# L-Band 3G Ground-Air Communication System Interference Study

Produced for: Eurocontrol
Against Works Order No: 3121

Report No: 72/06/R/319/R

December 2006 – Issue 1

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## SUMMARY

Roke Manor Research Ltd. has been tasked by Eurocontrol to perform a study of interference issues between a 3G (UMTS) air-to-ground communication system and other aeronautical communication and navigation systems operating in the L-band. The investigation addressed the worst-case interference scenarios of UMTS in conjunction with DME, UAT, JTIDS/MIDS and GNSS. Interference caused by GSM base stations has also been studied.

The conclusions of the study are:

- The UMTS carrier frequencies that provide the best allocation of guard bands are 968 MHz in the forward link direction (ground to air) and 1149 MHz in the reverse direction (air to ground);
- Interference protection measures have to be introduced into UMTS. These measures include a custom duplexer and UMTS receiver blanking;
- Frequency reallocation of DME stations operating on channels close to 1150 MHz is recommended. The percentage of DME stations in Europe that would need to be reallocated to facilitate coexistence with UMTS is estimated to be around 1%;
- Interference to GNSS may be reduced if reverse link is set at 1147 MHz but at the expense of refarming a larger number of DME stations;
- UMTS transmission blanking is a potentially attractive technique of protection of co-sited airborne ARNS equipment. The optimal trade-off between the protection level and UMTS performance loss needs to be established through computer simulations;
- Co-siting of UMTS and ARNS equipment on the ground is impractical due to the mutual interference;
- Other systems operating in the L-band, e.g. JTIDS/MIDS and UAT will have only a moderate effect on UMTS link performance.

As a conclusion, the operation of a new UMTS-based air to ground communication link in L-band may be possible if additional protection measures are introduced. The issue of in-band interference into the co-sited airborne DME receivers is seen as the greatest potential concern. However, this conclusion would apply to any continuously transmitting communication system with similar receiver sensitivity, transmit power and bandwidth that operates in the same band. UMTS transmitter and receiver blanking is a potentially promising technique to address the coexistence problem but requires further investigation.



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# CONTENTS


1 INTRODUCTION ............ 9
2 PROJECT RATIONALE ............ 10
2.1 INTRODUCTION ............ 10
2.2 EXISTING AND PLANNED SYSTEMS ............ 10
2.3 ALLOCATION OF BANDS TO LINK DIRECTIONS ............ 11
3 METHODOLOGY ............ 12
3.1 GENERAL PRINCIPLES ............ 12
3.2 TYPES OF INTERFERENCE ............ 12
3.2.1 In-Band Interference ............ 13
3.2.2 Out-of-Band Interference ............ 14
3.2.3 Spurious Interference ............ 15
3.2.4 Other Effects of Interference ............ 15
4 INTERFERENCE ASSESSMENT ............ 17
4.1 SELECTED INTERFERENCE SCENARIOS ............ 17
4.2 INITIAL ASSUMPTIONS ............ 18
4.3 SCENARIO 1: AIRBORNE UMTS TX TO AN ONBOARD DME RX ............ 19
4.3.1 Scenario Description ............ 19
4.3.2 UMTS Return Link Frequency Allocation, In-Band Interference ............ 19
4.3.3 Out-of-Band Interference ............ 20
4.3.4 Spurs ............ 23
4.4 SCENARIO 2: AIRBORNE UAT TX TO AN AIRBORNE UMTS RX ............ 24
4.4.1 UMTS Forward Link Frequency Allocation, GSM Interference ............ 24
4.4.2 Out-of-Band Interference ............ 25
4.4.3 Effects of UAT interference on UMTS FDD ............ 26
4.4.4 UAT Interference from Other Aircraft ............ 27
4.5 SCENARIO 3: GROUND UAT TX TO AN AIRBORNE UMTS RX ............ 29
4.6 SCENARIO 4: GROUND UMTS TX TO A GROUND UAT RX ............ 30
4.6.1 Adjacent Band Interference ............ 30
4.6.2 UAT receiver blocking and IP3 ............ 32
4.7 SCENARIO 5: AIRBORNE UMTS TX TO AN AIRBORNE GNSS RX ............ 34
4.7.1 Co-sited UMTS Tx and GNSS Rx ............ 34
4.7.2 Airborne UMTS Tx and GNSS Rx ............ 36
4.8 SCENARIO 6: AIRBORNE UMTS TX TO AN AIRBORNE DME RX ............ 37
4.9 SCENARIO 7: GROUND UMTS TX TO A GROUND DME RX ............ 38
4.10 SCENARIO 8: AIRBORNE JTIDS/MIDS TX TO AN AIRBORNE UMTS RX ............ 41
4.10.1 Out-of-Band Interference ............ 41
4.10.2 In-Band and Out-of-Band Interference ............ 43
4.10.3 ICAO Coexistence Study ............ 44
4.10.4 JTIDS/MIDS Operation Without Frequency Hopping ............ 45
4.11 SUMMARY ............ 45
5 OTHER EFFECTS OF INTERFERENCE ............ 47

5.1 Receiver Blocking ....47
5.2 Intermodulation Products ....48
5.2.1 3rd Order Products ....48
5.2.2 2nd Order Products ....50
5.3 Reciprocal Mixing ....50
5.4 Power Amplifier Noise ....51
6 CONCLUSIONS ....52
7 REFERENCES ....54
8 GLOSSARY ....56
APPENDIX A SYSTEM PARAMETERS ....58
A.1 General Parameters ....58
A.2 UMTS ....59
A.3 GNSS ....60
A.4 DME ....61
A.5 UAT ....62
A.6 JTIDS/MIDS ....63
APPENDIX B TERRESTRIAL GSM BS TO AN AIRBORNE UMTS RX INTERFERENCE ....64
B.1 GSM to UMTS Frequency Plan ....64
APPENDIX C EFFECTS OF PULSED INTERFERENCE ON UMTS SIGNAL RECEPTION ....67

## FIGURES

FIGURE 1: FREQUENCY ALLOCATIONS OF SYSTEMS OPERATING IN THE VICINITY OF 960 AND 1150 MHZ BANDS. ....10
FIGURE 2: LINK ALLOCATION; (A) FORWARD LINK AT 960 MHZ; (B) REVERSE LINK AT 1150 MHZ. ....11
FIGURE 3: TYPES OF INTERFERENCE ....13
FIGURE 4: IN-BAND INTERFERENCE ....13
FIGURE 5: TYPES OF OUT-OF-BAND INTERFERENCE ....14
FIGURE 6: INVESTIGATED INTERFERENCE SCENARIOS ....17
FIGURE 7: AIRBORNE UMTS TRANSMITTER INTERFERING WITH AN ONBOARD DME RECEIVER ....19
FIGURE 8: DME REPLY CHANNEL FREQUENCIES AND THE NUMBER OF STATIONS IN EUROPE ....19
FIGURE 9: UMTS UE TX ACLR AND DME RX ACS ....20
FIGURE 10: AIRBORNE UAT TRANSMITTER INTERFERING WITH AN ONBOARD UMTS RECEIVER ....24
FIGURE 11: UAT, GSM FORWARD LINK AND UMTS FORWARD LINK BANDS ....24
FIGURE 12: UAT TX ACLR AND UMTS UE RX ACS ....25
FIGURE 13: AIRBORNE UAT TRANSMITTER INTERFERING WITH A NEARBY UMTS RECEIVER28
FIGURE 14: GROUND UAT TRANSMITTER INTERFERING WITH AN ONBOARD UMTS RECEIVER ....29

FIGURE 15: GROUND UMTS TRANSMITTER INTERFERING WITH A GROUND UAT RECEIVER30
FIGURE 16: UMTS NODEB TX ACLR AND UAT RX ACS......31
FIGURE 17: AIRBORNE UMTS TRANSMITTER INTERFERING WITH AN ONBOARD GNSS RECEIVER......34
FIGURE 18: UMTS UE TX ACLR AND GNSS RX ACS......34
FIGURE 19: AIRBORNE UMTS TRANSMITTER INTERFERING WITH A GNSS RECEIVER......36
FIGURE 20: AIRBORNE UMTS TRANSMITTER INTERFERING WITH AN AIRBORNE DME RECEIVER......37
FIGURE 21: GROUND UMTS TRANSMITTER INTERFERING WITH A GROUND DME RECEIVER38
FIGURE 22: AIRBORNE JTIDS/MIDS TRANSMITTER INTERFERING WITH AN AIRBORNE UMTS RECEIVER......41
FIGURE 23: UAT TX ACLR AND UMTS UE RX ACS......41
FIGURE 24: TERRESTRIAL GSM BASE STATION INTERFERING WITH AN AIRBORNE UMTS RECEIVER......64
FIGURE 25: UAT, GSM FORWARD LINK AND UMTS FORWARD LINK BANDS......64
FIGURE 26: GSM BS TX ACLR AND UMTS UE RX ACS......66

## TABLES

TABLE 1: AIRBORNE UMTS UE TX → DME RX INTERFERENCE LINK BUDGET......21
TABLE 2: AIRBORNE UAT TX -> COLLOCATED UMTS UE RX INTERFERENCE LINK BUDGET 26
TABLE 3: AIRBORNE UAT TX -> NEARBY UMTS UE RX INTERFERENCE LINK BUDGET......28
TABLE 4: GROUND UAT TX -> UMTS UE RX INTERFERENCE LINK BUDGET......29
TABLE 5: GROUND UMTS NODEB TX -> UAT RX INTERFERENCE LINK BUDGET......31
TABLE 6: GROUND UMTS NODEB TX -> UAT RX BLOCKING LINK BUDGET......33
TABLE 7: AIRBORNE UMTS UE TX -> COLLOCATED GNSS RX INTERFERENCE LINK BUDGET35
TABLE 8: AIRBORNE UMTS UE TX -> DME RX INTERFERENCE LINK BUDGET......37
TABLE 9: GROUND UMTS NODEB TX -> DME RX INTERFERENCE LINK BUDGET......39
TABLE 10: AIRBORNE JTIDS/MIDS TX -> UMTS UE RX INTERFERENCE LINK BUDGET......42
TABLE 11: JTIDS/MIDS TX -> UMTS UE RX PULSED INTERFERENCE LINK BUDGET......43
TABLE 12: JTIDS/MIDS TX -> UMTS UE RX PULSED INTERFERENCE BUDGET BASED ON [19]......44
TABLE 13: COMBINATIONS OF JTIDS/MIDS HOPPING FREQUENCIES AND LEVELS THAT INTERFERE WITH AIRBORNE UMTS RECEPTION......45
TABLE 14: SUMMARY OF INTERFERENCE ISSUES......46
TABLE 15: RECEIVER BLOCKING LINK BUDGET......47
TABLE 16: IP3 LINK BUDGET......49
TABLE 17: RECEIVER RECIPROCAL MIXING LINK BUDGET......50
TABLE 18: PA TX NOISE LINK BUDGET......51
TABLE 19: GENERAL PARAMETERS......58
TABLE 20: UMTS SYSTEM PARAMETERS......59
TABLE 21: GNSS SYSTEM PARAMETERS......60

TABLE 22: DME SYSTEM PARAMETERS......................................................................61
TABLE 23: UAT SYSTEM PARAMETERS ......................................................................62
TABLE 24: MIDS SYSTEM PARAMETERS ...................................................................63
TABLE 25: TERRESTRIAL GSM BASESTATION -> UMTS UE RX INTERFERENCE LINK BUDGET65

# 1 INTRODUCTION

Roke Manor Research Ltd. (Roke) has been tasked by Eurocontrol to perform a study of interference issues between a 3G (UMTS) air-to-ground communication system that would operate in the L-band and other aeronautical communication and navigation systems present in the same band, [1]. This report is the output of the activities undertaken during the study.

In October 2006, Roke delivered a Working Paper [2] to Eurocontrol with a list of parameters of the interfering systems. This list of parameters, updated with some minor modification to values is included as Appendix A to this report.

The content of this Technical Report is structured as follows:

- Section 2 provides a rationale for the study and lists the interference scenarios that are investigated;
- Section 3 provides classification of types of interference that have been investigated and explains the methodology that is followed;
- Section 4 contains an assessment of individual interference scenarios and expected interference levels. It also analyses the effects of excess interference on the interfered system and proposes methods of addressing this excess interference;
- Section 5 contains analysis of other effects of strong interference, such as receiver blocking and reciprocal mixing;
- Section 6 provides a conclusion to the project.

A list of references and a glossary are provided after the concluding remarks.

Appendix A contains the list of system parameters that was used in this study.

Appendix B provides an assessment of interference between the UMTS air-to-ground system and the terrestrial GSM systems. This scenario was not included in the work proposal. However, it has been identified during the study that this scenario needed to be addressed, as it had an impact on selection of the UMTS forward link carrier frequency.

