Breathing Apparatus Telemetry System Interference Study

Ofcom

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1 INTRODUCTION

This document reports on a study concerned with estimating the risk of interference to breathing apparatus telemetry systems used by the Fire and Rescue Services (FRS) in the UK.

The work was undertaken by Aegis Systems and ERA Technology in response to tender requirement MC/091 "*Breathing Apparatus Telemetry System Interference Study*", which was commissioned by Ofcom on behalf of the Fire and Rescue Service Working Group on the same subject.

There are a number of options being considered by the Working Group, including:

i) remaining in the current allocation of 862.9625MHz with operational management of potential interference

ii) retuning the existing telemetry to 869.5MHz within the Short Range Device (SRD) band

iii) moving the telemetry system to an alternative frequency close to 450MHz

iv) moving the telemetry system to an alternative frequency above 870MHz

EU harmonisation of the 870 to 876MHz band is not yet complete and Ofcom have not concluded its position on which applications may use this band. One of the current options being considered within technical bodies in Europe (CEPT) is that this is allocated for SRD or applications with similar RF properties to SRDs.

This study therefore considers the interference environment likely to be encountered in options i), ii) and iii) above. In one outcome of the EU harmonisation process, the lower end of option iv) may be considered to be similar to option ii).The work included both theoretical modelling and laboratory measurements.The high-level results of the study are given in the main body of the report, with the majority of technical detail and supporting information relegated to the annexes.

It should be noted that this study only looks at the technical impact of the various options. It does not consider specific FRS operational procedures, cost, or timescale implications of the options.

2 BREATHING APPARATUS TELEMETRY

The Fire and Rescue Services (FRS) have long used self contained breathing apparatus (SCBA) to undertake operations in hazardous areas such as those filled with smoke or toxic vapour. It is imperative for users to have a very clear understanding of the safe operating duration of the apparatus. The original arrangement, still used where telemetry systems have not been adopted, is for the contents of the apparatus to be assessed by weight, and an operational time-limit or duration to be set accordingly. Audible alarms (manual or automatic) are used to signal the withdrawal of firefighters, or as individual distress signals.

In many brigades, this system is being upgraded or supplemented with the use of radio telemetry. These updated systems perform the dual role of:continuously reporting the contents of individual breathing apparatus sets; and of allowing signalling, in either direction, between the control board and portable units (attached to the BA set), thus facilitating messages such as 'withdraw all units' or 'alarm'. This radio telemetry system operates at UHF with a terminal power of 500mW ERP. The system uses FSK modulation in narrowband (25 kHz) channels, with a protocol set out in a set of Home Office specifications [3], [4],[5]. The operation of the system is described in detail in Annex B.

2.1 Interference risk

The BA telemetry equipment currently operates in a licensed Emergency Services allocation of 862.9625 MHz. Following the 'Digital Switchover' (DSO) of television broadcasting, it is expected that the spectrum immediately below 862 MHz will be used by the uplink (i.e. handset transmissions) of 4G cellular systems which is likely to operate under the LTE standard. As there will be a guard band of less than 1 MHz between the two systems, it seems likely[1] that the BA telemetry system has the potential to suffer interference from the out-of-band emissions from LTE handsets.

2.2 Interference management

As discussed in section 1, one possible mitigation approach that is being considered is to retune the operating frequency of the BA telemetry system to 869.5 MHz. This frequency falls in a licence-exempt allocation harmonised across Europe. This allocation is already used for BA telemetry elsewhere in Europe as well as for industrial use in the UK, so equipment is readily available[2]. The additional frequency separation should ensure that interference from 4G handsets (operating below 862MHz) would be considerably less significant. However, there is the risk that 'short-range devices' (SRDs) (such as industrial telemetry and intruder alarm systems) operating in the same licence-exempt band may cause harmful interference.

The work described in this study has examined both issues (interference from 4G handsets and from SRDs) using a combination of theoretical modelling and practical measurements. The interference from 4G handsets is also analysed for the current band of 862.9625MHz.

Another of the potential solutions mentioned in section 1 is that the BA telemetry system might be modified to use frequencies within the 450-470MHz band. In this case, potentially significant sources of interference could come from the analogue FM radios used for local communication by the FRS and from digital TETRA

[1]see the earlier report commissioned from Thales by Ofcom, ref [1]

[2] This report does not consider the significant operational issues involved in such a change of frequency.

communications systems such as “Airwave”. Currently, fireground radio is allocated frequencies close to 457 and 463 MHz. Ofcom has therefore suggested some channels which have potential availability for a telemetry system close to 450 MHz in order to try and maximise the frequency separation between the two systems. The co-existence of BA telemetry with fireground or Airwave radios is addressed in Section 6 of this report.

3 POTENTIAL INTERFERING SYSTEMS

As discussed above, interference to BA telemetry has been considered at the following three frequency options:

i) The current allocation at 862.9625 MHz

ii) An allocation within the licence-exempt SRD band at 869.5 MHz

iii) A new allocation close to 450 MHz

In the first allocation, the primary risk of interference is from radiated out of block (OOB) emissions from 4G mobile phone handsets, when they transmit back to the base station.

If the 869.5MHz licence-exempt band is used, interference from such handsets must still be considered, but it also becomes necessary to include interference from the ‘short range devices’ (SRD) that currently use that band.

For the third case, the most likely sources of interference are from the FRS’s own radio communications systems: fireground radio and Airwave. Further detailed analysis of other adjacent bands with current and predicted future use should also be completed prior to finalising any decision around moving to this band.

These potential interfering systems are introduced briefly below, and described in more detail in the annexes.

3.1 4G mobile handsets

For options i) and ii) above (and also option iv) of section 1, the concern is with interference from LTE handsets (or User Equipment, ‘UE’) transmitting in the uplink band of 832-862MHz and in particular the upper of three 10 MHz channels in the 800 MHz harmonised uplink band, i.e. at 852-862 MHz .

One of the key characteristic of the uplink is that it is allocated resources by the overall system on the basis of ‘Resource Blocks’ (RB). Each Resource Block contributes to the OOB emissions from that handset and the number of resource blocks allocated contributes to the overall shape of the out of band emissions (as can be seen in Figure 3.1) and the likelihood that these fall on the frequencies of interest for BA telemetry.

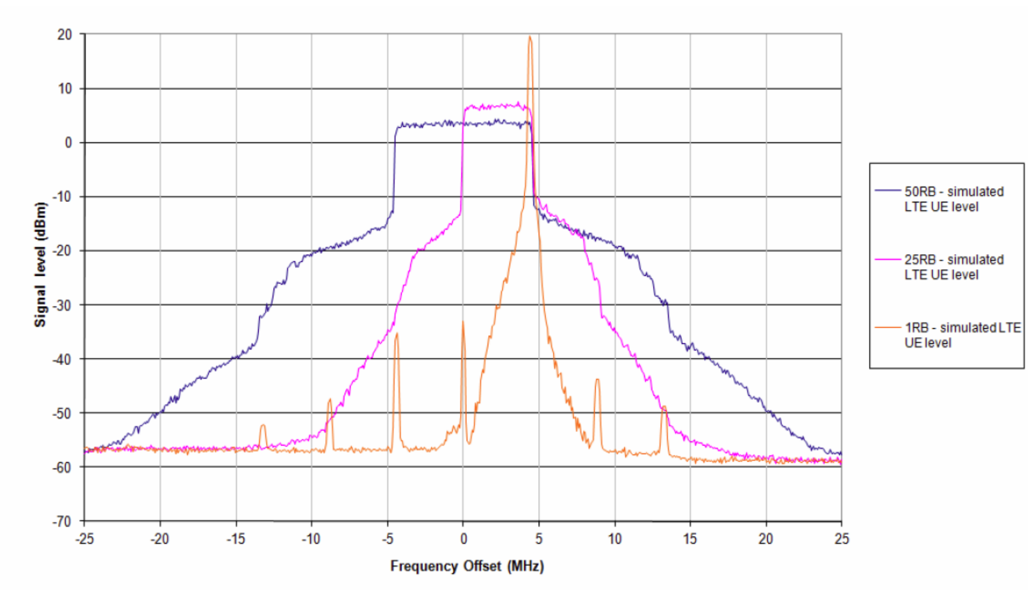

Figure 3.1: Varying out of band emissions from LTE handsets with different resource block allocations(100 kHz resolution bandwidth)

Ofcom is proposing a maximum transmit power of +23dBm in its technical licence conditions for the 800MHz LTE. This value has therefore been assumed in the modelling and measurement in this study to represent a worst case scenario. However, the actual transmit power of the UE will vary below this value depending on the distance from the LTE base station.

The specifications [6] for the LTE system define the maximum permitted power that can be radiated outside the channels actually allocated to the system, known as the Out of Block emissions (OOB) mask. These limits are normalised relative to the BA telemetry system bandwidth to ensure a like-for-like comparison and are indicated by the red line in the figure below. This figure also shows two emissions curves that are representative of actual mobile handsets (Profiles 2 and 3). These show the amount of power that is emitted in the adjacent band. The current allocation for BA telemetry is shown by a dashed line and the potential allocation at 869.5MHz is shown by the dotted line.

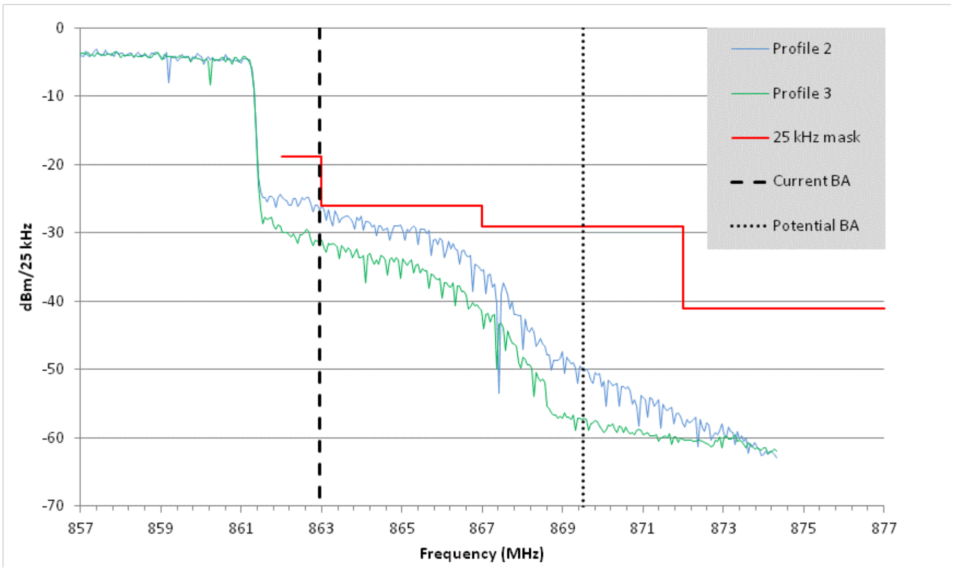

Figure 3.2: Typical emissions for LTE handsets as frequency separation increases. [Profile 2 is most relevant for current telemetry band, Profile 3 is most relevant for the SRD telemetry band]

The 'Profile 2' spectrum has been chosen to just meet the emissions mask at the worst point, and gives a radiated power of -26.5dBm/25 kHz at the current BA telemetry frequency. This is representative of the emissions from real LTE devices at this frequency. The 'Profile 3' curve has an improved out-of-band emission spectrum and has an EIRP of -30.9dBm/25kHz at the BA frequency and a level of -57.3dBm /25kHz at the potential BA telemetry frequency of 869.5MHz. This profile is representative of the emissions from real LTE devices at this higher frequency and shows that performance of real devices is significantly better than allowed by the standard.

If the potential BA telemetry frequency of 869.5 MHz is considered, it can be seen that the mask requires an Out of Block emission some 10dB lower than at the present frequency. If the emission profiles representative of actual hardware are examined, however, it can be seen that emissions falling at the SRD band frequency are reduced by some 23-26dB with respect to the current situation. Such a change in BA telemetry frequency would therefore be expected to reduce interference significantly, and this reduction has been quantified in this study.

Annex D gives further details of the LTE system, and describes the signal characteristics assumed in modelling and measurement.

3.2 Short-range devices (SRD)

One of the potential new allocations for the BA telemetry system falls in a segment (869.4-869.65 MHz) of a pan-European licence-exempt band in which operation at the relatively high power of 500 mW EIRP is permitted. This is the same power that the BA telemetry system currently operates at. An SRD device that is compliant with the requirements of the standard for this band segment may operate, however known applications for SRDs operating in this segment include:

- Traffic light control (temporary lights)
- Intruder alarms
- Environmental monitoring
- Short range audio communications e.g. for stage management
- RFID used for stock control
- Nautical man Overboard systems
- Ticketing systems

What is not known, and would be very difficult to determine, is the density of deployment of such devices. Anecdotal evidence suggests that significant levels of interference exist in only very few locations. Informal measurements made as part of the present work found no evidence of any devices radiating in this band along routes driven in Brighton, Leatherhead, Cobham or on a route including the A23, M23 and parts of the M25, although we understand that Ofcom is trying to source more detailed information from other example routes.

