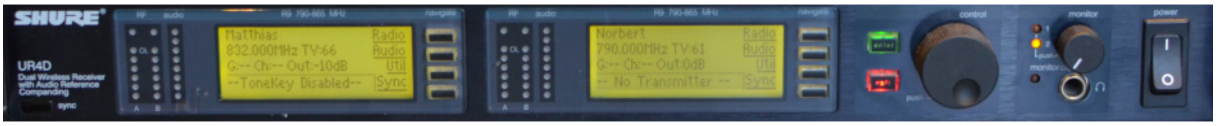
USB Stick B3740

Router B1000

2) PMSE hardware tested

EW500G3

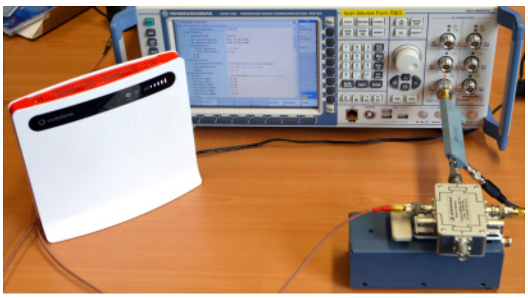
SLX4



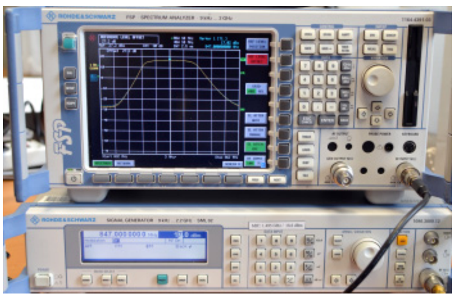
UR4D

EM3732

3) Test arrangements



Arrangement used in the first laboratory test



Test generator and spectrum analyser

Arrangement used in second laboratory test