Finally, Appendix C provides an assessment of the effects pulsed interference and receiver or transmitter blanking can have on UMTS signal reception.

# 2 PROJECT RATIONALE

## 2.1 INTRODUCTION

A new aeronautical communication system is being investigated by Eurocontrol that may use frequency bands from 960 to 977 MHz and from 1145 to 1156 MHz. These nominal frequencies have been selected as they have a minimal number of DME stations operating on them. The system is based on UMTS FDD technology, with the lower frequency used for forward and the other one for a reverse link.

Frequency band between 960 and 1215MHz is allocated to the Aeronautical Radio Navigation Service (ARNS). The band is used by SSR, DME, TACAN, JTIDS/MIDS and future satellite navigation systems (GNSS). There are also some radio astronomy stations in the UK and France that use the lower end of the band to monitor pulsars.

Frequency bands occupied by these existing and future systems are shown in Figure 1.

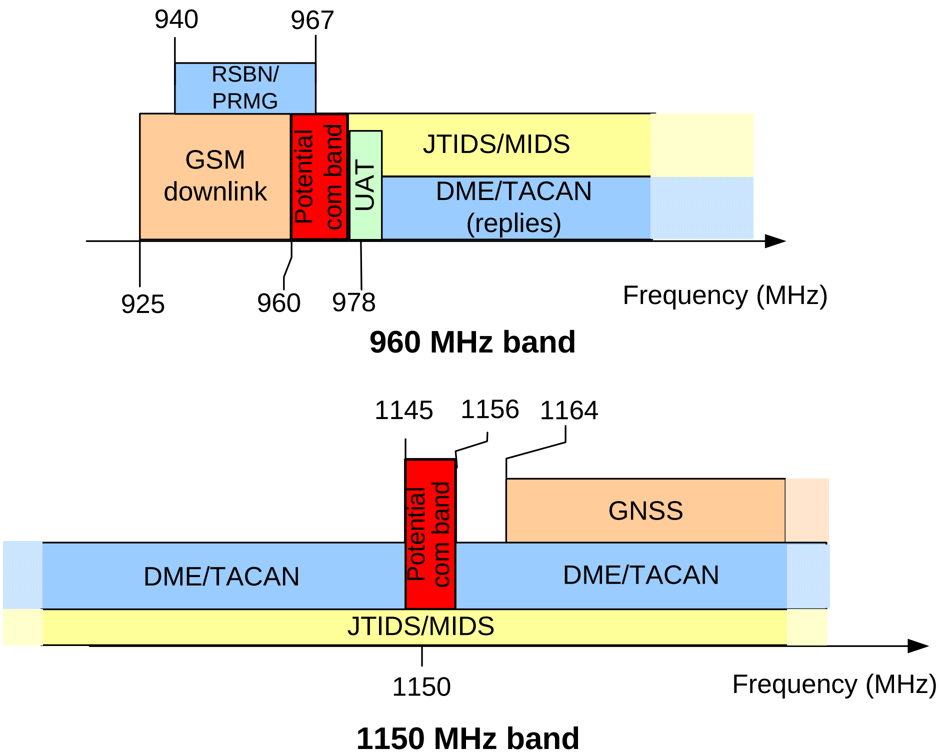


**Figure 1: Frequency allocations of systems operating in the vicinity of 960 and 1150 MHz bands.**

## 2.2 EXISTING AND PLANNED SYSTEMS

There are several existing and planned aeronautical navigation and communication systems operating in the frequency bands of interest. They are:

- DME/TACAN

- UAT
- JTIDS/MIDS
- SSR
- GNSS (i.e. GPS and Galileo)
- GSM and UMTS900
- RSBN/PRMG

The critical ones, from the coexistence point of view, are DME, JTIDS/MIDS and GNSS. Other important systems from the point of co-existence are GSM and UAT. The SSR is sufficiently removed in frequency not to be taken into consideration at this stage.

## 2.3 Allocation of Bands to Link Directions

In order to minimise the interference from DME, the following allocation of frequency bands to directions of the UMTS communication link has been selected as:

- Forward link at 960 – 977 MHz, and
- Reverse link at 1145 – 1156 MHz.

This allocation is shown in Figure 2.

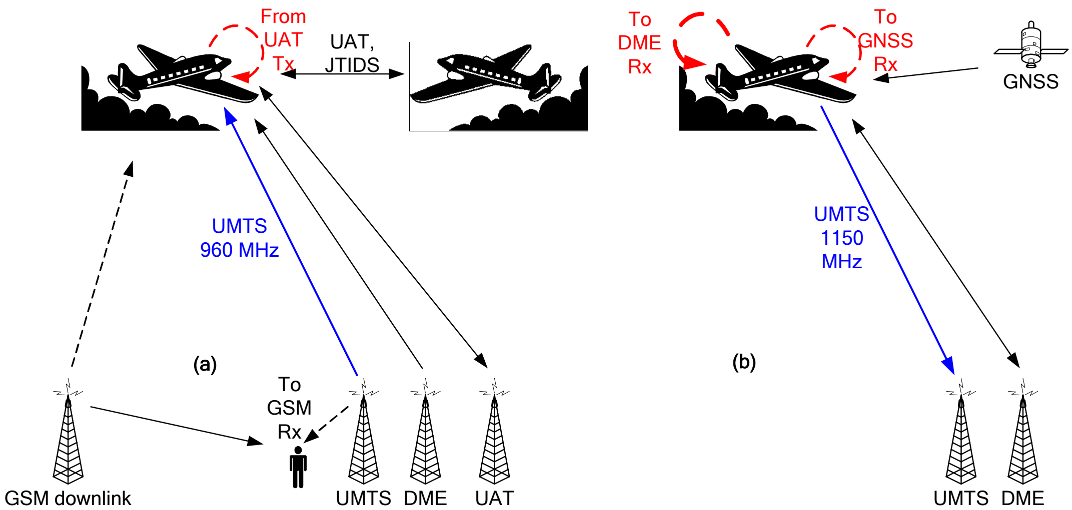


**Figure 2: Link allocation; (a) forward link at 960 MHz; (b) reverse link at 1150 MHz.**

In this figure the wanted signal paths are shown in full lines, while interference paths are shown in dashed lines.

# 3 METHODOLOGY

## 3.1 General Principles

Interference scenarios analysed in this report refer to introduction of the new aeronautical communication system in the ARNS band between 960 and 1215 MHz (L-band). There is a number of existing navigation and communication systems in the same band. The underlying approach adopted in this work has been to address each interference scenario using a deterministic approach with an interference link budget.

The general outcome from the link budget for each scenario is the level of interference to be expected, amount of additional suppression required to bring that interference below the allowed level and the distance at which propagation loss would provide the required suppression.

Where analysis of a particular scenario shows that interference is above the allowed level, the effect of this on the interfered system is discussed. Also, a suggestion on possible ways to address the interference problem, such as guard bands, better filtering or antenna nulling, is made.

The approach where individual interference scenarios are treated separately brings forward the risk that more than one type of interference and more than one interference scenario may happen simultaneously. To accommodate for this, the methodology has followed the approach used by ITU in their interference studies. That methodology consists in reducing the allowed interference in each individual scenario by an interference appointment margin. This margin is commonly set to 6 dB. For example, in Recommendation M.1639 [7], Table 1, the value of 6 dB is used for protection of aeronautical navigation in the L-band from emissions from aeronautical navigation satellites (GPS and Galileo) in the same band.

Investigated UMTS communication system as well as other aeronautical systems operating in the same band, are seen as safety critical. For this reason, the interference level is reduced by another 6 dB as a safety margin for safety critical systems.

For systems where the allowed interference is not defined, it is derived as equal to the receiver noise floor, after which the protection margins (6+6 dB) were applied.

## 3.2 Types of Interference

Allowed interference margins, its effects and available methods of suppression depend on the frequency relationship between the interfering and the interfered system. In order to accommodate this, the analysis of the interference effects has been done by addressing the interference as belonging to one of the following types:

- In-band interference;
- Out-of-band interference;
- Spurious interference;
- Other effects of interference: blocking, IP3 products, PA noise etc.

A similar approach has been used e.g. by ICAO in [17] or by ITU in [4], where terms such as necessary bandwidth, out-of-band and spurious emissions are defined. The meaning of these terms is illustrated in Figure 3.

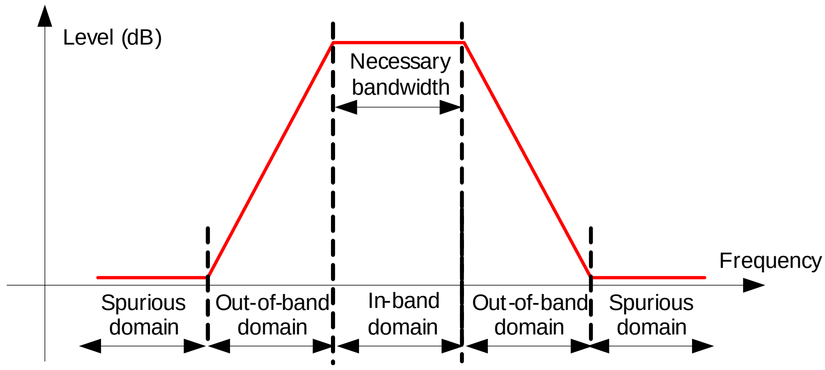


**Figure 3: Types of interference**

These types interference are explained in more detail in the following text.

### 3.2.1 IN-BAND INTERFERENCE

In-band interference occurs when the interfering and interfered systems operate in the same frequency band. Figure 4 shows a power spectral density of the interfering signal as well as filter characteristics of the interfered receiver in a typical in-band interference scenario.

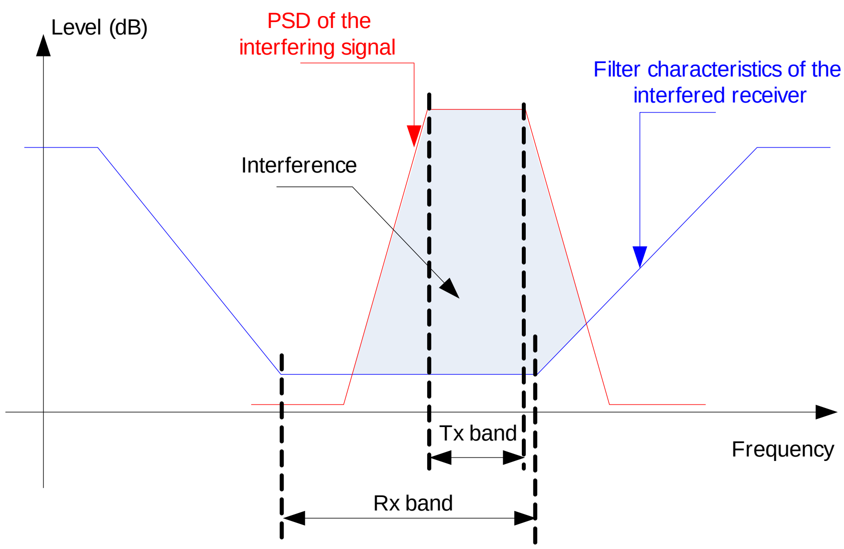


**Figure 4: In-band interference**

In-band interference is potentially the most serious case of interference, as the majority of interference occurs on frequencies where the receiver is most sensitive. Due to its criticality, this type of interference is addressed by allocating different frequency bands to different systems.

In order to reduce the potential in-band interference between the existing aeronautical radio navigation service (ARNS) systems in the L-band and the new UMTS air-to-ground communication system, the forward link frequency is selected to be nominally at 960 MHz and the reverse link at 1150 MHz, as described in Section 2. Those particular frequencies are less heavily used by existing ARNS systems, e.g. DME. The proposed frequency allocation minimises the in-band interference problem, but does not remove it completely, as it is shown in Section 4. In particular, the in-band interference coming from airborne JTIDS/MIDS and DME stations is still an issue. The in-band interference is considered in more detail in individual interference scenarios analysed in Section 4 where appropriate.

### 3.2.2 Out-of-Band Interference

Once in-band interference has been addressed by choosing relatively "quiet" nominal bands for the UMTS air-ground communication links, the critical issue becomes out-of-band interference. This interference is the central topic of investigation in this study.

Out-of-band interference occurs in scenarios where the interfering transmitter transmits on a frequency close to the interfered receiver's receive frequency. There are two mechanisms by which undesired emissions can get into the interfered receiver. One is caused by adjacent channel leakage (ACL) of the transmitter. The other is caused by insufficient adjacent channel selectivity (ACS) of the receiver. These two mechanisms are illustrated in Figure 5.