In addition to the low geographic density of these devices, the likelihood of interference is also limited by the fact that European regulations [2] require that devices in this band operate with a duty cycle of only 10% (i.e. the transmitter must be switched off for 90% of the time).

The details of a selection of SRDs operating in the 869.40-869.65 MHz band are given in Annex C.

3.3 Fireground radios (PMR Radio)

Most FRS currently use analogue (narrowband FM) UHF radios for voice communications at incident sites, although a small number have switched to digital versions. These systems include both mobile (vehicle-mounted) and handheld units and operate with powers of 1 to 3W ERP depending on the configuration.

These systems operate at frequencies allocated to the emergency services around 457 MHz in a 25 kHz channel bandwidth.

3.4 Airwave radios (TETRA standard)

For wider area communications than afforded by the fireground radio, the national ‘Airwave’ system for emergency services communications is used. This digital system uses the TETRA standard and operates in 25 kHz channels at frequencies around 380 MHz paired with 390 MHz. In the London area, an additional allocation at around 410 MHz paired with 420 MHz is used.

4 INTERFERENCE FROM LTE HANDSETS

The previous study [1] showed that LTE handsets operating at frequencies just less than 1MHz away from the current (862.9625 MHz) telemetry allocation could cause significant interference to BA telemetry systems. The present study therefore investigated the extent to which interference might affect telemetry systems operating at different frequencies and how such interference might be technically managed.

Figure 3.2, above, showed the out-of-band emission limits prescribed by the equipment standard, together with two realistic profiles based on actual hardware. The radiated power falling in the BA telemetry receiver bandwidth at the two potential frequencies are tabulated below for these three assumptions.

Table 4.1: LTE handset emissions assumed in measurement & modelling

	862.9625 MHz	869.5 MHz	Difference
Mask	-18.8 dBm/25 kHz	-29.0dBm/25kHz	10.2 dB
Profile 2	-26.5 dBm/25kHz	-49.8 dBm/25kHz	23.3 dB
Profile 3	-30.9 dBm/25kHz	-57.3 dBm/25kHz	26.4 dB

It can be seen that in practice there is a greater reduction in OOB emissions at the higher frequency than might be assumed from an inspection of the mask alone.

It is noted that the handset emission power assumed in the Thales report [1] at 862.9625 MHz was -26dBm/25 kHz, so the results in that study should be directly comparable with Profile 2 of this one.

In our analysis of interference for simplicity we refer to the source of interference as the interferer (in this case the LTE device and in the subsequent chapters this will be the SRD device or fireground/Airwave radio) and the device suffering interference as the victim (in all cases the BA telemetry operating at the appropriate frequency).

4.1 Measurement

In order to characterise the impact of LTE emissions on the BA telemetry system and compare the current and SRD band options, the protection ratio between the two systems has been determined at which the telemetry system just fails. In the case of LTE operating in adjacent spectrum to the BA telemetry, this protection ratio determines how much stronger than the victim (telemetry) the interferer (LTE signal) can be when both are measured in their own frequency and bandwidth allocations. The shape of the OOB emissions profile (Figure 3.2) and the differences in bandwidth of the two systems means that in practice the overall power of the LTE signal can be much stronger than that of the BA telemetry.

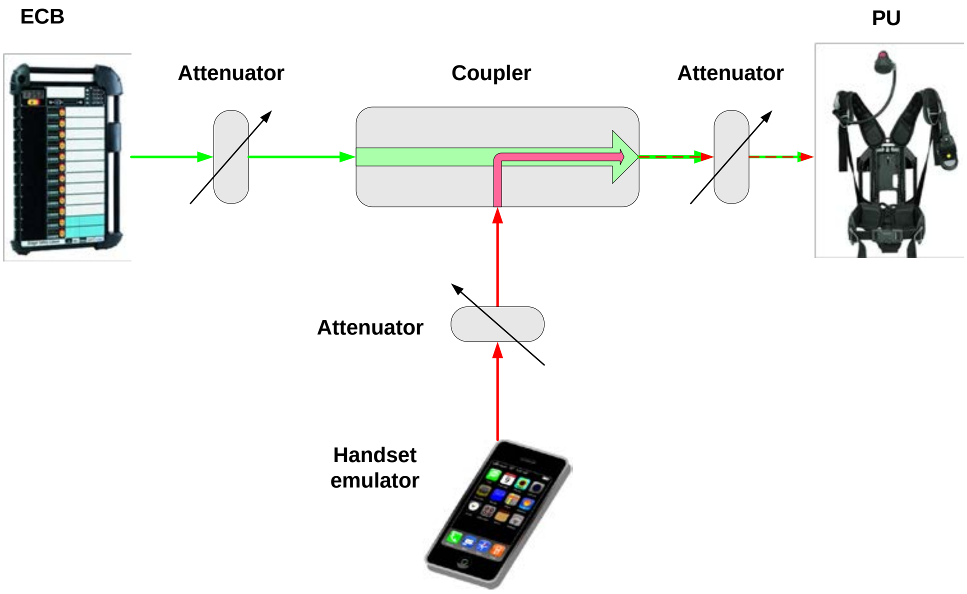

Figure 4.1: Generic test setup for conducted measurements

The arrangement used to determine this failure point is indicated in Figure 4.1 above. In this case, the interfering signal from the handset is emulated by a signal generator playing back the signals recorded from a prototype LTE handset, suitably processed with other RF components (a power amplifier, filter and attenuator) to give the emissions profile reproduced in Figure 3.2 above. Although the setup for testing interference into the portable unit (BA wearer) is shown, the directional coupler could also be configured to allow the failure point of the control board to be determined (i.e. with the horizontal 'signal flow' arrows pointing in the opposite direction).

The failure point of the system was judged by observing, on a spectrum analyser, the attempts of the ECB to poll the PU; a poll is made every 20 seconds, and if this is not successful, two further attempts are made within about one second of each other. If all three attempts failed, the interference was judged to have exceeded the threshold.

Table 4.2: Protection ratios for LTE UE into BA

LTE profile	**BA frequency: 862.9625 MHz**		**BA frequency: 869.5 MHz**	
	ECB (dB)	**PU (dB)**	**ECB (dB)**	**PU (dB)**
Mask				
Profile 2	-45.6	-41.1	-69.3	-64.8
Profile 3	-51.1	-47.8	-75.7	-68.2

Table 4.2 shows the determined protection ratios for both tested frequencies in the 800MHz band. The results indicate that the in-block power of the LTE signals at the victim BA telemetry device can be some 40 to 75dB higher than those of the wanted telemetry signal.

The results show, as would be expected from Table 4.1, that emissions from LTE cause around 20-25dB less interference at the higher frequency than at the lower frequency.

The results also show that the ECB is somewhat less sensitive to interference than the PU (by typically 4-5dB). Detailed further testing has shown this result to be repeatable. It has also been confirmed by inspection that the radio modem modules are the same in both units; the cause of this discrepancy remains unclear.

4.2 Modelling

4.2.1 Monte Carlo simulations

The majority of modelling within this study has used the Monte Carlo approach. This is a statistical approach to modelling whereby a large number of ‘trials’ are made and the results analysed to determine the overall probability of interference occurring which is the most appropriate mechanism for determining the probability of systems with many variables. In each trial, the interference is assessed for a realistic, but arbitrary arrangement of victim (BA telemetry) and interferer (LTE) devices. For each trial, the parameters of the terminals (power, activity, location) and the propagation path loss (including effects for signal fading and building penetration loss) are varied according to statistical distributions chosen to represent the behaviour (known or assumed) in the real world.

The probabilities predicted are simply the risk of a BA telemetry message or poll being lost. It is important to note that the simulations do not take into account the absolute timing structure of the signals, but only the duty cycles. This is unavoidable in a generic model, as the details of the behaviour of the interferers in time (particularly the SRDs considered in the next chapter) cannot be known (although models could be constructed for specific examples). This implies that the statistics can be considered to be valid over any period (larger than the frame structure) of the BA telemetry, LTE or SRD devices (i.e. an interference probability of 10% would imply that a tenth of all messages would be lost, whether considered over a minute, or 30 minutes, or a day).

Two scenarios were modelled, for interference to the control board and for interference to portable units. In each case, it is assumed that the minimum C/(N+I) required by the BA telemetry receiver is 11dB.[3]

In the first scenario, the interference from outdoor LTE handsets into an entry control board was simulated. This was defined to represent the case where onlookers at ground level, or at the upstairs windows of nearby buildings, might use their terminals near an incident scene. Interferer ranges of up to 100m from the ECB are modelled, but it is assumed that an exclusion zone could keep onlookers at least

[3]the modelling was undertaken prior to the measurements; the 11B figure for C/(N+I)was based on the E_b/N_0 figure assumed in the earlier Thales report for Ofcom [1].

1m from the ECB. The portable units linked to the ECB are assumed to be indoors, with a maximum range of 70m intended to coincide with the typical distances covered by firefighters with hose runs, although we understand that this range may be exceeded in certain buildings and circumstances. It is assumed that the LTE handset is streaming video content and therefore active continuously with all 50 resource blocks in use. This represents a worst case scenario where 1 or multiple users in close proximity are collectively using up all the cell resources. In practice the transmissions maybe a little discontinuous thus causing *less* interference to the ECB than has been modelled.

In the second scenario, the interference is assumed to be from a handset in the same building as that being attended by the portable units, and within 10m (i.e. within the same room). Again, it is assumed that the ECB is outside the building, and that the maximum range between PU and ECB is 70m. It is assumed that the device is representing a single user and is operating with a much lower 10% duty cycle.[4]

Table 4.3: Probability of LTE interference to BA telemetry: modelling results

LTE profile	**telemetry frequency 862.9625 MHz**		**telemetry frequency 869.5 MHz**	
	ECB	**PU**	**ECB**	**PU**
Mask (free space)	1.72%	0.04%	0.39%	0.02%
Profile 2(free space)	0.49 %	0.01 %	< 0.006 %	< 0.006%
Profile 3(free space)	0.21 %	0.01 %	< 0.006 %	< 0.006%
Mask (D^4 at >10m)	3.20 %	0.05 %	0.97 %	0.04 %
Profile 2 (D^4 at >10m)	1.15 %	0.04 %	0.03 %	0.01 %
Profile 3 (D^4 at >10m)	0.79 %	0.03 %	0.01 %	< 0.006 %

It is noteworthy that the closer range of the 'handset to PU' in the indoor scenario is more than offset by the low duty cycle assumed for the handset in this case. When considering the overall likelihood of interference to either end of the telemetry link, the probability for each end should be considered separately along with the likely number of terminals within the vicinity of each end of the link.

In the modelling results given above, the median path loss was modified by shadow (lognormal) and multipath (Rayleigh) fading and by building penetration loss. The simulations were run firstly assuming free space path loss (attenuation proportional to distance squared) and then using a path-loss model that assumed free-space loss up to 10m and a more aggressive attenuation that is typical of longer scattered

[4] although the emission profiles still assumes that all 50 resource blocks are in use, potentially supporting an intensive application

paths (related to a distance to the power of 4) beyond that. This assumption (of increased path loss) *increased* the probability of interference, because, although the interference power is lower, the wanted power is lower still. In the worst case (the 'mask' values into the ECB), the probabilities increase from 1.7% to 3.2% at the lower frequency and from 0.4% to 1.0% at the higher frequency.

It should be noted that, although the results above relate to a single interfering device, for the case of interference to the ECB this device is assumed to either load the coverage cell completely or represents multiple users in close proximity to each other (at a cordon for example) who in aggregate are loading the cell completely (i.e. using all resource blocks for 100% time).For interference to the PU, however, it is assumed that the handset is operating with only a 10% duty cycle[5]; if there are multiple handsets present, the probability of interference will, therefore, scale accordingly.

4.2.2 Protection Distances

Monte Carlo modelling is generally appropriate for cases in which the location of interfering devices cannot be known or controlled. It is useful, however, to determine the protection (or separation) distances necessary to protect BA telemetry systems from interference.

In lieu of any published performance requirement for the BA telemetry, it was assumed that the interferer should not raise the system noise level by more than 3dB (i.e. the range of the system would be reduced by 30% in open space).This is consistent with the approach taken in the Thales report [1] and determined as a "rural" environment. In this report, it was assumed that BA telemetry systems operating in urban areas would be subject to higher levels of man-made electrical noise which would raise the system noise floor by 20dB; this criterion is also modelled for comparison.

Under these assumptions, and knowing the power of the interferer and the performance (noise figure) of the victim receiver, the required separation distances can be determined.

[5] This assumption is made because it seems unlikely that a handset being used inside the same building as the BA set will be carrying extremely high data rates.

Table 4.4: Separation distance required from LTE handset

BA frequency	862.9625 MHz		869.5 MHz	
Assumed BA link margin	**Rural (3dB)**	**Urban (20dB)**	**Rural (3dB)**	**Urban (20dB)**
Mask	4,486 m	633 m	1,376 m	196 m
Profile 2	1,849 m	261 m	126 m	18 m
Profile 3	1,114 m	158 m	53 m	8 m

It is clear that a telemetry system operating at system ranges and signal levels to cope with the urban noise levels as high as those assumed by Thales would greatly reduce the impact of any interference. The values for the more conservative '3dB degradation' assumption appear rather large. It must be borne in mind that this calculation takes no account of the low probability of collision shown in the above sub-section.