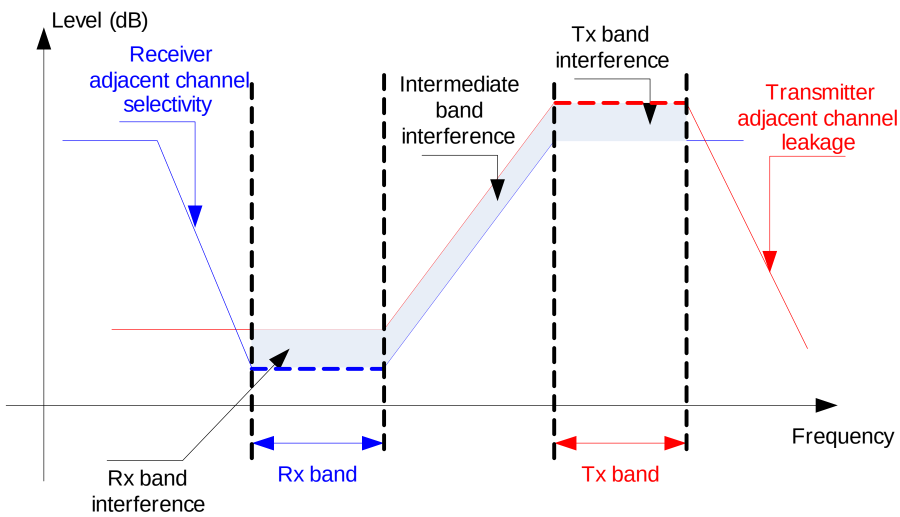


**Figure 5: Types of out-of-band interference**

The total out-of-band interference power can be seen as consisting of three components. These components are the transmit (Tx) band, receive (Rx) band, and intermediate band interference.

- **Rx band interference** refers to out-of-band emissions of the interfering transmitter that fall into the receive band of the nearby receiver. ITU ([4], [5]) defines them as products of modulation process and transmitter non-linearity.

- **Tx band interference** consists of signals received by the receiver in the operational band of the interfering transmitter. These signals get into the receiver through its non-ideal adjacent channel selectivity.

- **Intermediate band interference** occurs on frequencies between the transmit and receive bands. This interference is caused by a combination of the transmitter ACL and insufficient receiver ACS.

The reason why the out-of-band interference is analysed as consisting of separate components is because the means of combating them are potentially different. For example, Tx band interference can be reduced if the receiver's ACS is improved, while Rx band interference can be reduced if the transmitter has a better ACL ratio.

Relative contribution of the intermediate band interference component to total out-of-band interference is typically small, compared to the interference in the transmit and receive bands. For this reason, further analysis will concentrate on Rx and Tx band interference analysis.

### 3.2.3 SPURIOUS INTERFERENCE

Spurious interference is defined here as consisting of two cases: spurious emissions by the transmitter (or transmit spurs) and particular sensitivity of the receiver to interference at particular frequency (or receive spurs).

- **Spurious emissions** are generated by the interfering transmitter. They can be classified as harmonic emission, parasitic emission, intermodulation and frequency conversion products. Typically, they appear as components that overcome the general adjacent band and out-of-band transmission masks at a finite set of frequencies.

- **Receive spurs** represent increased receiver sensitivity (i.e. more than what follows from the adjacent band selectivity mask) to interference appearing at certain frequencies. One cause of receive spurs is superhet receiver architecture where the receiver is particularly sensitive to interference on the image frequency.

Careful transmitter and receiver design can ensure that spurs do not fall at frequencies where strong interference is likely to appear, e.g. at operating frequencies of other transmit or receive equipment likely to be present on the same platform. For this reason, spurious interference will only rarely be a problem for coexistence of two systems. The issue of spurious interference is only analysed in scenarios where it could potentially be a dominant type, i.e. when the interference is not in the adjacent band of the receiver.

### 3.2.4 OTHER EFFECTS OF INTERFERENCE

Receivers in the new aeronautical communication system in L-band are likely to have to operate in presence of strong interferers while receiving weak desired signal. If RF front-end filtering in a receiver is not sufficient, strong interferers, or blockers, will be suppressed only by intermediate frequency filtering stages, after the first down-conversion. This leaves the first RF amplifier (LNA) and mixer preceding the IF filters potentially exposed to strong out-of-band interference. This strong interference can give rise to the following adverse effects:

- Receiver desensitization;
- Intermodulation products created in the receiver;
- Intermodulation products created in the transmitter; and
- Noise increase caused by reciprocal mixing.

Also, wideband thermal noise generated by the transmitter can potentially increase the noise floor in the collocated receiver.

**Receiver desensitisation** is caused by very strong interfering signals that get through the first RF (“roofing”) filter into the LNA. If these strong signals are within few decibels of the LNA’s input 1dB compression point (1dBCP), they will change the operating point of the LNA and reduce its gain. This prevents the receiver from receiving weak desired signals, thus desensitizing it, even if the interferer gets rejected by the filtering stages that follow the LNA in the receiver.

In some cases the interfering signals may not be strong enough to saturate the LNA, but they are still close enough in frequency to get amplified in the LNA and get through the second stage of RF filtering, after which there is a risk they may saturate the mixer stage.

**Intermodulation (IM) products**. Even if the interferer is not strong enough to saturate the receiver front end, it may combine with another strong interference on a particular frequency to create non-linear products that may fall into the receiver pass-band and mask the weak desired signal. Third order intermodulation products can be created by interferers that operate in the same frequency band (L-band) as the interfered receiver; second order intermodulation products can fall into other frequency bands (e.g. VHF band).

**Transmit intermodulation products**. When two transmitters are co-sited, strong signals generated by one transmitter may enter the other transmitter’s non-linear power amplifier and create harmonics that may fall into the neighbouring receiver’s receive band. Power and frequency of intermodulation products thus generated depend on the transmit filter selectivity, linearity of the amplifiers and the interference scenario; therefore this effect needs to be assessed in individual installations. It is worth mentioning that this effect is expected to be of secondary importance to receiver blocking.

**Reciprocal mixing** refers to a scenario when a strong out-of-band interferer mixes with the phase noise of the local oscillator (LO) to create additional noise that falls into the intermediate frequency (IF) band of the receiver. This additional in-band noise increases the overall receiver noise floor and degrades the receiver's performance. In situations where a strong interferer is expected at the receiver’s input, a low phase noise LO has to be used.

**PA noise** refers to thermal noise (AWGN) generated in the power amplifier (PA) stage of the transmitter and the stage preceding it (driver stage). Although this noise is typically suppressed by the duplexer, it may be of importance in some cases.

# 4 INTERFERENCE ASSESSMENT

## 4.1 SELECTED INTERFERENCE SCENARIOS

Following the discussions with Eurocontrol, it is decided that coexistence analysis will be limited to the following interference scenarios:

1. An airborne UMTS transmitter to an onboard DME receiver;
2. An airborne UAT Tx to an airborne UMTS Rx;
3. A ground UAT Tx to an airborne UMTS Rx;
4. A ground UMTS Tx to a ground UAT Rx;
5. An airborne UMTS Tx to an airborne GNSS Rx;
6. An airborne UMTS Tx to an airborne DME Rx;
7. A ground UMTS Tx to a ground DME Rx;
8. An airborne MIDS TX at the distance of 1000 ft slant to airborne UMTS RX.

The investigated interference scenarios are shown in Figure 6, together with an additional scenario of GSM base station interfering with an airborne UMTS receiver.

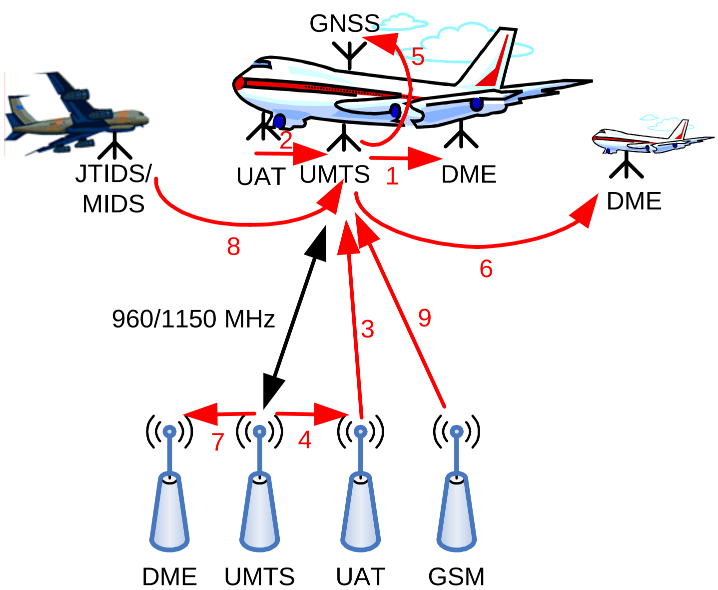


**Figure 6: Investigated interference scenarios**

Interference with terrestrial UMTS stations in the 900 MHz band (UMTS900) is seen as out of scope of this study. It is assumed that coexistence issues would be less severe than between the UMTS and GSM.

The issue of coexistence between the GSM pico basestations onboard a commercial aircraft providing the service to the passengers and the analysed air-ground UMTS system is seen as not critical, as these airborne systems will most likely operate in the 1800 MHz band.

## 4.2 Initial Assumptions

The following assumptions have been adopted at the beginning of the study work:

- The Ground – Air 3G communication system is UMTS FDD.
- Only a single carrier 3G communication system has been considered.
- The frequency allocation is:
  - Forward link (ground to air) in 960-977 MHz;
  - Reverse link (air to ground) in 1145–1156 MHz.
- The system parameters used to model the selected interference scenarios has been taken from the respective standardisation documents for each system unless otherwise agreed with Eurocontrol. Realistic values have been chosen such that the model depicts a typical operating scenario.
- The minimum vertical separation of aircraft is 1000 ft and the minimum horizontal separation distance is 3 nautical miles (nmi).
- The minimum altitude for operational of the 3G system is 1000 ft above ground level.
- The results presented here refer to the worst case scenarios, with maximal transmit powers, an aircraft located at the edge of UMTS cell coverage, peak transmit power of pulsed transmitters etc.
- The study has considered analogue receiver stages; possible effects of digital processing, FEC etc on interference suppression and data recovery in a pulsed environment has not been taken into account.
- Methodology has been based on the ITU method of safety margins and apportionment of particular interference to all the interference sources, similar to e.g. what is given in ITU-R M.1639, [7], Annex 1, Table 1.

## 4.3 Scenario 1: Airborne UMTS Tx to an Onboard DME Rx

### 4.3.1 Scenario Description

In this scenario airborne UMTS transmitter emissions interfere with the onboard DME receiver. The interference scenario is illustrated in Figure 7.

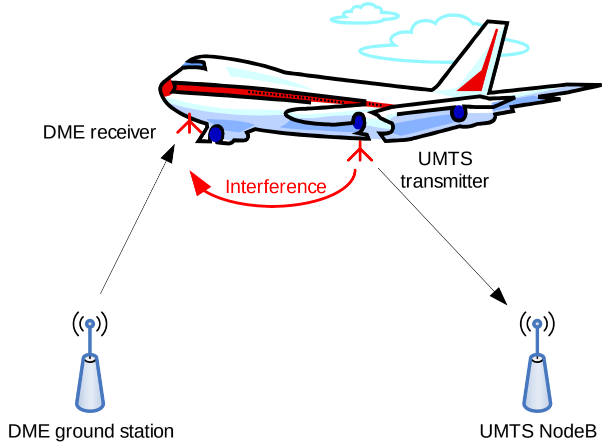


**Figure 7: Airborne UMTS transmitter interfering with an onboard DME receiver**

The UMTS Tx → DME Rx interference is potentially critical, as both UMTS and DME antennas are placed at the underside of the same aircraft. With the two antennas mounted on the same platform and in proximity to each other, isolation between them will generally be different from what can be inferred from their gain and free space loss, as close-field effects and the proximity of aircraft skin will have a significant effect. As described in [2], isolation between the two antennas is assumed to be 35 dB.

### 4.3.2 UMTS Return Link Frequency Allocation, In-Band Interference

Frequency plan of the band which two systems share is shown in Figure 8.

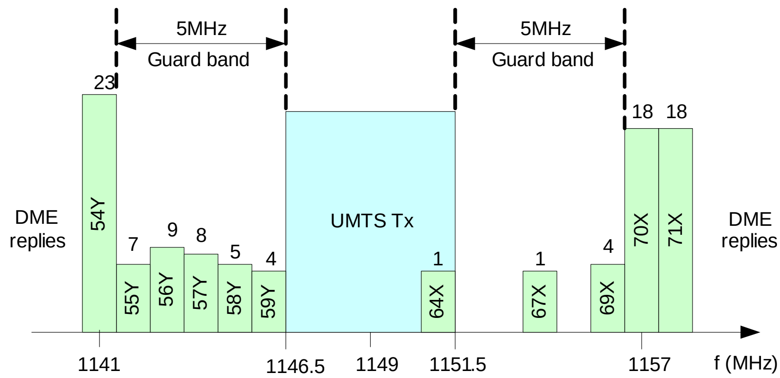


**Figure 8: DME reply channel frequencies and the number of stations in Europe**

Figure 8 shows carrier frequencies of individual DME reply channels together with the number of DME stations in Europe that operate on that channel. The numbers are derived from the dataset [8] provided by Eurocontrol. The total number of stations with associated DME channels listed in the dataset was 2967.