Both sets of figures show that the effect of LTE interference on the BA telemetry system operating in the 869.5MHz SRD band is significantly less than the current band, however it should be noted that interference from other SRD devices also operating in that band are discussed in the following chapter.

4.3 Summary

The undertaken simulations show that the current allocation of 862.9625MHz will suffer more than 20dB greater interference than a retune to the higher frequency of 869.5MHzfrom representative LTE handsets. This is manifest in more than a tenfold reduction in protection distances required at the higher frequency.

Statistical modelling using Monte Carlo techniques shows the risk of interference from a single handset would reduce from around 0.5% in the current band to a risk of <0.0006% at 869.5 MHz, assuming 100% utilisation of all 50 resource blocks and free space propagation.

It is not straightforward to interpret this risk in overall system terms, as no availability targets have been specified for the BA telemetry system, nor have any formal measurements been made. **It seems likely, however, that the probability of interference from LTE handsets to BA telemetry at 869.5 MHz is so low as to be insignificant in the operation of the telemetry system**. This could only be confirmed, however, with an extensive programme of field trials and the input of the Fire and Rescue Service on how this would fit with their current or future operational procedures.

5 INTERFERENCE FROM SRDS

It was seen in the above chapter that the impact of LTE as the interferer on a telemetry system operating at 869.5MHz was low, however in this band there is also a risk of interference being caused by other Short Range Devices (SRDs) operating in the 869.40-869.65MHz band.

As for the LTE case, both measurements and modelling have been used.

5.1 Conducted measurements

The test setup shown in Figure 4.1 was used, with a variety of SRDs as the interferer rather than the LTE terminal shown in the figure. In each case, the SRD was set to the same frequency[6] (co-channel) as the BA telemetry (i.e. 869.5 MHz).

In each case, the power of the interfering signal was increased until no communication could be established between the BA terminals (i.e. all three poll or response attempts in a 20 second period failed). The SRD interference is more complicated than for the LTE case, as both the BA telemetry system has a low duty cycle operating over a 20 second period and (most of) the SRDs also have a fairly low duty cycle operating over a repeat period of several seconds in some cases. It is therefore necessary to observe the failure statistics over an extended period to allow an interference event (a collision between an SRD message and a BA telemetry message) to occur.

Four different SRDs were used as the source of interference, each with a slightly different transmission profile in the time domain (see Appendix C). Each device also has a differing emphasis in the way the signal is transmitted in the frequency domain. The BA telemetry signal has a particular frequency profile as shown in Figure 5.1. If the interfering source is a very wideband interferer this will cause an even increase in noise across the entire 25kHz channel that the telemetry operates in. In the case of a very narrow signal this will only affect the middle part of the telemetry signal and information in the outer edges may still get through.

Additive White Gaussian Noise (AWGN) is a representation of the wide band signal affecting all of the telemetry signal, whereas a carrier wave (CW) is an unmodulated signal that will only affect the middle part of the telemetry signal, this has the least impact on the signal. These cases are always transmitting (with a 100% duty cycle) represent the two bounding extremes of interference. The four test SRD signals have an interference impact between[7] these two extremes, depending on the degree to which their transmitted spectrum resembles one or the other.

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[6] In one case (SRD 4) the centre frequency could not be set to exactly 869.5, but the emissions from the device were sufficiently wideband to cover the whole 25kHz BA telemetry channel.

[7] The situation is complicated by the differences in pulse width and duty cycle between the devices, so that SRD 2 actually gives rise to less interference than the CW tone, although its spectrum (see Figure C.7) is similar.

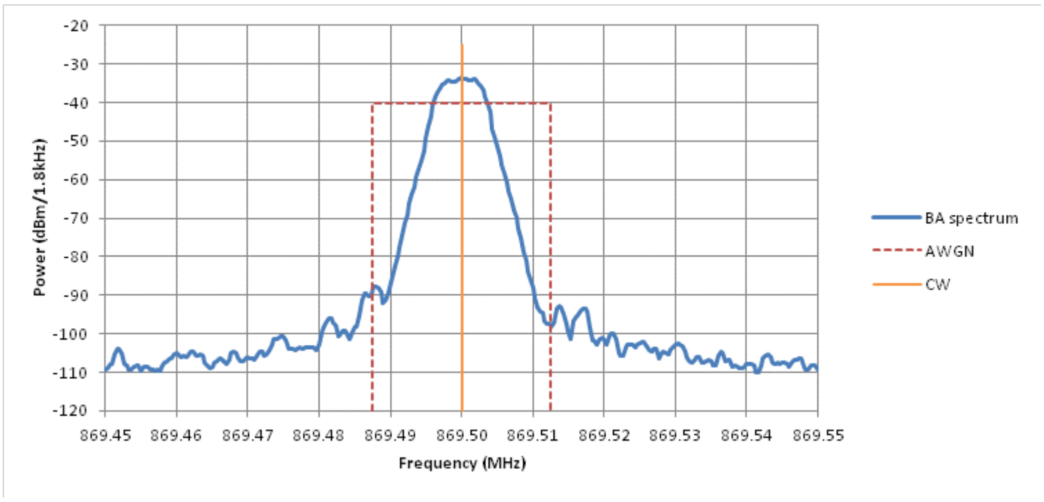


Figure 5.1 Spectral Profile of Telemetry.

The resulting values of Signal to interference plus Noise (SINR) are shown in the table below

Table 5.1: Measured values of protection ratio required by BA telemetry with respect to SRD interference

Interferer	SINR for BA telemetry failure	
	ECB (dB)	PU (dB)
CW		1.5
AWGN		6.4
SRD1 (Radiometrix)	0.9	3.7
SRD2 (Audio link)		-0.9
SRD3 (Xnet)	1.5	2.5
SRD4 (Adeunis)	0.4	4.8

In the Thales report [1], it was assumed thatthe SINR required is 11.8dB for a Bit Error Rate of 1.0035 x 10^{-3}. This value seems surprisingly high, and theoretical considerations suggest that the actual SINR required may be somewhat lower at around 7dB (i.e. the wanted signal must be 7dB greater than the combined power of interference and noise). This is supported by the measurement of 6.4dB for the AWGN (noise) interferer.

5.2 Radiating measurements

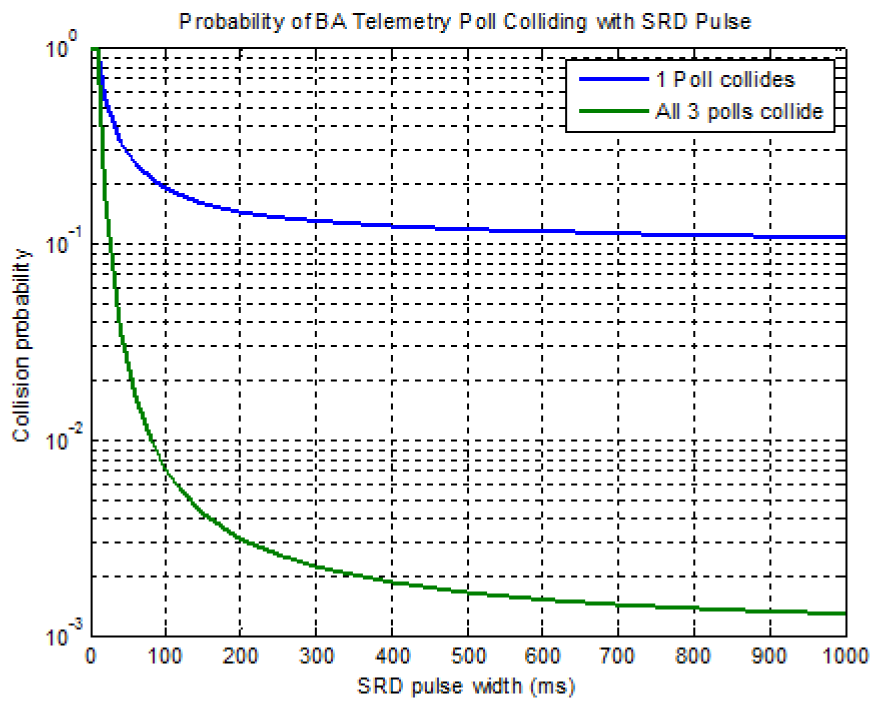
Very brief practical trials were made with the BA telemetry system and a set of SRD interferers radiating freely within an anechoic chamber (to eliminate unintended interference). It was found that for a BA telemetry system range of 8 metres[8], the

[8]the largest that could be accommodated in the chamber

polling of a single portable unit was successful for 53% of trials with all four SRDs operational and positioned only 20cm from the ECB receiver. The same SINR levels would be expected in free space for a BA system range of 70m with the four SRDs at 1.75m from the ECB[9].

5.3 Duty Cycle

Assuming that the risk of a collision between an SRD transmission pulse and a BA frame is equal to the duty cycle is a simplistic approach that can be used when the temporal pattern of SRD emissions is unknown. In practice the risk of collision will increase as the SRD pulse width reduces, *assuming the overall duty cycle remains the same*. This is simply because there will come a point where there is not enough time between the SRD pulses for a complete BA frame to be sent. The effect is illustrated in Figure 5.2, which shows the risk of collision with a single BA poll, and with all three polls required by the BA specification. The green line (indicating that all 3 polls will collide) assumes that the probability of each poll colliding is independent. The repeated poll request is in fact related to the first poll by a randomised delay that seems to be centred around 1 second. This means that as the SRD pulse width increases there will be a period where the second or third poll request does not collide thus reducing the probability of a collision of all 3 polls further. However as the SRD transmission may not be entirely regular we have assumed a slightly conservative approach and assumed collision events can occur independently.



[9] These four SRDs were set in some cases to a higher duty cycle than is permitted in practice and therefore might be considered to be a somewhat extreme case.

Figure 5.2: Relationship between SRD pulse duration and collision probability.

It can be seen that the probability of a single collision tends to the 10% value of the duty cycle of the SRD. There are SRD pulse widths (typically 10ms or less) where the risk of a collision is 100%. It is relevant to note that the devices measured had (in their test or default modes) pulse widths of between 120ms and 750ms. Therefore for the modelling we have assumed 3 test points, 100% chance of collision, 10% chance of collision and also a 20% chance of collision which corresponds to an SRD pulse width of 100ms.

5.4 Modelling

As for the LTE case, modelling was undertaken to assess the risk of interference from SRDs into BA telemetry systems operating at 869.5 MHz.

In this modelling, the risk of interference to a BA telemetry ECB receiver from SRDs with different duty cycles is determined. The model considers the interference probability (taking account of the relative signal strengths of the two systems for 10%, 20% and 100% probability of collision (P_{coll}). It is assumed that the ECB is located outdoors and is communicating with a PU inside a building, at ranges of up to 70m.

In the first scenario the interference was assumed to be from an outdoor SRD into the ECB; the second interference from an indoor SRD to the PU was modelled.

As with the Monte Carlo modelling for LTE, consideration was given to the propagation loss being based on free space (attenuation related to distance squared) and also a more aggressive attenuation that is typical of longer scattered paths (related to a distance to the power of 4)

Table 5.2: Probability of SRD interference to BA: modelling results

Interference probability	P_{coll} = 10%		P_{coll} = 20%		P_{coll} = 100%	
	ECB	PU	ECB	PU	ECB	PU
Free space	0.12 %	0.11 %	0.24 %	0.22%	1.20%	1.10 %
D^4 at > 10m	0.10 %	0.13 %	0.20 %	0.26 %	1.00 %	1.30 %

The interference probabilities refer to the risk of interference on any individual link (PU to ECB or ECB to PU). For an ECB with more than one linked PU, the overall risk of interference (i.e. to any of the links) simply scales with the number of linked PUs).

5.5 Summary

BA telemetry operating at 869.5 MHz has (in addition to the LTE interference risk) a risk of interference from SRDs operating in the SRD band. The risks for both interferer sources are independent therefore can be added together to form an overall risk where both interferer devices were present. However the likelihood that these devices are actually within the area of influence for telemetry should also be considered.

Conducted measurements made on four representative SRDs show that the impact on the BA telemetry system is broadly in line with expectation, with protection ratios of up to 5dB being required.

Statistical modelling using Monte Carlo techniques predicts a probability of losing around one message or poll in 1000 when the BA telemetry system is operated in the vicinity of a single SRD operating at the same frequency.

It is not straightforward to interpret this risk in system operation terms, as no availability targets have been specified for the BA telemetry system, nor have anyquantitative measurements of performance been made. It seems likely, however, that the probability of interference from co-channel SRD devices to BA telemetry at 869.5 MHz is so low as to be insignificant in the operation of telemetry system. This could only be confirmed, however, with an extensive programme of field trials and reliable data on the deployment density of such SRD devices.

6 INTERFERENCE AT 450 MHZ

In the context of interference to the 862.9625 MHz BA telemetry channel from LTE, an alternative potential option has been considered in which the telemetry would be moved to a frequency in licensed allocations between 410 and 450 MHz.