It can be seen from Figure 8 that the frequency band 1145-1156 MHz considered for the UMTS system return link (Section 2.1) is not completely free of DME ground stations. What is more, no 5 MHz-wide segment in the observed band of frequencies is completely free of DME stations; therefore no UMTS return link frequency allocation would completely avoid in-band interference. Based on the number of DME stations in Europe between 1141 and 1158 MHz, it is decided that the UMTS carrier should be placed at 1149 MHz, i.e. in the middle of the window of smaller DME channel occupation in Europe, as shown in Figure 8.

With the UMTS carrier located at 1149 MHz, in-band interference into the co-located DME receiver at DME channels between 60Y-64X will prevent any DME signal reception. It is also expected that on-board DME receiver will be effectively jammed in the guard bands as well, i.e. in the DME channel range from 55Y to 69X. DME ground stations operating in these channels (39 in total in Europe) will have to be reallocated to different DME channels.

### 4.3.3 Out-of-Band Interference

DME Rx ACS and UMTS Tx ACL are shown in Figure 9. The diagram also shows frequencies at which Tx and Rx band interference levels were calculated.

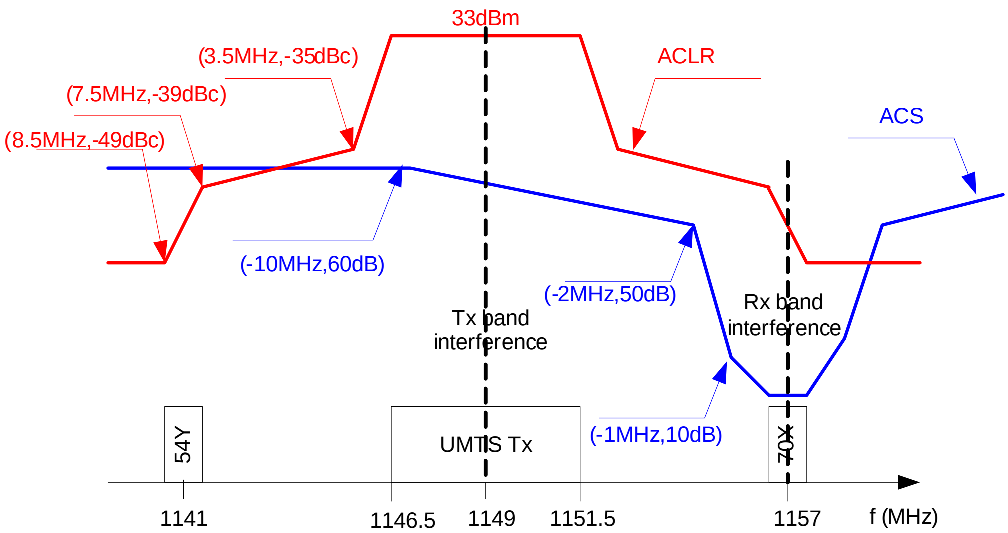


**Figure 9: UMTS UE Tx ACLR and DME Rx ACS**

Based on the data given in Appendix A, a link budget has been developed for the UMTS Tx→DME Rx interference scenario. The link budget is given in Table 1.

| **Parameters** | **Units** | **In Rx band (ACL)** | **In Tx band (ACS)** |
|---|---|---|---|
| | | | |
| **General** | | | |
| Tx and Rx frequencies | MHz | 1157.0 | 1149.0 |
| Frequency offset (abs) | MHz | 8.0 | 8.0 |
| | | | |
| **Transmitter (UMTS)** | | | |
| Transmit power (airborne) | dBm | 33.0 | 33.0 |
| Spectrum emission mask (UE) | dBc/MHz | -44.0 | N/A |
| Level of spurs in 1MHz | dBm | -30.0 | |
| Duplexer attenuation at 1157 MHz | dB | 30.3 | |
| | | | |
| **Channel** | | | |
| Isolation between UMTS and DME antennas (onboard) | dB | 35.0 | 35.0 |
| | | | |
| **Receiver (DME)** | | | |
| Adjacent channel selectivity | dB | N/A | 57.5 |
| Interference threshold of DME receiver (without margin) | dBm | -99.0 | -99.0 |
| Safety margin | dB | 6.0 | 6.0 |
| Interference margin to accommodate other sources | dB | 6.0 | 6.0 |
| Rejection of spurs | dB | | 75.0 |
| | | | |
| **Interference** | | | |
| Interference allowed | dBm | -111.0 | -53.5 |
| Received adj. band interference power | dBm | -76.3 | -2.0 |
| Additional adj. band interference suppression required | dB | **34.8** | **51.5** |
| | | | |
| **Spurs** | | | |
| Level of spurs | dBm | -95.3 | -77.0 |
| Additional suppression of spurs required | dB | **15.8** | **34.0** |

**Table 1: Airborne UMTS UE Tx → DME Rx interference link budget**

The link budget in Table 1 is addressing two types of adjacent channel interference: in the DME receive band and in the UMTS transmit band, as described in Section 3.2.2. The budget is based on the following assumptions:

- Tx- and Rx- band interferences dominate the overall adjacent band interference link budget. It has been confirmed that transitional band interference (see Section 3.2.2) is 30 dB below those two types of interference;
- Roll-off of the UMTS duplexer is 5.5 dB/MHz beginning from 2.5 MHz away from the carrier (UMTS channel bandwidth);
- The DME receiver front end has a wide roofing filter that covers the full ARNS band, which leaves it open to a UMTS blocker at 1149 MHz.

**Interference in the DME receive band.** Level of this interference depends on the adjacent channel leakage ratio of the onboard transmitter, defined in UMTS specifications [9] and [10] as the spectrum emission mask. The value used in Table 1 is for user equipment (UE).

Even with allocated guard bands, Tx and Rx interference is still significantly stronger than allowed. This is shown in Table 1 as an "additional adjacent band interference suppression" requirement. This additional filtering is of the order of 34.8 dB, even with 5 MHz guard bands in place. As UMTS is using spread spectrum direct sequence modulation, its effects on the interfered DME receiver in channels 54Y or 70X will be the same as AWGN of the equivalent power. The noise of this power will desensitise the receiver, preventing reception of DME signals on the channels adjacent to guard bands.

**Interference in the UMTS transmission band.** Level of this interference is significantly above (by 51.5 dB) the allowed Tx band interference in DME receiver. This interference remains a potential problem, as the leakage is on the UMTS carrier frequency, and cannot be suppressed by UMTS filtering. The same coexistence problem will, however, exist with any other continuously transmitting communication system in the operating in the DME band.

**Blocking.** The level of blocker at the DME receiver input in the worst case is potentially -2 dBm, which is signal level that can saturate the DME receiver front end (see Section 5.1). It follows from the discussion in Section 5.1 that UMTS blocking signal is around 14 dB above the level it is allowed in order not to desensitize the DME receiver.

It can be concluded from these results that interference issues in the analysed scenario are severe. There are several ways how they can be addressed.

**More linear PA.** ACL interference can be significantly reduced if it is assumed that airborne PA will have better linearity than what can be achieved in a typical handset. For example, taking the adjacent channel leakage requirement for a NodeB instead of the UE, the leakage is expected to be lower by 12 dB.

**High quality UMTS duplexer.** Adjacent channel Tx leakage can be additionally suppressed by a high quality UMTS duplexer, or channel filter after the PA. A selective filter can help solve other potential interference issues, such as e.g. PA generated noise. A custom cavity duplexer would have to be designed to satisfy the requirements of the non-standard carrier frequency, acceptable in-band group delay and narrow transition bands.

From specifications of COTS transmit filters designed for similar frequencies (e.g. AMPS transmit filter, [11]) or duplexers for the same service (e.g. UMTS duplexer, [12]), it can be concluded that a high quality cavity filter can provide an acceptable group delay characteristics, transitional bands of the same order as passbands, acceptable insertion losses (e.g. 0.5 dB) and adjacent band rejection of the order of 50 dB or more. The issue with a custom filters is their cost, size (volume of the order of 1 to 2 litres) and weight.

**Increasing the guard band.** As it can be seen, even with high quality filters, interference can still be above the allowed level due to insufficient DME receiver selectivity. The possible solution would be here to increase the guard bands between the UMTS and DME systems. This will require, however, potential frequency reallocation of a large number of DME stations.

**Improved isolation.** Filtering requirements (or guard band width) may be reduced if DME and UMTS antennas are placed on the aircraft underside in a way to increase isolation between the two. One possible option is to place the UMTS antenna close to the tail end of the aircraft, assuming the DME antenna is close to the nose end. It is unlikely, however, that any arrangement of antennas would provide enough isolation between the antennas to render additional high quality RF filters unnecessary. This would also depend on the actual aircraft.

**Intermittent transmission.** One promising approach to DME protection is to interrupt the UMTS transmission while DME is expecting replies. This solution can potentially replace more expensive DME protection methods listed above.

As it can be seen from the ling budget, a combination of the proposed methods of UMTS interference suppression is needed to achieve suppression of UMTS interference that would not significantly increase the noise floor of the onboard DME receiver. Interference from an in-band airborne transmitter in the DME receive band remains a potential problem, not only for UMTS, but for any system operating in this band. Intermitted UMTS transmission is potentially a promising DME protection technique; its effects on UMTS system performance need to be further investigated through computer simulation.

### 4.3.4 SPURS

Spurious component generated by the UMTS UE transmitter are defined in [10], Section 6.6.3.1 and Table 6.12. One of the general requirements defined there is that spurs, measured in 1MHz bandwidth shall not exceed -30 dBm, and measured in 1 kHz (here interpreted as CW) shall not exceed -36 dB.

The value of 75 dB for receiver selectivity at image and spurs is taken from ICAO Annex 10, [14].

It should be noted that it is unlikely that a DME channel will fall at a frequency where there spurs will appear. If that happens, however, additional filtering may be required. Filtering requirements are less stringent than the ones for out of band interference rejection. It is therefore expected that the additional filtering that would satisfy the adjacent band interference requirements will also reject the spurs.

## 4.4 SCENARIO 2: AIRBORNE UAT TX TO AN AIRBORNE UMTS RX

In this interference scenario signal generated by an airborne UAT transmitter is leaking into the onboard UMTS receiver. The scenario is illustrated in Figure 10.

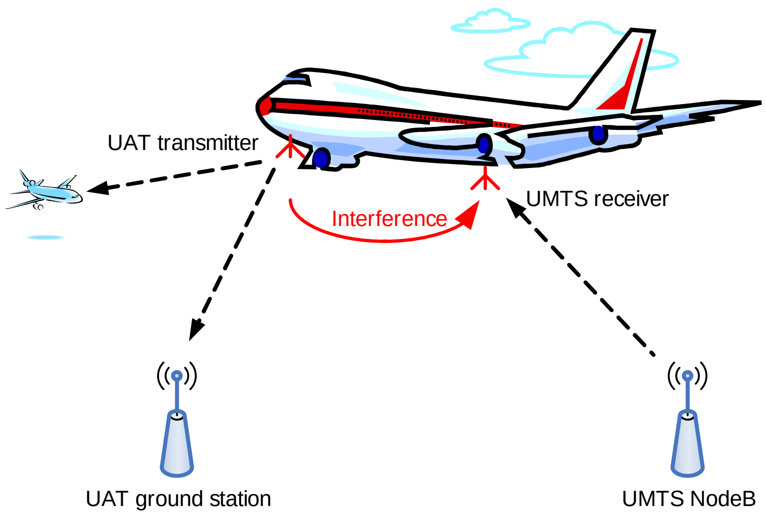


**Figure 10: Airborne UAT transmitter interfering with an onboard UMTS receiver**

The UAT Tx → UMTS Rx interference scenario is potentially critical, as both UMTS and DME antennas are placed on the underside of the aircraft. Isolation between the two antennas is assumed to be 35 dB.

### 4.4.1 UMTS FORWARD LINK FREQUENCY ALLOCATION, GSM INTERFERENCE

Frequency plan of the band which two systems share is shown in Figure 11.

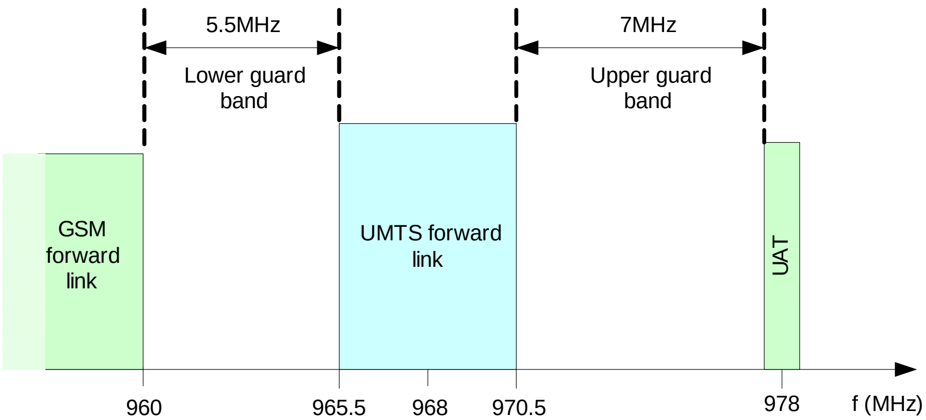


**Figure 11: UAT, GSM forward link and UMTS forward link bands**

Cross-system interference from airborne UAT transmitter into a UMTS receiver on the same aircraft will depend on the guard band between the two systems, marked "upper guard band" in Figure 11. However, width of the upper guard band depends in turn on the minimal acceptable width of the lower guard band. This guard band has to be wide enough to provide sufficient protection of an airborne UMTS receiver from GSM forward link emissions coming from the terrestrial base stations.

Analysis of GSM to UMTS adjacent band interference has not been included in the interference scenarios. However, the need to define the guard bands led to an investigation of the terrestrial GSM base station interference into an airborne UMTS receiver. The results of the analysis given in Appendix B show that a guard band of 5.5 MHz is needed between the terrestrial GSM band and the UMTS forward link. This lower guard band is shown in Figure 11, together with the selected UMTS forward link carrier of 968 MHz that is defined by this lower guard band width.

### 4.4.2 OUT-OF-BAND INTERFERENCE

UMTS Rx ACS and UAT Tx ACLR are shown in Figure 9.

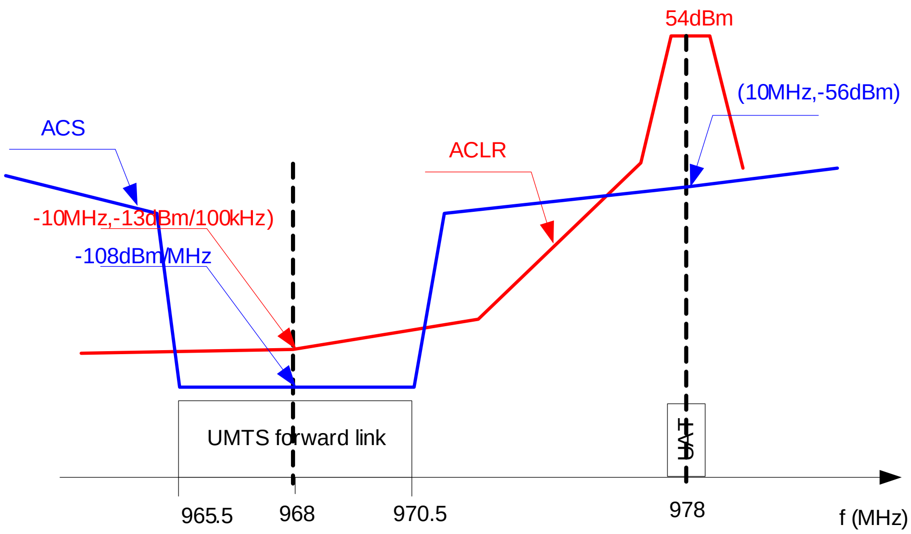


**Figure 12: UAT Tx ACLR and UMTS UE Rx ACS**

With the UMTS forward link placed at 968 MHz, the effects of UAT transmitter on collocated UMTS receiver are investigated. The results are presented in the following Table.

| Parameters | Units | In Rx band (ACL) | In Tx band (ACS) |
|---|---|---|---|
| | | | |
| **Transmitter (UAT)** | | | |
| Frequency | MHz | 968.0 | 978.0 |
| Frequency offset (abs) | MHz | 10.0 | 10.0 |
| Transmit power (airborne) | dBm | -13.0 | 54.0 |
| Duplexer attenuation at 978 MHz | dB | | 41.3 |
| Measurement BW | MHz | 0.1 | N/A |
| | | | |
| **Channel** | | | |
| Isolation between UMTS and DME antennas (onboard) | dB | 35.0 | 35.0 |
| | | | |
| **Receiver (UMTS)** | | | |
| Interference threshold of UMTS receiver to UAT transmitted signal (without margin) | dBm | -108.0 | -56.0 |
| Safety margin | dB | 6.0 | 6.0 |
| Interference margin to accommodate other sources | dB | 6.0 | 6.0 |
| Receiver bandwidth | MHz | 3.8 | N/A |
| | | | |
| **Interference** | | | |
| Interference allowed | dBm | -120.0 | -68.0 |
| Receive interference power | dBm | -32.2 | -22.3 |
| Additional suppression required | dB | **87.8** | **45.8** |

**Table 2: Airborne UAT Tx -> collocated UMTS UE Rx interference link budget**

UAT SARPS give out-of-band transmit mask only for frequency offsets of up to 3.25 MHz from the UAT carrier ([17], Section 12.1.2.3.3, Table 2). Frequency offsets greater than 3.25 MHz are considered to be the spurious emission domain. Implementation Manual [19] gives the value of -13 dBm as a worst-case value, measured in a 100 kHz band.

It should be noted that the probability of spurious emissions falling into the UMTS UE receive band is low. Therefore, the scenario captured in the third column ("In Rx band (ACL)") in Table 2 represents the worst-case scenario that is very unlikely to happen in practice.

The results for both Rx and Tx band interference indicate that, in the worst case, a significant additional filtering is required to protect the UMTS receiver from strong UAT pulses. During UAT transmissions, interference power on the co-located UMTS receive antenna can be of the order of -22 dBm, which may potentially desensitise the receiver (see Section 5) unless protection measures are taken. One appropriate measure would be to blank the UMTS receiver (i.e. turn the airborne RF stage off or disconnect the front end from the antenna) during UAT bursts, using e.g. the suppressor line as a control signal.

Effects of receiver blanking on UMTS signal reception further discussed in the next section and in Appendix C.

### 4.4.3 Effects of UAT interference on UMTS FDD

UAT SARPS [17] and Implementation Manual [19] show that onboard UAT transmitter will transmit bursts of either 280 μs (short ADS-B) or 420 μs (long ADS-B) of duration. The airborne UAT transmitter transmits one message per second at pseudo-randomly chosen moment within the last 4/5 of the one second long timing frame. This means that onboard

UAT transmitter will appear to a co-located UMTS receiver as a source of a strong pulsed interference with long pulse duration of 420 μs, pulse repetition frequency of 1 per second, and pseudo-randomly staggered pulses.

During the pulse duration, its power is much higher than the expected UMTS signal level at the receiver input. Such strong pulse can cause two types of effects in the UMTS receiver:

- It can force carrier and code tracking loops to drift away from the synchronous state. This will cause the receiver to perform signal reacquisition after the pulse has ended, thus significantly prolonging the receiver recovery time after the pulse;

- It can cause large soft decision errors in the symbol decoder.

The method to overcome problems caused by strong interference is to effectively turn the receiver front end off during the UAT transmission. Keeping the tracking loops and soft decision algorithms "on hold" during the same periods enables them to continue from the synchronous state after the pulse has ended. Signalling on the suppressor bus can be used to achieve UMTS receiver blanking.

Assuming, therefore, that the effects of very strong interference pulses can be contained by effectively turning the input signal off for slightly longer than 0.43 ms (UAT suppression pulse duration including receiver recovery time), the question is what effect would this have on UMTS FDD reception.

The answer to this very much depends on the particular channel type and coding rates. The period of 0.43 ms is a significant percentage of a single frame. The decoder might in some situations be able to recover the frame; in other occasions the whole frame will be lost. There is a potential trade-off between the coding rate and the vulnerability of coded frames to interruptions.

As a conclusion, some loss in system capacity is possible in situations where the airborne UMTS is receiving through the DME transmissions. These issues and possible means of combating the pulsed interference are discussed in Appendix C

### 4.4.4 UAT Interference from Other Aircraft

Since interference from UAT transmitter into a co-sited UMTS receiver is so strong that it will desensitise the UMTS receiver, it is possible that UAT interference coming from nearby aircraft will also be significant. This scenario is illustrated in the following Figure.

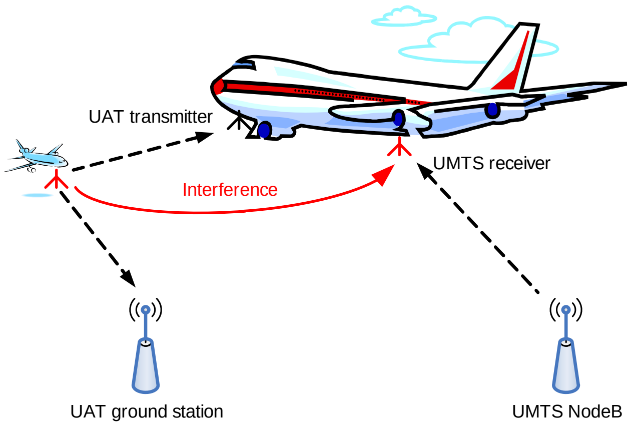


**Figure 13: Airborne UAT transmitter interfering with a nearby UMTS receiver**

Effects of UAT interference coming from a nearby aircraft are investigated. The results are presented in the following Table.

| Parameters | Units | In Rx band (ACL) | In Tx band (ACS) |
|---|---|---|---|
| | | | |
| **Transmitter (UAT)** | | | |
| Frequency | MHz | 968.0 | 978.0 |
| Frequency offset (abs) | MHz | 10.0 | 10.0 |
| Transmit EIRP (air) | dBm | -13.0 | 58.0 |
| Transmit duty cycle | dB | -33.8 | -33.8 |
| Duplexer attenuation at 978 MHz | dB | | 41.3 |
| Measurement BW | MHz | 0.1 | N/A |
| | | | |
| **Channel** | | | |
| Tx-Rx distance | km | 5.6 | 5.6 |
| Free space loss | dB | 107.1 | 107.1 |
| Polarisation mismatch loss | dB | 0.0 | 0.0 |
| Receive antenna gain | dBi | 0.0 | 0.0 |
| | | | |
| **Receiver (UMTS)** | | | |
| Interference threshold of UMTS receiver to UAT transmitted signal (without margin) | dBm | -108.0 | -56.0 |
| Safety margin | dB | 6.0 | 6.0 |
| sources | dB | 6.0 | 6.0 |
| Receiver bandwidth | MHz | 3.8 | N/A |
| | | | |
| **Interference** | | | |
| Interference allowed | dBm | -120.0 | -68.0 |
| Receive interference power | dBm | -138.0 | -124.2 |
| Additional suppression required | dB | -18.0 | -56.2 |
| Distance at which no additional fitering is required | km | **0.7** | **0.0** |

**Table 3: Airborne UAT Tx -> nearby UMTS UE Rx interference link budget**

Interference link budget in Table 3 shows that, due to the low interference duty cycle, the effect of interference when UAT transmitter and UMTS receiver are not co-sited is not an issue. The distance where interference falls below the noise floor in the worst case is 0.7 km, which is less than minimal horizontal separation distance.

## 4.5 SCENARIO 3: GROUND UAT TX TO AN AIRBORNE UMTS RX

In this interference scenario signal generated by a terrestrial UAT transmitter is jamming an airborne UMTS receiver. This scenario is illustrated in Figure 14.

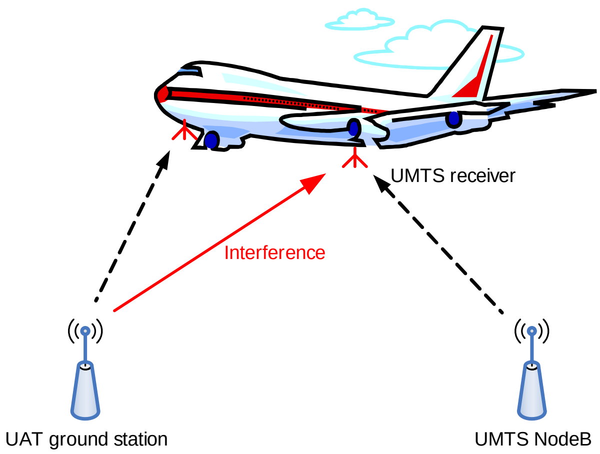


**Figure 14: Ground UAT transmitter interfering with an onboard UMTS receiver**

The UMTS Rx ACS and UAT Tx ACLR are the same as shown in Figure 9 for the airborne interference scenario. The only difference is the higher DME terrestrial station EIRP.