While this would remove some uncertainty regarding interference from LTE and other users of the SRD band at 869.5MHz, it would raise other issues, particularly regarding the possibility of interference from existing communications systems used at incident sites.

Figure 6.1 below shows the allocations currently used in this part of the spectrum, and indicates possible frequencies for BA telemetry use.

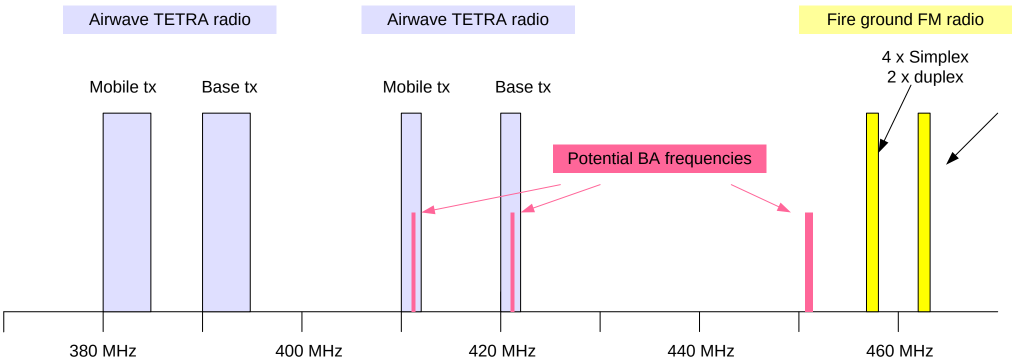


Figure 6.1: Relationship of frequencies at 380 – 470 MHz

It should be noted that the higher pair of Airwave allocations is only used in the London area. These allocations (411 MHz and 421 MHz) would only be used for BA telemetry in areas where they were not used for Airwave.

6.1 Fireground radios

The worst-case scenario is when the BA telemetry and fireground radio are operating closest in frequency to one another. Where the BA telemetry system uses 451.0475 MHz and fireground radios operating at 457.0475 MHz are in use, a frequency separation of 5.72 MHz is achieved.

A comparison of the spectral mask for fireground out-of-band emissions falling into the BA telemetry receiver bandwidth indicates that calculated coexistence requirements will also satisfy the co-existence requirements from the response of the BA telemetry receiver at the fireground frequency.

The scenario of most concern is the case in which a firefighter is equipped with both a BA telemetry unit and a fireground radio. In this case the separation distance between the two may be only a few tens of centimetres dependent upon the location of the fireground radio in accordance with the individual fire and rescue service procedures.

Minimum required free space distances have been calculated for a set of assumed BA telemetry link interference margins and for fireground out-of-band emissions corresponding to the two states defined in the specifications [7-9].

Table 6.1: Free-space separation distances (fireground radio at 457 MHz to BA telemetry at 451 MHz)

(EIRP values relate to the power of spurious emissions at the BA frequency)	**Assumed BA Link Interference Margin**	
	Rural (3 dB)	**Urban (20 dB)**
Fireground Transmitter Active (EIRP = -42 dBm / 25 kHz)	588 m	59 m
Fireground Transmitter Standby (EIRP = -63 dBm / 25 kHz)	53 m	6 m

It can be seen that sharing would appear to be impossible. It should be noted, however, that the figures given in [7-9] as the mask limit for out-of-band emissions are likely to be considerably higher than the values actually generated by in-service equipment. This is exactly the same as the OOB emissions from an LTE handset falling below the emission mask levels (see figure 3.2). Further testing of examples of fireground radios will be required in order to provide more realistic and accurate levels of separation distances. In addition, the BA telemetry system for large periods of time will often be operating with link margins in excess of 30dB resulting in much reduced separation distances.

More importantly, as both the fireground radio and the BA telemetry units are under the control of the FRS, it should be possible to address this compatibility issue through additional filtering at the fireground radio transmitter output and, perhaps, the receiver front-end of the telemetry system.

In addition, Monte-Carlo simulations were also carried out, assuming that a single fireground radio is located randomly within 50m of a portable unit (i.e. not allocated to the same user). The **probability of interference was found to be zero**, due to the low probability of a collision between a fireground transmission and a telemetry signal and due to the existence for most trials or relatively large telemetry link margins.

6.2 Airwave radios

As the 411/421 MHz allocations would never be used for telemetry and Airwave communications in the same area, the minimum frequency separation to be considered is that between an Airwave base station operating at 395 MHz and a BA telemetry system at 411.6375 MHz, a frequency separation of 16.6 MHz[10].

[10] The minimum frequency separation in the case of the TETRA mobile is 26.5 MHz

A comparison of the mask limits for TETRA out-of-band emissions [10] falling into the BA receiver bandwidth indicates that the coexistence requirements are satisfied by default when considering the response of the BA receiver at the TETRA frequency.

Table 6.2: Free-space separation distances (Airwave radio at 385/395 MHz to BA telemetry at 411 MHz)

	Assumed BA Link Interference Margin	
	3 dB	**20 dB**
Airwave mobile terminal Transmitter (EIRP x RX selectivity: -61.8 dBm / 25 kHz)	72 m	8 m
Airwave base station Transmitter(EIRP x RX selectivity: -47.8dBm / 25 kHz)	349 m	33 m

Monte-Carlo simulations were also carried out, assuming that a single Tetravehicle radio or base station is located randomly within 100m of an ECB or a PU. The **probability of interference was found to be zero in all four cases**[11], due to the low probability of a collision between a TETRA transmission and a telemetry signal and due to the existence for most trials or relatively large telemetry link margins.

6.3 Propagation effects

A recent, unrelated study [11] undertaken by Aegis for Ofcom compared propagation effects in domestic buildings at various frequencies. Two of the frequencies investigated were 500 MHz and 800 MHz.

For *free space* propagation between isotropic antennas it would be expected that the path loss at 800 MHz would be greater than that at 500 MHz by 4.1dB.

[11] Base to ECB, base to PU, vehicle to ECB and vehicle to PU

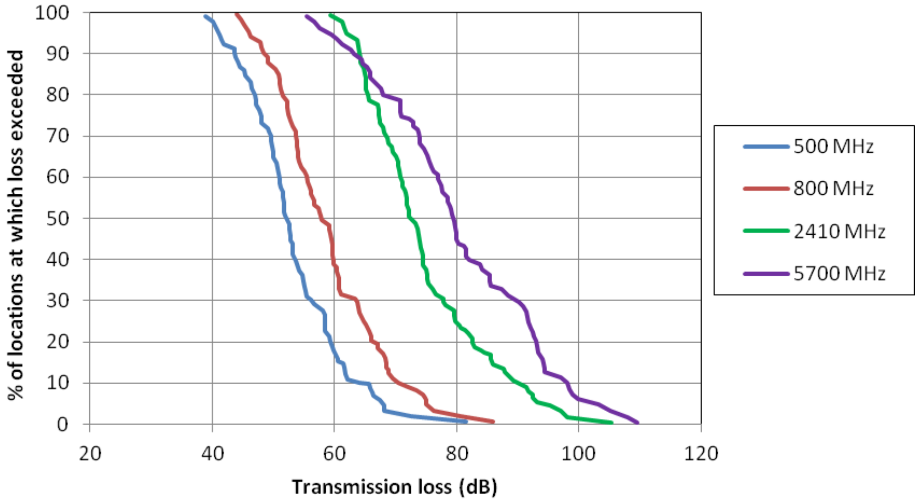


Figure 6.2: Indoor propagation measurements made in separate Aegis study [11]

The measurements made in the propagation study indicated that the median path loss[12] at 500 MHz is some 6 dB less than at 800 MHz, so that in addition to the expected difference due to the change in wavelength, there is a slight reduction in loss due to diffraction and material absorption.

In free-space conditions with no interference, this would imply that a system operating at the lower frequency would have a maximum range two times greater than a system at the higher frequency. In practice, interference, noise and decreased antenna efficiency may degrade this potential advantage but range would not be expected to be any worse than the current frequency of 862.9625MHz.

[12] Basic (isotropic) path loss

7 CONCLUSIONS

This study has considered the risk of interference to FRS breathing apparatus telemetry systems under a number of different scenarios. The key findings and conclusions are provided below.

- Probabilistic modelling shows that the risk of interference to BA telemetry from typical 4G mobile handsets is lower at a telemetry frequency of 869.5 MHz than it is at 862.9625 MHz (less than 0.006% and 0.49% respectively).
- This change in BA frequency corresponds to a reduction of the worst-case separation distance required (between a 4G handset and a telemetry receiver) from 1.8 kilometres to 126 metres. This may to reduce further to 53m in rural locations and 8m in urban locations with a telemetry system operating at 869.5MHz and an LTE device with emissions similar to Profile 3.
- There will be some risk of interference from licence-exempt, low-power radio equipment (SRD) at the 869.5 MHz frequency. Modelling predicts a probability of losing around one message or poll in 1,000 when the BA telemetry system is operated in the vicinity of a single SRD. For comparison, if typical BA deployments are for 30 minutes and involve four firefighters, a single poll- or message-failure for every three to five deployments would correspond to a probability of around 1 in 1,000.
- Anecdotal evidence from a brief drive survey suggests that the deployment of SRDs at the 869.5 MHz frequency is sparse.
- If a frequency around 450 MHz were to be used for the BA telemetry system, there is a risk of problems of compatibility with the fireground radio system, particularly when used by a BA wearer. It is likely to be possible to overcome such incompatibility with careful engineering of both systems. Additional measurements and investigation may be needed before final conclusions on the suitability of this band can be drawn.
- Airwave radio base stations or vehicle installations are not predicted to have any impact on BA telemetry operating in the 450 MHz band.
- A move to 450 MHz from 862 MHz would probably give a slight increase in telemetry system range, in the absence of interference.
- It is not straightforward to interpret interference risk in system operation terms, as no availability targets have been specified for the BA telemetry system, nor have any quantitative measurements been made. It seems likely, however, that the probability of interference from co-channel SRD devices or 4G handsets to BA telemetry operating at 869.5 MHz is so low as to be insignificant in the technical operation of the telemetry system

It is suggested that it would be valuable to undertake a brief set of field trials under realistic conditions. These might take the form of an exercise in which one or two test buildings are explored by firefighters wearing breathing apparatus. The BA ECB would be monitored with a spectrum analyser to detect whether polling attempts are successful, involve re-tries or fail completely. A set of representative SRD or LTE simulators would be deployed within the building, and the difference in failure statistics with these switched on or off would be noted

A REFERENCES

[1] "*862 - 863 MHz Breathing Apparatus Telemetry System Interference Study*", Thales Technical Report P7784-10-003, 15 December 2010

[2] "*…(SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW; Part 2: Harmonized EN covering essential requirements under article 3.2 of the R&TTE Directive"*, ETSI Standard EN 300 220-2, version 2.3.1 (2010-02)

[3] "*A Fire Service requirement for telemetry at incidents*", JCDD/40 issue 2, Draft v5.0, 2nd September 1999

[4] "*Performance & Regulatory standards for Radio Telemetry System for use by the Fire Service in the 862-863 MHz band*", Type Approval Technical Specification MG41, issue 1.4, Radio Frequency & Communications Planning Unit, Strategic Planning Group 1, Home Office, 3rd August 1999

[5] "*At-Incident Telemetry Common Air Interface Document*" MG 41A Issue 1.4,Radio Frequency & Communications Planning Unit, Strategic Planning Group 1, Home Office, 3rd August 1999

[6] "*3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) conformance specification Radio transmission and reception Part 1: Conformance Testing*" 3GPP TS 36.521-1 (Release 9), 2011-09

[7] "I*ncident Ground Communication* Study", Fire Research Technical Report9/2008, December 2008

[8] ETSI Standard EN 300 086

[9] ETSI Standard EN 300 113

[10] ETSI Standard EN 300 392-2

[11] "*In home propagation*", Aegis Systems report 2216/IHP/R/2/1.4, 30th June 2011

B FRS BREATHING APPARATUS TELEMETRY

This annex provides an overview of the characteristics of the telemetry system used by the Fire and Rescue Services in the UK.

B.1 Overview

Fire and Rescue Services have long used self contained breathing apparatus to undertake operations in hazardous areas such as those filled with smoke or toxic vapour. It is necessary for users to have a very clear understanding of the safe operating duration of the apparatus; the original arrangement, still used where telemetry systems have not been adopted, is for the contents of the apparatus to be assessed by weight, and an operational time-limit or duration to be set accordingly. Audible alarms are used to signal the withdrawal of firefighters, or as individual distress signals.

In many brigades, this system is being replaced or supplemented with the use of radio telemetry systems,the majority of which has been acquired from the German Dräger company[13], This system performs the dual role of reporting, continuously, the contents of individual breathing apparatus sets and of allowing signalling, in either direction, between the control board and portable units, of messages such as ‘withdraw all units’ or ‘alarm’ (sent manually or triggered automatically by a motion sensor).

The commonly used Dräger system consists of base unit (‘Entry Control Board’, ECB) which will be located outside the risk area, and acts as a tally system for all deployed units (Fig.B.1).

Figure B.1: Dräger Entry Control Board

[13] Other suppliers offer similar systems, meeting the same standards. Equipment from these sources may be acquired by the FRS in the future. To date, however, most BA telemetry equipment in the UK is from Dräger.

Each ECB can support up to 12 portable units, polling each in a 20 second cycle. A leaky feeder can be connected to the ECB for use in situations such as a London Underground tunnel, and the system allows the use of up to two 'store and forward' repeaters, intended for use where building penetration is poor.

Extensive testing was carried out in April 2008 in a variety of building types. Coverage was apparently found to be good with no requirement for repeaters or leaky feeders except in London Underground and the Houses of Parliament. The full test report is, however, no longer available following the closure of the 'Firebuy' procurement organisation which conducted the work.

A document reporting on further testing by the West Midlands Fire Service has been obtained This indicates that, in a high rise block of flats, it was necessary to use a repeater to give coverage beyond the 9th floor (with an ECB in the lobby at ground level). During testing in a large warehouse, coverage was found to fail in a corner screened by steel racking.

B.2 Specification

The BA telemetry system is specified in three Home Office documents, all dating from 1999. These are a User Requirement [3] and a Technical Specification [4] with associated Technical Standard [5].

The user requirement describes the messaging and user interface to be provided by the equipment, but little detail relevant to the present work. The Technical Specification gives only high-level requirements for the transmitter and receiver performance, effectively simply noting that ETS 300 220[14] applies. The Technical Standard is the most useful description of the operation of the telemetry system, and provides sufficient detail to allow a system to be implemented.

This radio telemetry system operates at UHF with a terminal power of 500mW ERP. The system uses FSK modulation in narrowband (25 kHz) channels

B.2.1 User requirement (JCDD/40)

The user requirement describes the messaging and user interface to be provided by the equipment, but little detail relevant to the present work. The following are noted:

Some further information was provided at the meeting with London Fire Brigade Protective Equipment Group on 16th September. In particular it was stated that, in the trials, it was found that the use of [two of the same identifying number] repeaters could cause problems with link failures. Furthermore, it seems that repeaters must be deployed in sequence, with R1 closest to the board and R2 closest to the users.

[14] Short Range Devices (SRD): Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW; Part 1: Technical characteristics and test methods

B.3 Principle of operation

The description below has been written on the basis of information given in the documents noted above, amplified by discussions held with the Protective Equipment Group of the London Fire Brigade and by observation of signals in laboratory testing.

The description given is intended only to address aspects relevant to interference modelling.

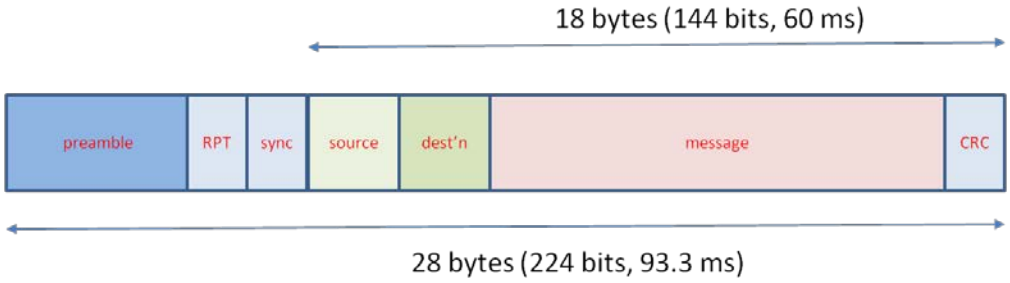


Figure B.2: Telemetry packet structure

Telemetry data transmission is in packets of 28 bytes (6 preamble, 2 repeater identification, 2 frame synchronisation and 18 message bytes). The pair of 'repeater flag' bytes allow identifying up to 7 repeatersto be identified (although it is understood that only two can be used in current systems).

The radiated symbol duration, at 4800 bit/s is 0.21 ms, but as Manchester coding is used, this corresponds to a data bit length of 0.42 ms. The entire 224-bit packet (with prefix) therefore has a duration of 93.3 ms.

A cyclic redundancy check on the 16 message bytes identifies errors, but no error correction is used. So a single lost bit (1 in 224) will cause the message to be lost (whether lost bits in the preamble, repeater flags or synchronisation word can be tolerated is uncertain). In the Thales report [1] it was assumed that the synchronisation word may need protection but not the preamble/repeater flag; in the present work it has been assumed that all 224 bits require protection.

The specification allows for systems to use either a 'random' or a 'polled' access method. In the latter, which was employed in the system tested during the study, packets are sent to each linked user, in fixed slots, at 20 second intervals. The 20 seconds are apportioned equally between users, giving a time-slot for each user that is determined by the total number of units logged on to the base station. When fully loaded with 12 users, a time-slot of 1.67 seconds is available to each, as illustrated below.

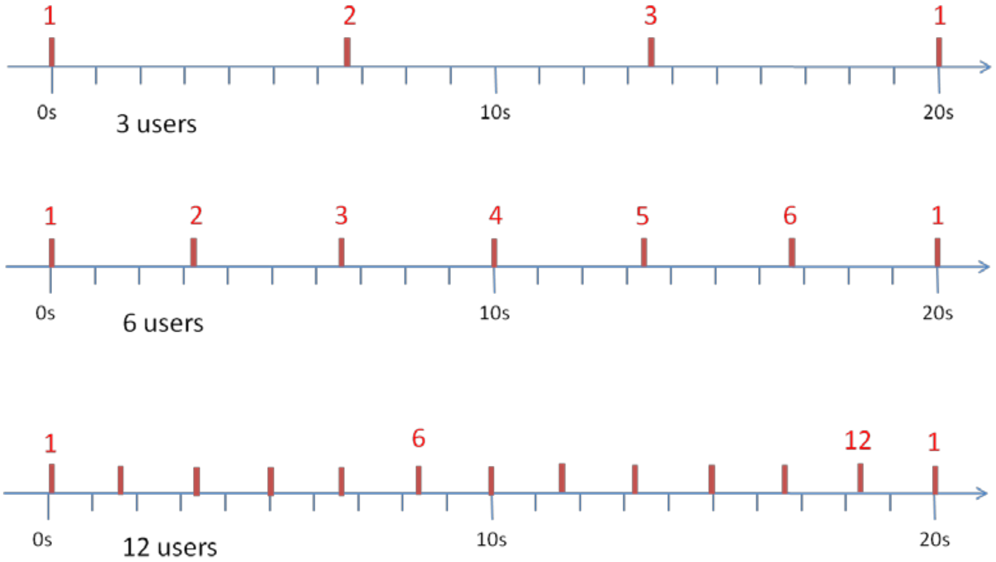


Figure B.3: Apportionment of timeslots between PU

The Base expects an acknowledgement from a polled PU within 0.5 seconds

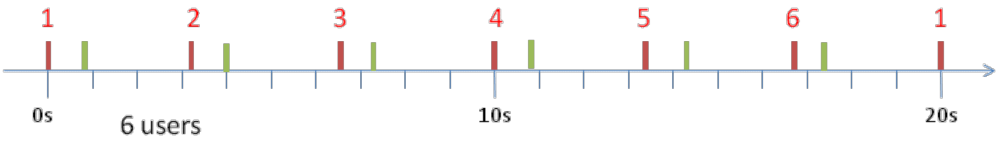


Figure B.4: PU acknowledgement

If no acknowledgement is received, the BU will retransmit the message a further two times. This has the effect of delaying the time of the next poll.

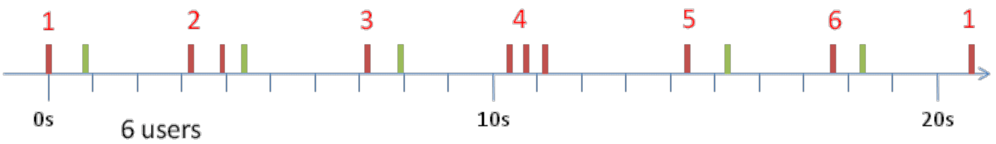


Figure B.5: PU acknowledgement and base re-transmissions

The following behaviour is required by the specification::

- If no acknowledgment is received from a portable unit following an '**evacuation**' signal, it is retransmitted five times in eight seconds, after which the unit returns to the normal 20 second repeat cycle.
- If a '**recall**' message is sent to a specific PU from the ECB, it overrides the normal 20 second cycle...

- If an '**Alarm**' signal is sent from a PU it overrides the normal 20 second cycle, with a retransmission every 4 seconds until an acknowledgement is received.

The screenshot of Figure B.6 shows the normal cycling of an ECB with one PU logged in, but out of range. The ECB makes three attempts to poll the PU, repeating the sequence as part of the 20 second cycle.

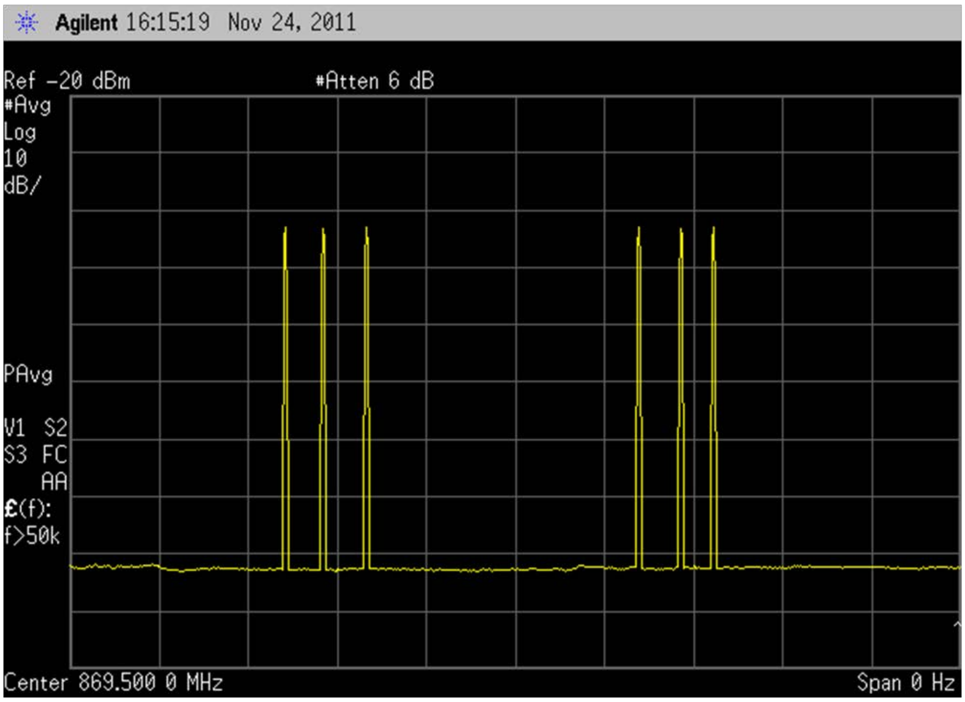


Figure B.6: PU acknowledgement and base re-transmissions (X-axis: 5 seconds/division)

B.3.1 Repeaters

In the systems currently used, one or two repeaters may be deployed to extend the range of the link in difficult circumstances (e.g. tower blocks). These repeaters operate on a simple 'store-and-forward' basis, with a message being retransmitted immediately on receipt.

C SRDs OPERATING IN THE 869.40-869.65 MHz BAND

C.1 Allocation

One of the potential allocations for the BA telemetry system falls in a segment (869.4-869.65 MHz) of the licence-exempt band in which operation at the relatively high power of 500 mW EIRP is permitted. The operation of RFID readers at up to 2W EIRP is permitted at a frequency some 2 MHz lower.

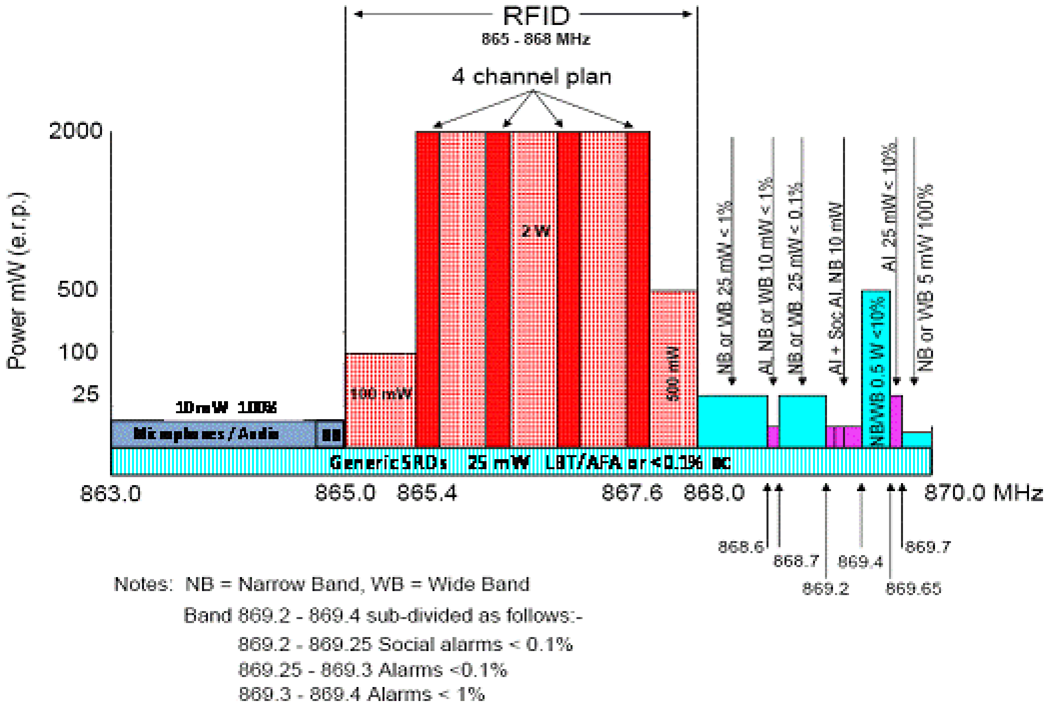


Figure C.1: SRD allocations at 863-869 MHz

In the 869.4-869.65 MHz sub-band[15], which is allocated for 'non-specific SRDs) operation at 500mW is subject to a 10% duty-cycle, or the use of 'listen-before-transmit' and 'Active Frequency Agility' operation to avoid collisions. The entire band may be used for wideband transmissions, or for narrowband (≤25 kHz) signals on a 25 kHz raster.