Based on the available data, a link budget has been developed for the UAT Tx→UMTS Rx interference scenario. The link budget is given in Table 4.

| Parameters | Units | In Rx band (ACL) | In Tx band (ACS) |
|---|---|---|---|
| | | | |
| **Transmitter (UAT)** | | | |
| Frequency | MHz | 968.0 | 978.0 |
| Frequency offset (abs) | MHz | 10.0 | 10.0 |
| Transmit EIRP (ground) | dBm | -13.0 | 58.0 |
| Duplexer attenuation at 978 MHz | dB | | 41.3 |
| Measurement BW | MHz | 0.1 | N/A |
| | | | |
| **Channel** | | | |
| Tx-Rx distance | km | 0.3 | 0.3 |
| Free space loss | dB | 81.8 | 81.9 |
| Polarisation mismatch loss | dB | 0.0 | 0.0 |
| Receive antenna gain | dBi | 0.0 | 0.0 |
| | | | |
| **Receiver (UMTS)** | | | |
| Interference threshold of UMTS receiver to UAT transmitted signal (without margin) | dBm | -108.0 | -56.0 |
| Safety margin | dB | 6.0 | 6.0 |
| sources | dB | 6.0 | 6.0 |
| Receiver bandwidth | MHz | 3.8 | N/A |
| | | | |
| **Interference** | | | |
| Interference allowed | dBm | -120.0 | -68.0 |
| Receive interference power | dBm | -79.0 | -65.2 |
| Additional suppression required | dB | **41.0** | **2.8** |
| Distance at which no additional fitering is required | km | **34.2** | **0.4** |

**Table 4: Ground UAT Tx -> UMTS UE Rx interference link budget**

Column three of the interference link budget addresses spurious UAT emissions in the UMTS band. Although the level plan shows relatively high level of interference (41 dB) during UAT transmissions, the probability of spurs actually falling in the UMTS band is relatively low. Also, the low duty cycle of UAT terrestrial transmissions (-23.7 dB) means that mean interference power will be reduced by this amount, making the interference in this scenario less relevant.

Although mean interference power in this scenario is not seen as a critical issue, peak interference from ground UAT station into an airborne UMTS receiver needs to be considered. The reason is that ground UAT transmission bursts are longer than airborne transmission bursts (FIS-B burst duration is 4.27 ms in one 1 s long frame). As a result, the particular UMTS frame that coincides with the terrestrial UAT transmission can be affected; whether the whole frame will be lost depends on the power of interference, power control in the UMTS channel and level of coding protection in the channel.

Out-of-band interference in the UMTS receiver is seen as not critical. ACS of the UMTS receiver has to be improved by 2.8 dB for this interference to fall below the threshold, which is seen as achievable with an appropriate custom UMTS duplexer.

## 4.6 Scenario 4: Ground UMTS Tx to a Ground UAT Rx

This interference scenario appears at locations where ground UMTS equipment (i.e. NodeB) is co-sited with a ground UAT station. This interference scenario is shown in Figure 15.

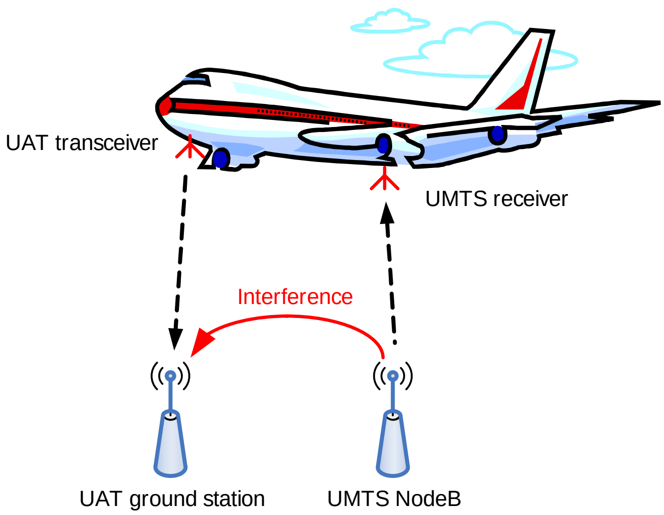


**Figure 15: Ground UMTS transmitter interfering with a ground UAT receiver**

### 4.6.1 Adjacent Band Interference

UMTS NodeB Tx ACL and ground UAT Rx ACS and are shown in Figure 16. The diagram also shows frequencies where Tx and Rx band interferences were calculated.

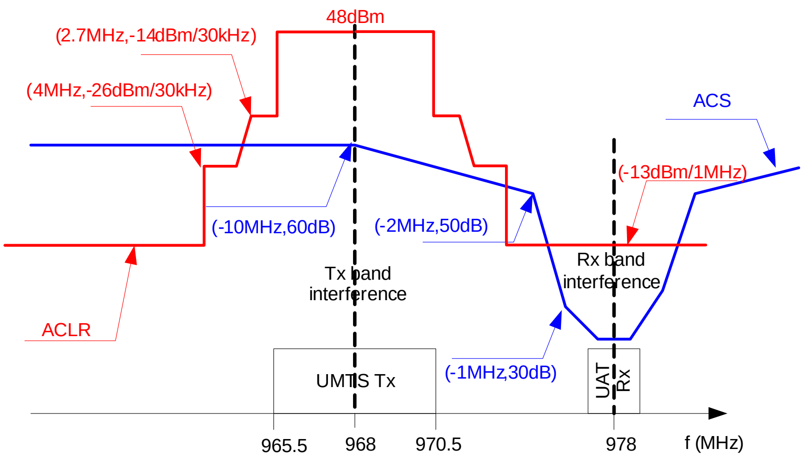


**Figure 16: UMTS NodeB Tx ACLR and UAT Rx ACS**

Based on the data given in Appendix A, a link budget has been developed for the UMTS Tx→UAT Rx interference scenario. The link budget, covering adjacent band interference is given in Table 5.

| Parameters | Units | In Tx band (ACS) | In Rx band (ACL) |
|---|---|---|---|
| | | | |
| **Transmitter (UMTS)** | | | |
| Frequency | MHz | 968.0 | 978.0 |
| Frequency offset (abs) | MHz | 10.0 | 10.0 |
| Transmit power (NodeB) | dBm | 48.0 | N/A |
| Duplexer attenuation at 978 MHz | dB | | 41.3 |
| Out-of-Tx band power / 1MHz | dB | N/A | -54.3 |
| | | | |
| **Channel** | | | |
| Isolation between co-sited antennas | dB | 20.0 | 20.0 |
| | | | |
| **Receiver (UAT)** | | | |
| Rx LNA IIP3 | dBm | -5.0 | -5.0 |
| Rx NF | dB | 7.0 | 7.0 |
| Rx Bw | MHz | 1.0 | 1.0 |
| Thermal noise power | dBm | -107.0 | -107.0 |
| Tolerable interference level | dBm | -101.0 | -101.0 |
| ACS at +-10MHz | dB | 60.0 | N/A |
| Interference margin to accommodate other sources | dB | 6.0 | 6.0 |
| | | | |
| **Interference** | | | |
| Interference allowed | dBm | -47.0 | -107.0 |
| Colocated interference power | dBm | 28.0 | -74.3 |
| Additional suppression required | dB | **75.0** | **32.8** |
| | | | |
| **Not co-located** | | | |
| Path loss exponent | | 2.0 | 2.0 |
| UMTS Tx antenna gain towards horizon | dBi | 4.5 | 4.5 |
| UAT Rx antenna gain towards horizon | dBi | 4.5 | 4.5 |
| Propagation loss required | dB | 104.0 | 61.8 |
| Distance at which no additional suppression is required | km | **3.9** | **0.0** |

**Table 5: Ground UMTS NodeB Tx -> UAT Rx interference link budget**

**Out-of-band interference.** Out of band UMTS interference into the UAT receiver will manifest itself as an equivalent increase in the UAT receiver noise floor that will in turn desensitise the UAT receiver. It follows from the level plan that interference coming from the ground UMTS transmitter into a co-located UAT receiver is very strong: it amounts to 75 dB above the threshold in the UMTS transmit band. In order to co-locate the terrestrial stations in two systems, an equivalent amount of additional interference suppression has to be achieved.

Additional interference suppression can be achieved by various methods or the combination of them. Some available techniques are Tx-Rx separation and antenna nulling.

- **Tx-Rx separation.** If UMTS and UAT stations are not collocated, additional propagation loss between the two sites can provide the required level of additional interference suppression. It is shown in the link budget in Table 5 that, if additional isolation is to be provided by free space loss only, the distance between the UMTS and UAT ground stations has to be at least 3.9 km (assuming a free space loss).

- **Antenna nulling.** Interference coming from a known direction can be suppressed by placing the null in the antenna radiation pattern in the direction of the incoming interference. Techniques to achieve this fall under the area of electronic countermeasures.

The appropriate solution might also be a combination of these two techniques, depending on the scenario in each individual case.

### 4.6.2 UAT RECEIVER BLOCKING AND IP3

The high level of adjacent band interference at the UAT receiver input raises question of receiver blocking and the level of intermodulation products. The link budget, covering receiver blocking and intermodulation products is given in Table 6.

It is assumed in Table 6 that UAT receiver 1dBCP is -10 dBm, as this is the highest allowed level of the desired signal ([17], Section 12.3.2.4). It is also assumed that IIP3 of the UAT receiver is 10 dB above the 1dBCP.

| Parameters | Units | In Tx band (ACS) |
|---|---|---|
| | | |
| **Transmitter (UMTS)** | | |
| Tx frequency | MHz | 968.0 |
| Rx frequency | MHz | 978.0 |
| Frequency offset (abs) | MHz | 10.0 |
| Transmit power (NodeB) | dBm | 48.0 |
| | | |
| **Channel** | | |
| Isolation between co-sited antennas | dB | 20.0 |
| | | |
| **Receiver (UAT)** | | |
| Rx LNA IIP3 | dBm | 0.0 |
| Rx NF | dB | 7.0 |
| Rx Bw | MHz | 1.0 |
| Thermal noise power | dBm | -107.0 |
| | | |
| **Blocking** | | |
| Allowed interference level to avoid blocking | dBm | -10.0 |
| Colocated interference power | dBm | 28.0 |
| Roofing filter suppression required | dB | **38.0** |
| | | |
| **IP3** | | |
| Input interf. level that takes IP3 12dB below the noise floor | dBm | -39.7 |
| RF stage filtering required to avoid IP3 | dB | **67.7** |

**Table 6: Ground UMTS NodeB Tx -> UAT Rx blocking link budget**

Strong adjacent band interference needs to be suppressed before the first active stage in the receiver. The additional suppression has to be achieved using an RF roofing filter placed between the receive antenna and the LNA. This has to be achieved for two reasons, as discussed in Section 5.1: to avoid receiver blocking and to avoid strong 3rd order intermodulation products.

The 3rd order intermodulation products are less critical, because there need to be two strong signals reaching the UAT receiver front end to create 3rd order intermodulation products. With UMTS NodeB transmitting at 968 MHz and co-sited with a UAT receiver operating at 978 MHz, the second strong interferer has to come from a nearby GSM base station operating at 958 MHz. It is assumed here that such a base station would not commonly be co-located with both UMTS and UAT equipment.

The UAT receiver front end blocking caused by collocated UMTS transmitter is, however, a more serious issue. Selectivity required from the receiver front end is shown in Table 6 to be 38 dB to avoid blocking. This selectivity has to be provided mostly by a roofing filter (pre-LNA) filter, and partially from the following RF filtering stages (to avoid blocking in the mixer stage). Additional means to avoid receiver blocking, such as highly linear UAT LNA or separation between the UMTS transmit and UAT receive antennas can also be implemented.

As a conclusion, due to strong adjacent channel interference caused by UMTS NodeB into the UAT ground receiver, co-siting of UAT receivers and UMTS transmitters is not practical. Measures such as custom bandpass filters, transmit and receive antenna separation and selective antenna nulling might have to be considered in individual installations.

## 4.7 Scenario 5: Airborne UMTS Tx to an Airborne GNSS Rx

Satellite navigation receivers in the aeronautical radionavigation satellite service (RNSS), (i.e. GPS or Galileo) are particularly vulnerable to interference, due to the extremely low levels of the desired signal. The interference scenario where the proposed UMTS air to ground communication system interferes with a global navigation satellite (GNSS) receiver is shown in Figure 17.