[15] The constraints applying in this band are specified in Annex 1(g3) of ERC Recommendation T/R 70-03.

C.2 Permitted characteristics & worst case

C.2.1 ETSI standard

The harmonised standard [2] applying to this band (and many others) is EN 300 220, version 2.3.1 (2010) of which is current. Some of the most important stipulations from the point of view of potential interference with BA telemetry are:

- A maximum power of 500mW ERP is allowed, which may be in a single 25 kHz channel or spread across the band.
- Devices must use either a 10% transmit duty cycle or implement a ‘Listen Before Talk’ (LBT) protocol, with or without ‘Adaptive Frequency Agility’ (AFA)
- The 10% duty cycle shall not be exceeded in a period of one hour (i.e. the maximum allowed transmit time is 6 minutes).

C.2.2 Worst-case scenario

As the BA telemetry devices operate in an allocation of 25kHz, the worst case interferer would be a narrowband SRD, in which case the permitted 500mW ERP will all fall within the BA receiver bandwidth.

The only mandatory restriction on the duty cycle is that transmissions shall not exceed 10% of a one hour period. Although the standard suggests a maximum ‘on’ time of 36 seconds, this is only advisory, and a device might, in principle, transmit continuously for 6 minutes once every hour. It is hard to imagine any application for which such behaviour might be chosen – in general, the requirement would be to pass traffic with as little latency as possible, so a duty-cycle defined relative to periods of seconds or less is more likely.

At present, we have no information regarding the protocols actually implemented in SRD devices operating at 869.5 MHz, but a reasonable initial assumption would be that at any instant the device has a 10% likelihood of being active.

If the study were concerned with interference from a specific SRD, it would be preferable to construct a model for interference that took into account the BA telemetry signal structure and the absolute and relative timing of transmissions from both victim and interferer systems.

C.3 Applications

Known applications for SRDs operating in this allocation include:

- Radio modems for industrial use or use by sensor networks
- Traffic light control (temporary lights)
- Intruder alarms
- Environmental monitoring
- Short range audio communications e.g. for stage management

- RFID
- Nautical man Overboard systems
- Ticketing systems
- Industrial telemetry systems

The details of a selection of SRDs operating in the 869.40-869.65 MHz band are given below.

C.4 Trial devices

Four SRDs were acquired for the purposes of testing. These were chosen to be broadly representative of the higher-power devices that can operate in this allocation and are more likely to be used with the full 10% duty cycle.

C.4.1 Warwick Wireless X8100 telemetry link

This unit provides telemetry connections in the 869 MHz band. The basic unit has two analogue & eight digital inputs, and can be configured to send data continuously. It can also be used to transfer serial data (e.g. from Hyperteminal).

Figure C.2: X8100telemetry link

The standard version operates at 500mW and costs £498. A pair of these units was purchased for testing, and configured by ERA to operate in a mode that gave a duty cycle of 33%. The output of the transmitter in the time domain is shown in Figure C.3.

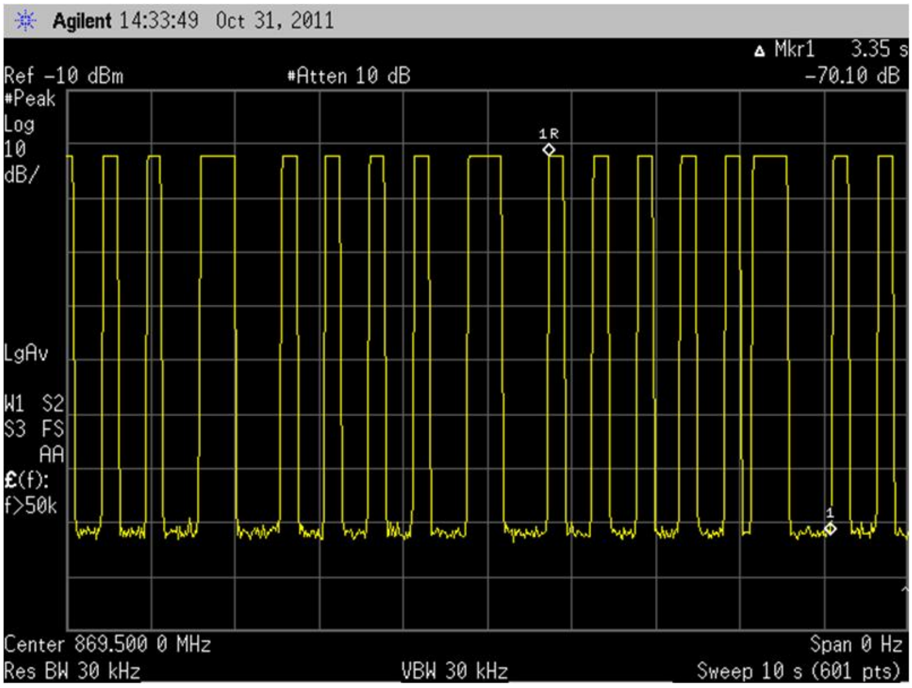


Figure C.3: X8100 output (30% duty-cycle)

The active time for the transmitter is 200 or 400 ms, depending on the data. The mark space ratio is 50/50. Assuming data transitions at 200ms, the risk of collision is 96.5%. For 400ms transitions, the risk of collision reduces to 73.3%.

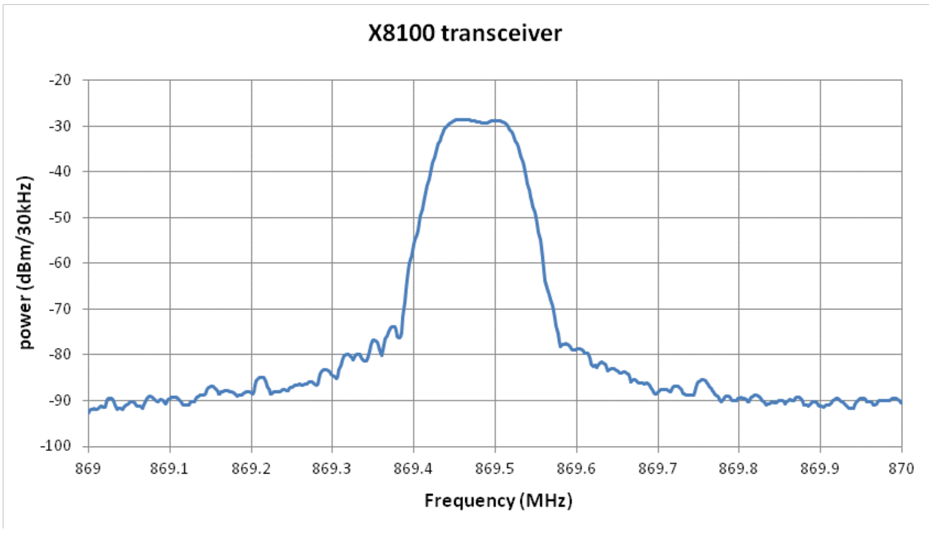


Figure C.4: Spectral characteristics of the X8100 transceiver

It can be seen from Figure C.4 that the X8100 occupies a 3dB bandwidth of some 100 kHz, implying that the output power falling in the BA telemetry bandwidth is around 6dB below the nominal 500mW value.

C.4.2 Aduenis ARF-53 PRO 500mW serial modem

This unit from a French manufacturer can be configured to use in wideband mode (2 channels, 500 kHz channel spacing, 57.6 kbit/s data rate) or narrowband (67 channels, 100 kHz spacing, 10 kbit/s data rate). Only one of the channels (869.525 MHz) can be used at 500mW in either mode.

Figure C.5: Adeunis ARF serial link module

Little detail is available on the technical specification, although the data sheet does reproduce the receiver selectivity curve (See Figure C.6)

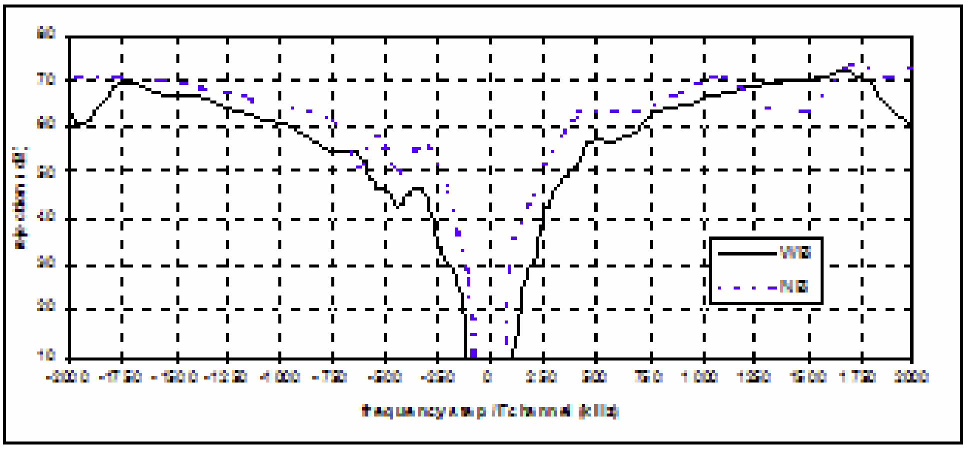


Figure C.6: Adeunis receiver selectivity

The device uses FSK modulation and the receiver has a sensitivity of -112dBm for a BER of 10^{-3}.

Two of these units were purchased, and configured by ERA to operate in narrowband mode on a channel centred at 869.525 MHz. It can be seen from Figure

C.7 that the occupied bandwidth is around 40 kHz, but with a spectral energy peak lying in the BA telemetry channel.

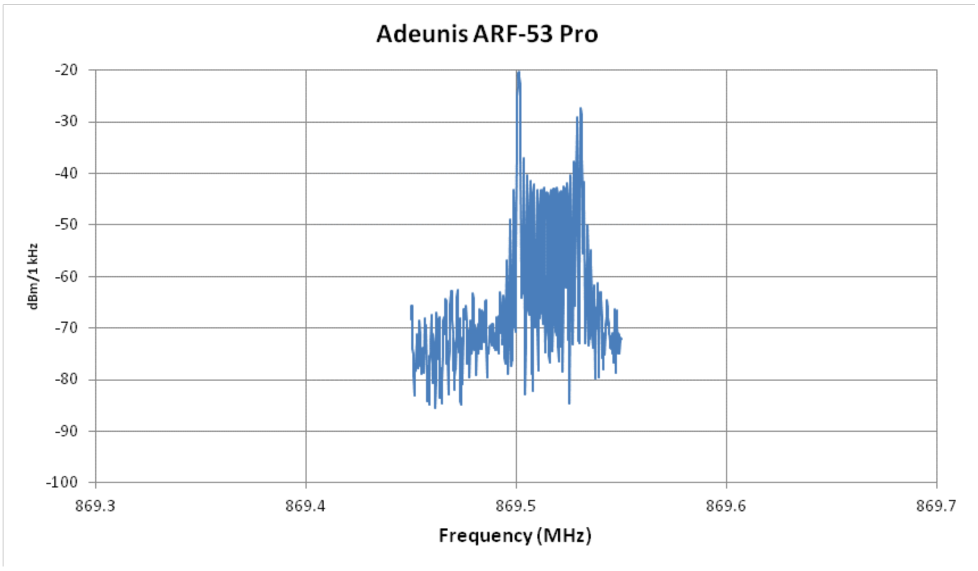


Figure C.7: Spectral characteristics of the ARF-53 transceiver

The unit was set to operate at 100% duty cycle, modulated with a 900 Hz test signal.

C.4.3 Audio communications link

A pair of audio communications devices were kindly made available to Aegis for the purposes of this study. These devices are intended to be used in theatres, broadcast studios and similar environments to allow communications between production staff. They are not intended as broadcast quality radio microphones, but operate on a voice-operated basis allowing hands-free operation. They provides full-duplex speech communication to a group of up to six users. This range manufactured elsewhere in the EU, but is available in the UK.