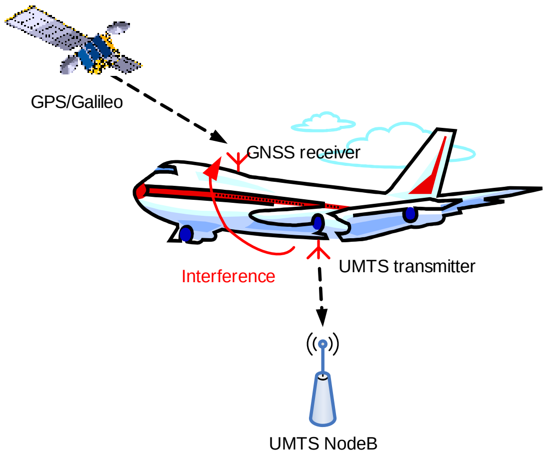


**Figure 17: Airborne UMTS transmitter interfering with an onboard GNSS receiver**

This scenario looks into issues of interference into satellite navigation carriers that specifically fall into the ANRS band. The analysis is therefore limited to GPS L5 and Galileo E5 signals. Regarding the GNSS signals that are out of this band, i.e. L1, L2, and E6, as well as Glonass G1 and G2 signals, the assumption is that frequency separation will ensure coexistence between them and the UMTS system.

### 4.7.1 Co-sited UMTS Tx and GNSS Rx

GNSS Rx ACS and UMTS Tx ACL are shown in Figure 9. The diagram also shows frequencies where Tx and Rx band interferences were calculated.

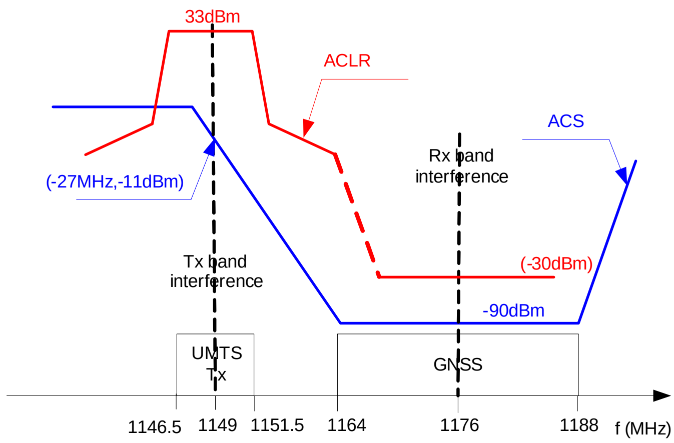


**Figure 18: UMTS UE Tx ACLR and GNSS Rx ACS**

UMTS standards do not give the level of ACLR in GNSS bands. The value assumed for interference into the GNSS band is therefore equal to the spurious emissions requirement of -30 dBm given in [10], Section 6.6.3.1, Table 6.12. It is also assumed that this value is a minimal requirement, and UMTS transmitter can be designed to have lower level of spurious response in RNSS band in particular. For example, Table 6.13 in [10] indicates that spurious emissions can be lower in protected bands such as terrestrial GSM and UMTS.

GNSS receiver ACS is taken from [18], Figures 3 and 4. The lower interference level, applicable to GNSS signal acquisition, is assumed.

The UMTS Tx to onboard GNSS Rx interference scenario is addressed in the link budget in Table 7.

| **Parameters** | **Units** | **In Rx band (ACL)** | **In Tx band (ACS)** |
|---|---|---|---|
| | | | |
| **Transmitter (UMTS)** | | | |
| Frequency | MHz | 1176.5 | 1149.0 |
| Frequency offset (abs) | MHz | 27.5 | 27.5 |
| Transmit power (airborne) | dBm | N/A | 33.0 |
| Spurious emission / 1MHz | dBm/MHz | -30.0 | N/A |
| Duplexer attenuation at 1176 MHz | dB | 70.0 | |
| | | | |
| **Channel** | | | |
| Isolation between UMTS and GNSS antennas (onboard) | dB | 45.0 | 45.0 |
| | | | |
| **Receiver (GNSS)** | | | |
| Interference threshold, w/o margin / 10.23MHz | dBm | -85.0 | -11.3 |
| Safety margin | dB | 6.0 | 6.0 |
| Interference margin to accommodate other sources | dB | 6.0 | 6.0 |
| | | | |
| **Interference** | | | |
| Interference allowed | dBm | -97.0 | -23.3 |
| Receive interference power in 10.23MHz | dBm | -134.9 | -12.0 |
| Additional suppression required | dB | **-37.9** | **11.3** |
| | | | |
| **Systems not collocated** | | | |
| Tx antenna gain | dBi | 0.0 | 0.0 |
| Tx-Rx distance | km | 0.3 | 0.3 |
| Free space loss | dB | 83.5 | 83.3 |
| Polarisation mismatch loss | dB | 3.0 | 3.0 |
| Receive antenna gain | dBi | 7.0 | 7.0 |
| Receive interference power | dBm | -109.5 | -46.3 |
| Additional suppression required | dB | **-12.5** | **-23.1** |

**Table 7: Airborne UMTS UE Tx -> collocated GNSS Rx interference link budget**

The link budget shows there is 11.3 dB of excess interference from UMTS into the co-sited GNSS receiver. This interference is caused by insufficient adjacent channel selectivity of the GNSS receiver.

Reduction of UMTS signal power leaking into the GNSS receiver can be obtained by:

- Moving the UMTS reverse link frequency below 1149 MHz. Reducing this frequency by 2 MHz (i.e. to 1147 MHz) will provide the additional 11 dB of attenuation required.

- Reducing the airborne UMTS Tx power. It should be noted that the peak power of 33 dBm is expected only in exceptional circumstances, at the edge of coverage.

As a conclusion, onboard GNSS receiver may be desensitised by an on-board UMTS transmitter in some exceptional scenarios, i.e. when aircraft carrying the UMTS transponder is at the edge of coverage. A change in UMTS reverse link carrier frequency may be considered to address this interference scenario.

### 4.7.2 Airborne UMTS Tx and GNSS Rx

This interference scenario is addressing interference into a GNSS receiver coming from a UMTS transmitter placed on a different aircraft. The interference scenario is shown in Figure 19.

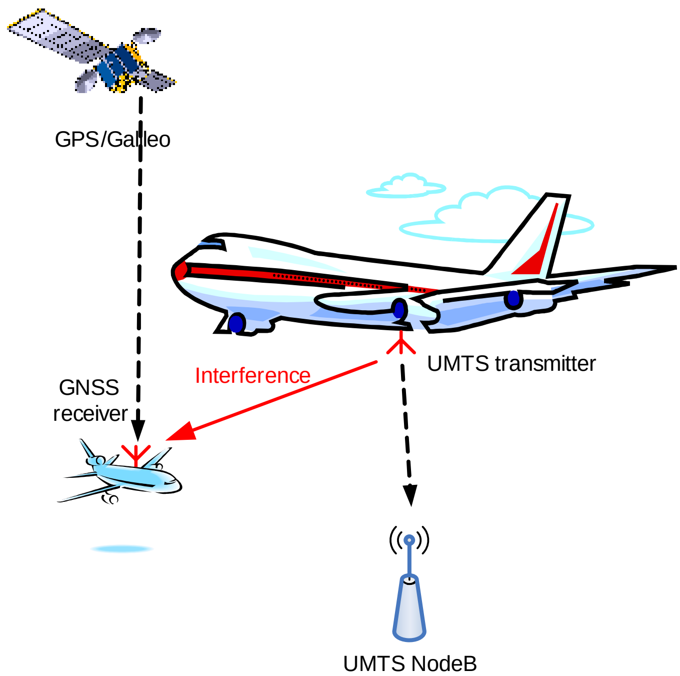


**Figure 19: Airborne UMTS transmitter interfering with a GNSS receiver**

This interference scenario is addressed in Table 7. It can be seen from the table that the path loss experienced on the 1000 ft separation between an aircraft equipped with the interfering UMTS transmitter and the aircraft with an interfered GNSS receiver is sufficient to provide the required protection to GNSS service from UMTS transmissions. It follows therefore that this interference scenario is not an issue.

## 4.8 SCENARIO 6: AIRBORNE UMTS TX TO AN AIRBORNE DME RX

It is shown in Section 4.3 that airborne UMTS transmitter into a collocated DME receiver scenario is a significant problem. This indicates that the scenario where UMTS and DME are not located on the same platform should also be investigated.

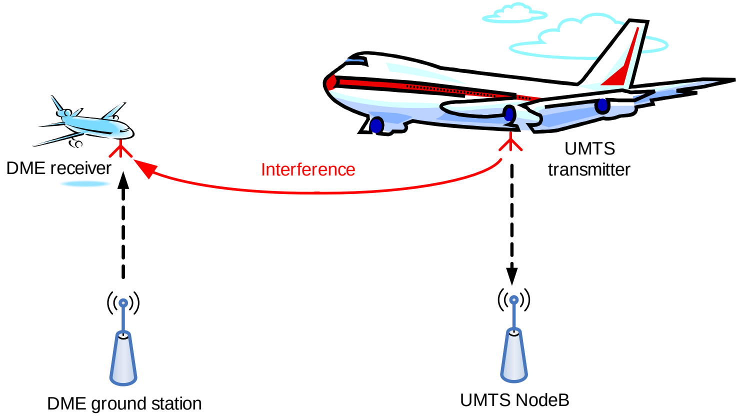


**Figure 20: Airborne UMTS transmitter interfering with an airborne DME receiver**

Frequency allocation, ACLR and ACS masks for this scenario are given in Figure 8 and Figure 9. The interference link budget is similar to the one given in Table 1 and is given in Table 8.

| Parameters | Units | In Rx band (ACL) | In Tx band (ACS) | Co-channel interference |
|---|---|---|---|---|
| | | | | |
| **Transmitter (UMTS)** | | | | |
| Tx and Rx frequencies | MHz | 1157.0 | 1149.0 | 1149.0 |
| Frequency offset (abs) | MHz | 8.0 | 8.0 | N/A |
| Transmit power (airborne) | dBm | 33.0 | 33.0 | 33.0 |
| Transmit bandwidth | MHz | 3.8 | 3.8 | 3.8 |
| Duplexer attenuation at 1157 MHz | dB | 30.3 | | |
| Out-of-band suppression (NodeB) | dB | 56.0 | N/A | N/A |
| | | | | |
| **Channel** | | | | |
| Transmit antenna gain | dBi | 0.0 | 0.0 | 0.0 |
| Tx-Rx distance | km | 0.3 | 0.3 | 0.3 |
| Free space loss | dB | 83.4 | 83.3 | 83.3 |
| Additional aircraft shadowing | dB | 0.0 | 0.0 | 10.0 |
| Polarisation mismatch loss | dB | 0.0 | 0.0 | 0.0 |
| Receive antenna gain | dBi | 7.0 | 7.0 | 7.0 |
| | | | | |
| **Receiver (DME)** | | | | |
| Receiver bandwidth | MHz | 1.0 | 1.0 | 1.0 |
| Adjacent channel selectivity | dB | N/A | 57.5 | N/A |
| Interference threshold of DME receiver (without margin) | dBm | -99.0 | -99.0 | -99.0 |
| Safety margin | dB | 6.0 | 6.0 | 6.0 |
| other sources | dB | 6.0 | 6.0 | 6.0 |
| | | | | |
| **Interference** | | | | |
| Interference allowed | dBm | -111.0 | -53.5 | -111.0 |
| Receive interference power (NodeB) | dBm | -129.6 | -43.3 | -59.2 |
| Additional suppression required | dB | **-18.6** | **10.2** | **51.8** |
| Distance at which no additional fitering is required | km | **0.0** | **1.0** | **119.0** |

**Table 8: Airborne UMTS UE Tx -> DME Rx interference link budget**

The results presented in Table 8 indicate that the interference scenario where the transmitter and receiver are located on different platforms is less critical than the case of collocated airborne UMTS Tx and DME Rx. Additional filtering required to provide the necessary protection of the DME receiver are less severe. Therefore, the same techniques used to address the problem of collocated units can be used here, such as UMTS transmitter PA linearity and better UMTS transmit filtering.

There is a potential issue of interference into the DME receiver at the UMTS Tx frequency (Table 8, 4th column). It is shown that the interference in this case is approximately 10 dB above the allowed level in the worst case. This amount of suppression will most probably be provided by shadowing by the aircraft body when the two aircraft are 1000 ft away from each other. The distance between the aircraft where interference will fall below the protection margin is 1 km.

The more relaxed interference requirements warrants revisit of the co-channel (i.e. in-band) interference of UMTS transmitters to DME receivers that operate on frequencies close to 1149 MHz. It is shown in Section 4.3 that DME receivers operating on channels near or at 1149 MHz will effectively be blocked by an airborne UMTS transmitter operating in the same band, even in situations where 10 dB of possible additional attenuation due to aircraft shadowing is taken into account. Therefore, DME operating on channels close to the UMTS return link band will have to be re-allocated, as discussed in Section 4.3.