The system operates on a primary UHF frequency of **869.525 MHz**, at a power of 200mW maximum, giving an approximate coverage of 300-400m depending on the environment. A further two EU licence exempt frequencies, are user selectable on 863.500 MHz and 864.500 MHz operating at a power of 10mW, giving an approximate coverage of 80-100m depending on the environment.

The devices use GFSK modulation with a data rate of 115 kbits/sec ('air-rate' – the useful throughput is, presumably, 90% lower).

The output of the transmitter in the time domain is shown in Figures C.7 and C.8 below. It can be seen that the system operates with transmissions in 50% duty-cycle bursts of around 750ms, with a pulse repetition frequency of some 30ms within each burst. The individual pulses are some 5-10ms in duration.

As the BA message length is 93 ms (60ms message data) long, and has no correction, it is inevitable that the message will be lost if a BA message is sent during one of the 750ms active bursts; overall, the risk of a collision is ~50%.

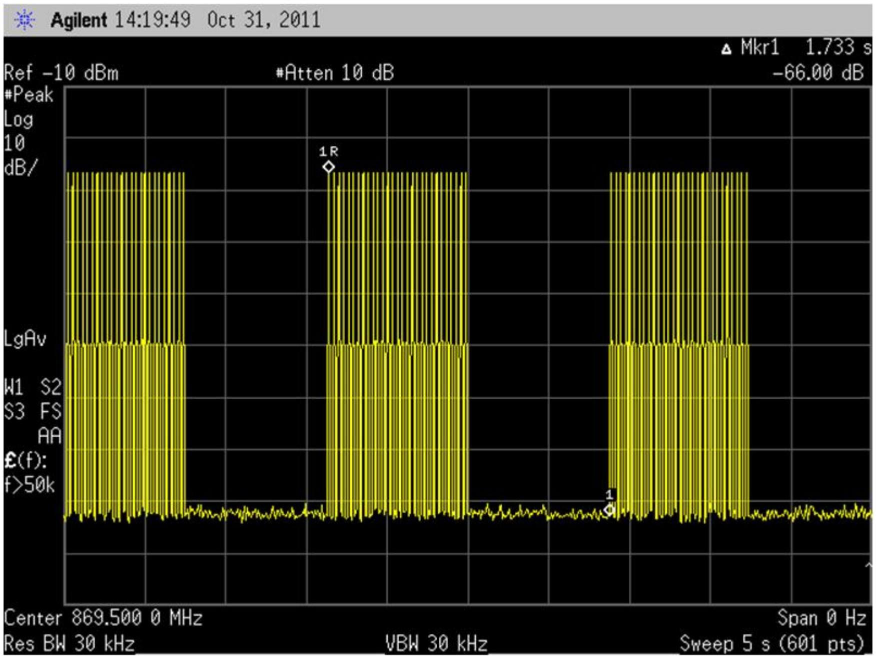


Figure C.8: Audio communications link output (5 second sweep)

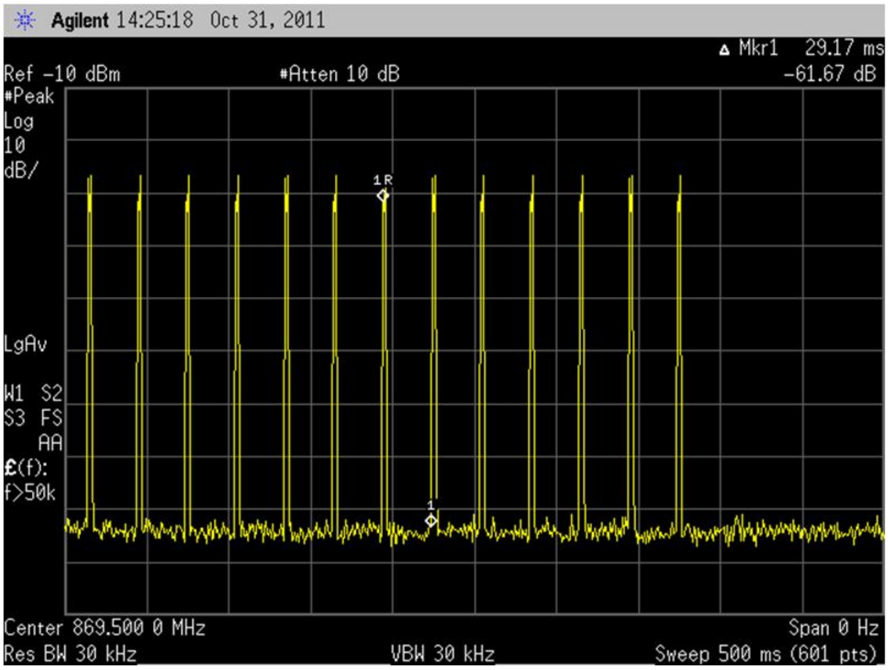


Figure C.9: Audio communications link output (0.5 second sweep)

The spectrum of the transmitter is plotted in Figure C.10, which shows that the 3dB bandwidth is approximately 110 kHz and includes the BA channel bandwidth.

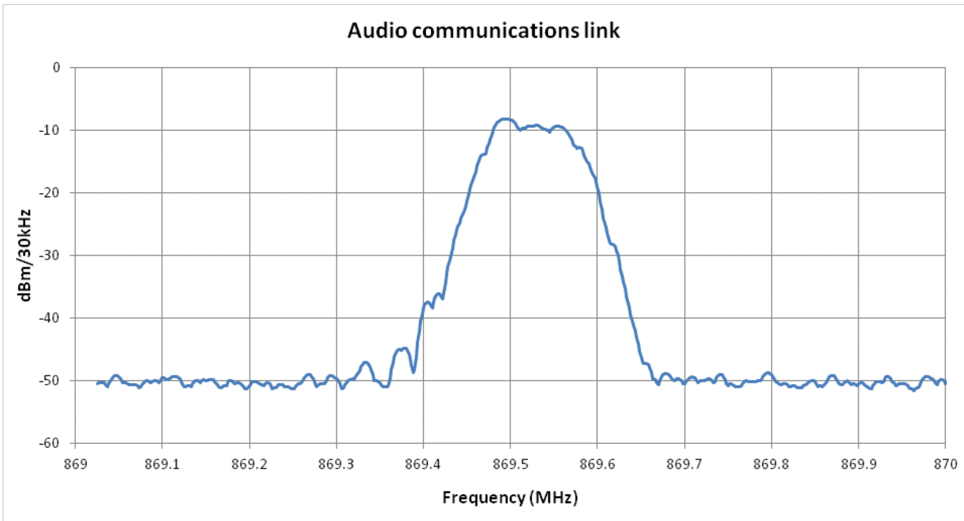


Figure C.10: Spectral characteristics of the ARF-53 transceiver

C.4.4 Radiometrix evaluation board

A pair of Radiometrix evaluation boards were purchased for this study, and equipped with the FPX3 high-power transceiver module.

The FPX3-869-20 module can be programmed to operate on any frequency within the 869.4-869.65 MHz band, and has an output power of 400mW (maintained at less than the 500mW limit, according to Radiometrix, to ensure good OOB performance).

Applications suggested by Radiometrix include:

- Asset tracking systems
- Industrial telemetry and telecommand
- High performance security system
- Fire alarms
- ROV control applications
- High speed data modems

Figure C.11: Radiometrix FPX transceiver module and evaluation board.

The unit has a deviation of +/- 16kHz, and has a frequency stability of better than +/- 5 kHz. Power in the adjacent channel is -37dBm and transmitted spurii are <-36dBm. The channel bandwidth is not specified, but Carson's rule, for data at 10kHz would imply some 50 kHz and the user-selectable channels are on a 100 kHz raster.

The FPX3 supports a maximum data rate of 20 kbit/s. It is the responsibility of the user to comply with the 10% duty cycle limit, as the unit itself does not implement any restriction. The receiver sensitivity is -115dBm (for 1KHz/12 dB SINAD)

A pair of these modules, with evaluation boards, were obtained (£336) for use in compatibility testing. The evaluation board allows the unit to be configured to operate in a number of modes (plain carrier, square-wave modulation, serial modem).

The output of the transmitter in the time domain, with the evaluation board in test mode C ('radar mode - master'), is shown in Figure C.12 below. In this test mode, a CTR44[16] test packet is transmitted, after which the module switches to receive for 100ms, before sending the packet again.

[16] A Radiometrix protocol for remote control, in which four bits (16 lines) can be controlled.

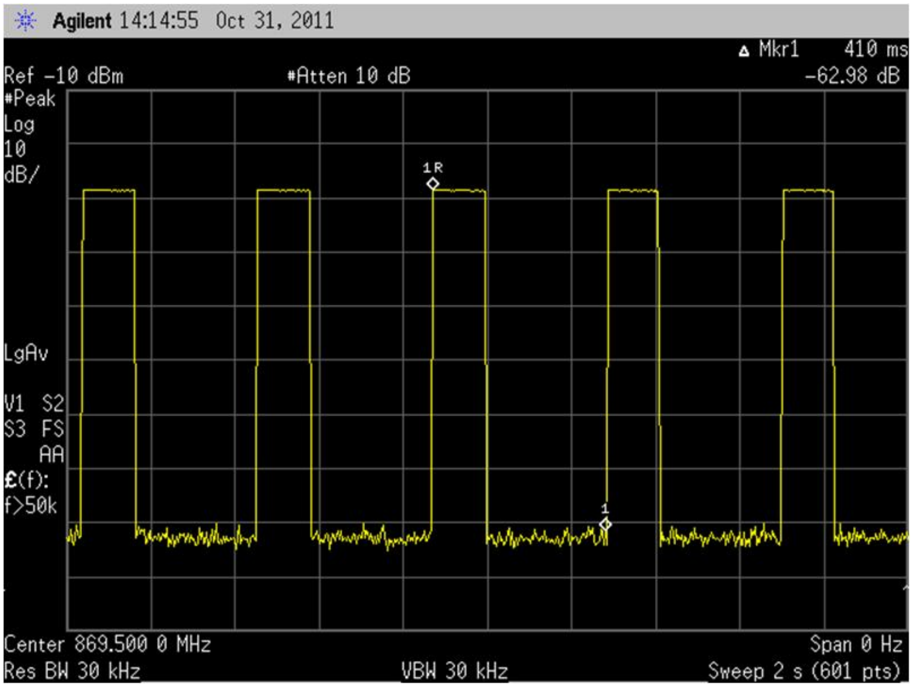


Figure C.12: Radiometrix output (mode C)

In this mode, the transmit active time is 120ms, with a 30% / 70% duty cycle. This gives a 25.4 % of a collision with a given BA telemetry message.

The spectrum of the FPX3, recorded in the same mode, is shown in Figure C.13.

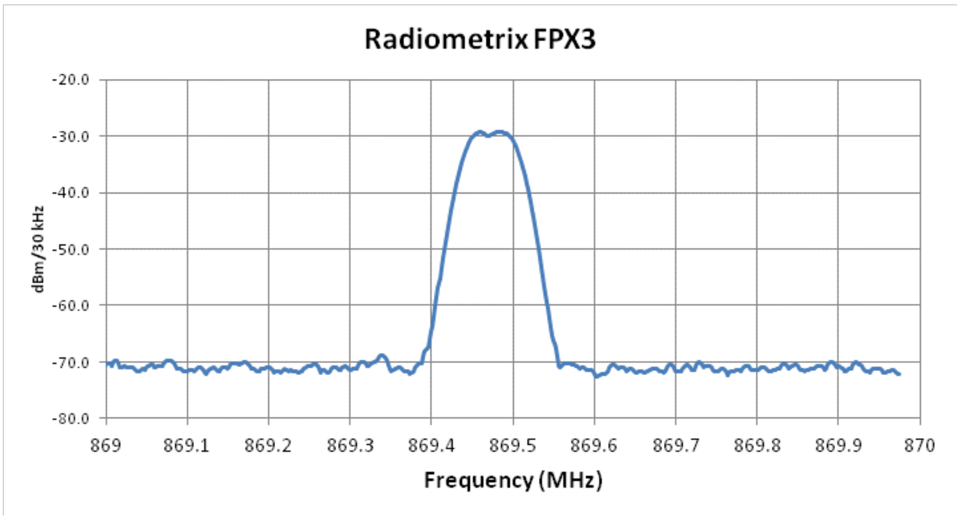


Figure C.13: Spectral characteristics of the Radiometrix FPX3 transceiver

Although the spectrum shown in Figure C.13 is centred on 869.475 MHz, the unit was reset to 869.5 MHz for the measurements. It can be seen that the 3dB bandwidth is of the order of 70 kHz.

C.5 Radio modems / telemetry

The remainder of this annex gives a brief, and unavoidably arbitrary, selection of other SRDs known to operate in the 869 MHz band.

C.5.1 X7120 telemetry link

These units, marketed by several firms but unbranded, form a one-way telemetry link, using the TX7120 transmitter and the RX7120 receiver. The devices have four digital inputs, 1 pulse-counting input and an analogue input.

The devices use GMSK in a **25 kHz channel**. The units support scanning telemetry, with transmissions in allocated timeslots. The transmit 'on' time varies from 0.15 to 2.5 seconds (typically 0.2s), but the datasheet gives no information on duty cycle.

It will only send data on a change of state at an input.

Figure C.14: X7120telemetry link

The devices are sold by several UK companies and retail for around £300-£400. A 25mW version is also available.

C.5.2 Westermo

Westormomake the RM-80 wireless Ethernet modem. This unit has a transmit power of 500mW at 869.525 MHz, with a 10% duty cycle (or 5mW on 869.275 MHz with a 100% duty cycle). The bandwidth is not specified, but the data rate suggests that this is a wideband device.

The unit interfaces to a 100 Mbps Ethernet, but the data rate across the UHF radio link has a maximum rate of 76.8kbps. Additionally, the unit has an RS232 port and can provide serial point-point connectivity at up to 38.4 kbps.

Figure C.15: Westermo RM-80 serial / Ethernet data link

The unit calculates the duty cycle in real time, and sets an alarm flag when the 10% limit is reached. The interval over which the duty cycle is calculated is set to 60 minutes by default, but can be changed by the user.

C.5.3 Elpro 805U

Westermo Data Communications Ltd (www.westermo.co.uk) are the UK distributors for Elpro radio modems, telemetry and Ethernet radios.

The 805U-D provides a serial (RS232) link, while the 805U-E provides Ethernet connectivity at up to 76.8 Kbits/sec. It can either use 500mW at a 10% duty cycle, or drop down to 5mW to allow 100% activity.Packet size is 530 bytes.

The 805U **occupies the full 250 kHz** bandwidth available.

Figure C.16: Elpro 805U serial / Ethernet data link

These units retail at around £1,300 for a pair of 805U-D. Elpro 105U

Another Elpro device is aimed at the telemetry market; The 105U range also makes use of 869.5 MHz at an EIRP of 500mW, but offers analogue, digital and pulse-counting data inputs.

Figure C.17:Elpro telemetry terminal

Using the RS232 port, user can obtain readout of channel noise & RSSI. DC 11-30v or AC15-24V. The device operates in a **250kHz channel** at 869.5 MHz, at powers of 10-500mW. Other units use 12.5 kHz (220 MHz) or 25 kHz (450 MHz)

Time between re-tries is randomised between 1-5 seconds.

A pair of 105U retail for around £1700.

C.5.4 Wood & Douglas RSX serial modem

The RSX850 radio modem operates at 500mW in the 869 MHz band, using GMSK modulation.

Figure C.18: Wood & Douglas RSX telemetry modules

The RSX radio modems allow 4800 baud (12.5 kHz channel spacing) or 9600 baud (**25 kHz channel spacing**) real over-air transmission rates. Serial data is passed to the modems via an RS232 interface at a data rate of up to 38,400 baud. Frame(Packet) size can be set to 64 or 128 bytes. The preamble has a default value of 20 bytes.

The units are available in a packaged version and as OEM modules (SXn50). Frequencies are pre-programmed, but can also be set via the serial port using software provided by W&D.

C.5.5 Wood & Douglas Orion telemetry

This unit is a serial modem, operating at up to 19,200 bps, and a telemetry link with four digital and four analogue inputs.

Figure C.19: Wood & Douglas 'Orion' telemetry modules

The unit uses a 4-level FSK system at 9600 baud (**25 kHz channel**) or 4800 baud (12.5 kHz channel). It can be configured to listen before transmit (LBT).3-4 preamble blocks are typical. The unit can also be configured as a repeater. Transmissions may include FEC.

The manual does not discuss duty cycles, but In test modes the unit will transmit for four minutes continuously.The devices retail at around £1200

C.5.6 Sateline 1870E radio modem

These transceivers from a Finnish manufacturer uses a 25 kHz channel at up to 500 mW to send serial data at 9600 bps. The duty cycle is not controlled by the device, so the user must ensure that regulatory limits are complied with.

Figure C.20: Satelline 1870E radio modem

The unit is normally supplied for operation on a 25 kHz raster starting at 869.4125 MHz (giving 10 channels in the sub-band). Operation in other sub-bands (868-870 MHz), at lower power, is possible.

The unit price is around £600.

C.5.7 Sateline 3ASd radio modem

These units are internally similar to the 1870E model, but are ruggedized for use in industrial environments.

Figure C.21: Satelline 3ASd radio modem

It is understood that this unit can be programmed to operate on 869.5 MHz (the centre frequency is a factory setting, and cannot be changed by the user). Unit cost is £700- £800.

C.5.8 Eldes alarm system

The Eldes alarm system (www.eldes.co.uk) is quoted as using a frequency range 866.1 MHz - 869.5 MHz for communication with its sensors.

Figure C.22:Eldes PIR sensor and EWT1 wireless module

When the EWT1 module is fitted to a control unit, that unit can be linked to a maximum of 16 wireless sensors (PIR, sirens, door sensors). The range is given as 150m in open areas. The frequency band and the quoted range imply that these devices operate at lower power than those described above.

C.5.9 Sapphire (distributor)

Sapphire Alarms Ltd (www.diy-alarms.co.uk) supply a variety of wirelessly-networked sensors, such as the passive IR movement sensor below.

Figure C.23: Powermax Plus Next K9-85 movement sensor

The Visonic 'Power G' system (www.visonic.com) uses FHSS with 4 channels in the '868-869 MHz' band.

C.5.10 Tensator ticketing system

Tensator(www.tensator.com) market a system that manages customers queuing for service. A choice of 869.5 or 869.9 MHz is available. As the range is given as '50m in open areas' it seems likely that the devices do not operate at 500mW.

Fig C.24: Tensator ticketing system

C.5.11 Maritime Personal locator system

WAVEMINDER is a 'man overboard' personal rescue locator to allow tracking and retrieval of crew from yachts.The device is marketed by Kannad (www.kannadmarine.com)

Figure C.25: Kannad WAVEFINDER beacon system

The system retails at around £900.

C.5.12 Motorola RFID system

The Motorola MC9090-G handheld reader/computer operates at 869.5 MHz (at 500mW)

Figure C.26: Motorola RFID reader

C.5.13 Radiometrix OEM module

Radiometrix are a major UK supplier of devices operating at 869.5 MHz. Their modules are known t0 be incorporated in, for example, transportable traffic lights.

Two transmit modules are available for use in the 869.5 MHz band, one of which is the FPX3 discussed above.

The TX3H-869.5-10 operates at 450mW on a nominal carrier frequency of 869.5 MHz, +/- 40kHz. The FM deviation is +/- 27 kHz and a raw data rate of 16 kbps is supported.

Figure C.27: Radiometrix TX and RX modules for 869.5 MHz

D THE LTE (LONG-TERM EVOLUTION) MOBILE SYSTEM

D.1 Overview

The LTE set of standard is enormously complex and allows a very high degree of flexible and reconfiguration. Many frequency bands, channel bandwidth, duplexing options and MIMO configurations are supported. Details relating to the physical layer are given in 3GPP are given in 3GPP Technical Report 25.814 "*Physical layer aspects for evolved Universal Terrestrial Radio Access (UTRA)*".

Fortunately, much of this complexity can be ignored in the present context. It is assumed that the only scenario of interest is interference from LTE handsets (or User Equipment, 'UE') operating in the upper of the three 10 MHz uplink channels in the 800 MHz harmonised band, i.e. at 852-862 MHz.

The LTE uplink physical layer uses a technique described as 'Single Carrier Frequency Division Multiple Access' (SC-FDMA), also referred to as 'DFT-spread OFDM'. This technique is closely related to the standard OFDMA used on the downlink transmissions, but with an addition Fourier transform prior to the symbol-to-subcarrier mapping. While an OFDMA signal will transmits symbols in parallel, one per subcarrier, SC-FDMA has the effect of transmitting M symbols in series over M x 15kHz subcarriers ('clumped' together to look like a single carrier) at four times the rate.

For the present purposes, the key characteristic of the uplink is that it is allocated resources by the overall system on the basis of 'Resource Blocks' (RB). A Resource Block describes the minimum time-frequency element of the channel that can be scheduled for a transmission, and in the LTE uplink corresponds to a frequency slot of 180 kHz and a time-slot of 0.5 ms. In practice two time-slots are aggregated to form a 1ms 'sub-frame' which is used as the basis for time-allocation to individual handsets.

In the frequency domain, the resource blocks at either edge of the channel are used for shared control channels (Physical Uplink Control Channel, PUUCH). The network will typically allocate RB to handsets in a random manner, so that the frequency difference between an uplink transmission and the BA telemetry frequency will change on a subframe-to-subframe basis.

Currently, only one UE 'power class' is defined, with an EIRP of 23 dBm. This value is assumed in the modelling and measurement below.

D.2 Emission Mask & simulated signals

It is assumed in this study that LTE services will use 10 MHz channels. In this mode, the occupied bandwidth of an uplink channel is typically around 8 MHz for a fully loaded system. Resource blocks at either side of the emitted spectrum are generally assigned to control channels.

The out-of-band emissions permitted from LTE UE devices are specified in 3GPP document TS.36.521-1, the latest revision of which is 9.6.0 (2011-09). This document [6] specifies the emission mask in Table 6.6.2.1.3-1, and this is reproduced as the red trace in Figure D1 below. In this plot, the tabulated power values have been re-normalised[17] to a uniform 25 kHz reference bandwidth, so that the power falling in the BA telemetry channel at any offset can be readily determined.

Frequency offset from channel edge	Permitted power/bandwidth	Frequency offset from channel centre	Permitted power referred to 25 kHz
± 0 – 1 MHz	-18 dBm /30 kHz	± 5 – 6 MHz	-18.8 dBm
± 1 – 5 MHz	-10 dBm/ 1 MHz	± 6 – 10 MHz	-26.0 dBm
± 5 – 10 MHz	-13 dBm/ 1 MHz	± 10 – 15 MHz	-29.0 dBm
± 10 – 15 MHz	-25 dBm/ 1 MHz	± 15 – 20 MHz	-41.0 dBm

First two columns taken from TS.36.521-1, Table 6.6.2.1.3-1

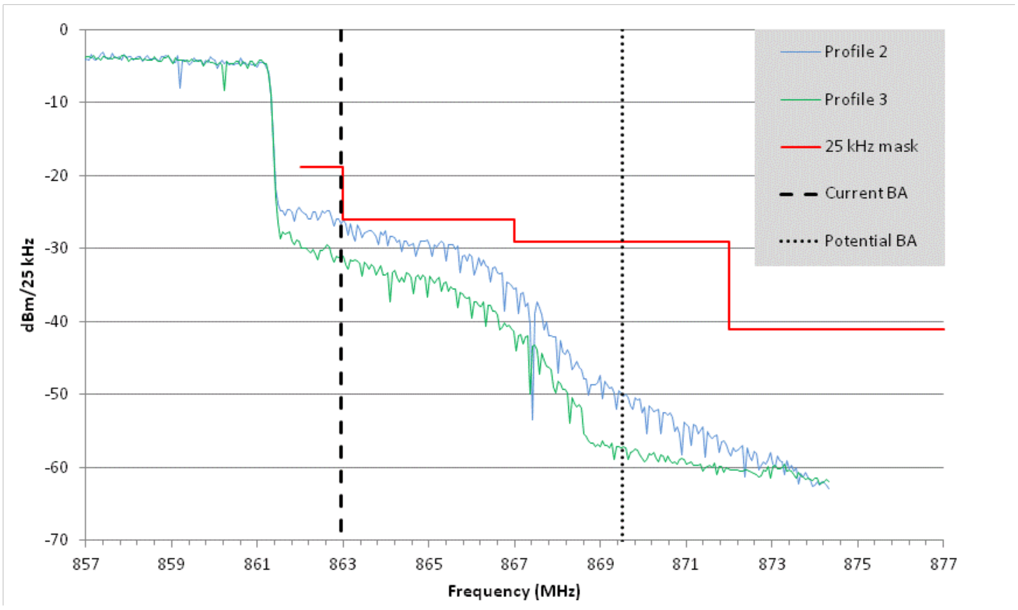


Figure D1: Permitted LTE out-of-band emissions and simulated signals

It can be seen from Figure D1 that the effect of moving the BA telemetry from 862.9625 MHz (an offset of 5.9625 MHz from the highest LTE channel centre) to

[17] The fact that the permissible in-band power now appears at zero on the ordinate is a coincidence.

869.5 MHz (an offset of 12.5 MHz) is to reduce the maximum permitted power in the BA receiver bandwidth from-18.8 dBm to -29.0 dBm.

E GLOSSARY

AWGN	Additive White Gaussian Noise
BA	Breathing Apparatus
CW	Continuous wave (a single sine-wave tone)
ECB	Entry Control Board
ERP	Effective Radiated Power
EIRP	Effective Isotropic Radiated Power
FSK	Frequency Shift Keying
LTE	Long Term Evolution (cellular radio standard)
PU	Portable Unit (Breathing apparatus)
RFID	Radio Frequency Identification
SINR	Signal to Interference & Noise Ratio
SRD	Short Range Device
UE	User Equipment