## 4.9 Scenario 7: Ground UMTS Tx to a Ground DME Rx

It is shown in Section 4.6 that UMTS NodeB cannot be collocated with a terrestrial UAT station due to excess interference and blocking it may cause to the UAT receiver. A similar scenario where a UMTS NodeB is co-sited with the DME ground station is investigated here. This interference scenario is illustrated in Figure 21.

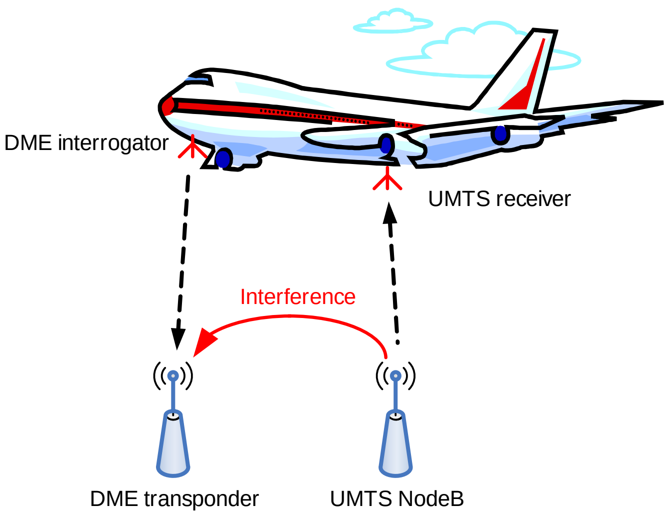


**Figure 21: Ground UMTS transmitter interfering with a ground DME receiver**

The scenario, similar to the one described in Section 4.6, happens when a UMTS NodeB is co-sited with the DME ground station. Interference link budget is given in the following Table.

| Parameters | Units | In Tx band (ACS) | In Rx band (ACL) |
|---|---|---|---|
| | | | |
| **Transmitter (UMTS)** | | | |
| Tx and Rx frequencies | MHz | 968.0 | 1140.0 |
| Frequency offset (abs) | MHz | 172.0 | 172.0 |
| Transmit power (UMTS ground) | dBm | 48.0 | N/A |
| Out-of-Tx band power / 1MHz | dBm | N/A | -100.0 |
| | | | |
| **Channel** | | | |
| Isolation between co-located antennas | dB | 20.0 | 20.0 |
| | | | |
| **Receiver (DME)** | | | |
| DME ground Rx sensitivity | dBm | -95.0 | -95.0 |
| Rx ACS | dB | 75.0 | N/A |
| Safety margin | dB | 6.0 | 6.0 |
| Interference margin to accommodate other sources | dB | 6.0 | 6.0 |
| | | | |
| **Interference** | | | |
| Interference allowed | dBm | -32.0 | -107.0 |
| Co-sited interference power | dBm | 28.0 | -120.0 |
| Additional suppression required | dB | **60.0** | **-13.0** |
| | | | |
| **Blocking** | | | |
| Allowed interference level to avoid blocking | dBm | -16.0 | N/A |
| Co-sited interference power | dBm | 28.0 | N/A |
| Roofing filter required | dB | **44.0** | N/A |
| | | | |
| **Not co-sited** | | | |
| Path loss exponent | | 2.0 | 2.0 |
| UMTS Tx antenna gain | dBi | 7.0 | 7.0 |
| Normalised UMTS antenna gain towards horizon | dB | -2.5 | -2.5 |
| DME Rx antenna gain | dBi | 7.0 | 7.0 |
| Normalised DME antenna gain towards horizon | dB | -2.5 | -2.5 |
| Propagation loss required | dB | 89.0 | 16.0 |
| Distance at which no additional suppression is required | km | **3.9** | **0.0** |

**Table 9: Ground UMTS NodeB Tx -> DME Rx interference link budget**

The assumptions the interference link budget is based on are:

- The lowest DME channel operational in Europe is 16X. The interrogation frequency of that channel (1140 MHz) is chosen as closest to the UMTS forward link frequency. However, the link budget is applicable to other DME channels, as values used in the spreadsheet are for spurious responses of the transmitter and the receiver.

- 1140 MHz is far enough from the UMTS forward link frequency of 968 MHz to be treated as a spurious emission band. The requirements are based on Category B spurious emission limits defined in ITU-R SM.329, [5], defined in Europe.

- Spurious response of the DME receiver in 960–1215 MHz band is based on ICAO Annex 10 V1, [14], Section 3.5.4.2.6.5.

- Normalised antenna gain towards horizon (0 deg elevation) is based on normalised antenna patterns from DME ground stations in Europe, given in UAT implementation manual, [19], Appendix C, Figure C-2 and Table C-1.

- Allowed signal levels to avoid blocking are based on the results presented in Section 5.1.

The interference link budget in Table 9 shows that the interference into a DME receiver from a co-sited UMTS NodeB is very strong. The additional suppression required is of the order of 60 dB, which is hard to achieve through improved filtering only.

Blocking analysis shows that the DME receiver on the ground will be desensitised by the strong UMTS transmissions unless additional means of interference suppression are being used. Again, additional suppression of the order of 44 dB needs to be achieved.

The possible way to achieve the needed additional interference suppression is expected to be a combination of spatial separation, additional filtering and antenna nulling, as described in Section 4.6. The link budget in Table 9 shows that if the distance between the interfering and the interfered system is to be used as only means of interference suppression, the UMTS NodeB and DME ground station would have to be at least 3.9 km apart.

It is also worth noting that this interference scenario is only important if DME receiver has spurious response that falls into the UMTS transmit band, which is not expected to be commonly the case.

## 4.10 SCENARIO 8: AIRBORNE JTIDS/MIDS TX TO AN AIRBORNE UMTS RX

Airborne UMTS receiver can be interfered by an airborne JTIDS/MIDS transmitter on a nearby military aircraft. This interference scenario is shown in Figure 22.

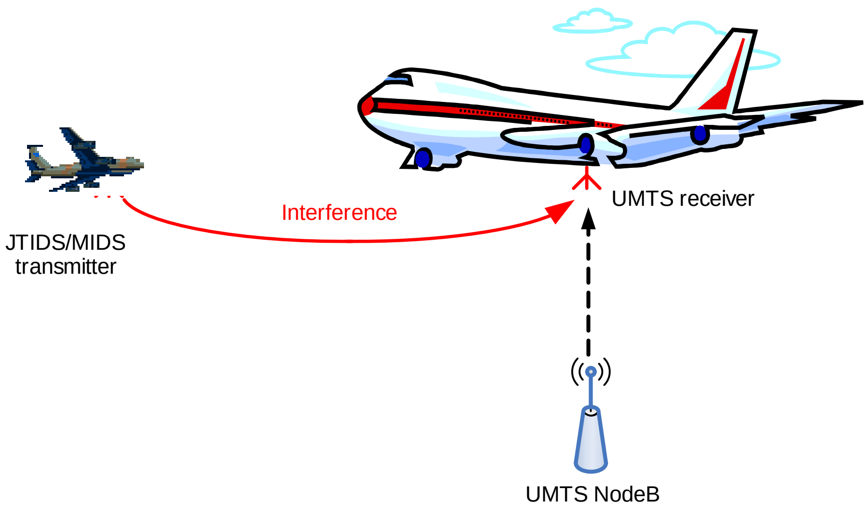


**Figure 22: Airborne JTIDS/MIDS transmitter interfering with an airborne UMTS receiver**

JTIDS/MIDS, or Link-16, is a tactical data link used by US DoD and NATO. It operates on a TDMA basis and frequency hopping (FH) between 51 carrier frequencies in the 960-1215 MHz band. The carriers are spaced by 3 MHz, and there are guard band around 1030 and 1090 MHz introduced for protection of SSR service.

### 4.10.1 OUT-OF-BAND INTERFERENCE

UMTS Rx ACS and JTIDS/MIDS Tx ACLR are shown in Figure 9.

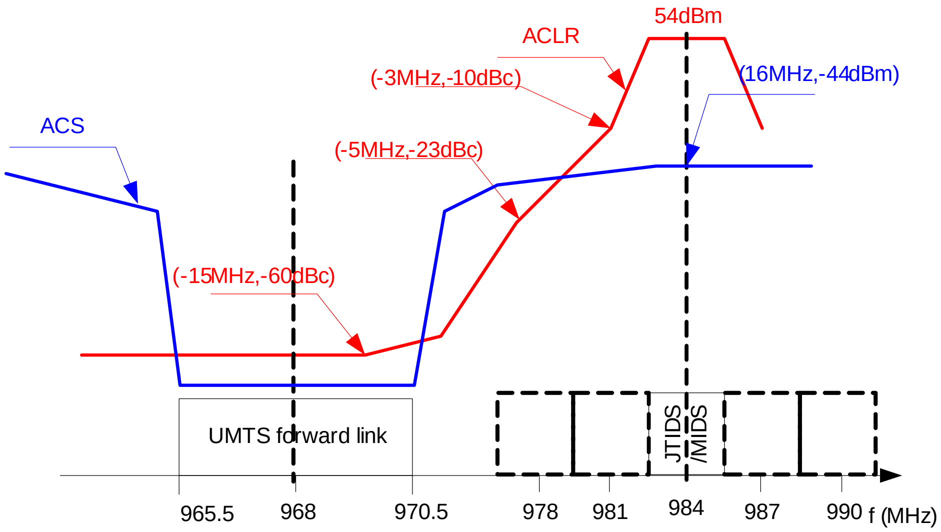


**Figure 23: UAT Tx ACLR and UMTS UE Rx ACS**

The interference power in the UMTS Rx band and the JTIDS/MIDS Tx band are calculated in the last three columns of the link budget in Table 10. Two JTIDS/MIDS channel frequencies are analysed in the Table. One is a co-channel interferer placed at 969 MHz. The other is an adjacent-band interferer placed at 984 MHz, giving a 15 MHz separation between the UMTS and JTIDS/MIDS carriers.

The values the interference link budget is based on are taken from [20], and are listed in Appendix A.6. The assumption that the effective JTIDS/MIDS bandwidth is 3 MHz is used to calculate adjacent channel leakage PSD.

| Parameters | Units | In band (Co-channel) | In Rx band (ACL) | In Tx band (ACS) |
|---|---|---|---|---|
| | | | | |
| **Transmitter (JTIDS/MIDS)** | | | | |
| Tx and Rx frequencies | MHz | 969.0 | 968.0 | 984.0 |
| Frequency offset (abs) | MHz | 1.0 | 16.0 | 16.0 |
| Transmit power | dBm | 53.0 | 53.0 | 53.0 |
| Duplexer attenuation at 984 MHz | dB | | | 70.0 |
| Signal bandwidth | MHz | 3.0 | 3.0 | 3.0 |
| Transmit PSD | dBm/MHz | 48.2 | 48.2 | N/A |
| Tx antenna gain | dBi | 7.0 | 7.0 | 7.0 |
| Out-of-Tx band suppression | dBc | 0.0 | 60.0 | N/A |
| | | | | |
| **Channel** | | | | |
| Tx-Rx distance | km | 0.3 | 0.3 | 0.3 |
| Free space loss | dB | 81.8 | 81.8 | 81.8 |
| Polarisation mismatch loss | dB | 0.0 | 0.0 | 0.0 |
| Receive antenna gain | dBi | 0.0 | 0.0 | 0.0 |
| | | | | |
| **Receiver (UMTS)** | | | | |
| Interference threshold of UMTS receiver (without margin) | dBm/MHz | -108.0 | -108.0 | -44.0 |
| Safety margin | dB | 6.0 | 6.0 | 6.0 |
| other sources | dB | 6.0 | 6.0 | 6.0 |
| | | | | |
| **Interference** | | | | |
| Interference allowed | dBm/MHz | -120.0 | -120.0 | -56.0 |
| Receive interference peak power | dBm/MHz | -26.6 | -86.6 | -91.8 |
| Additional suppression required | dB | **93.4** | **33.4** | **-35.8** |
| Distance at which no additional suppression is required | km | | **14.2** | **0.0** |

**Table 10: Airborne JTIDS/MIDS Tx -> UMTS UE Rx interference link budget**

It can be seen from the link budget that in-band interference is significantly (93.4 dB) above the allowed threshold. Adjacent band interference in the Rx band is approximately 33 dB above the allowed level. This means that the adjacent band interfering aircraft would have to be at least 14.2 km away for the interference to fall to the allowed level.

The link budget in Table 10 leads to the conclusion that the JTIDS/MIDS interference level to an airborne UMTS in both in-band and adjacent band scenarios is unacceptable. That link budget, however, does not take into account the fact that JTIDS/MIDS interference is pulsed in nature and is utilising fast frequency hopping. Interference derivation based on the Table 10 that considers pulse duration and frequency hopping is given in the following Table.

| Parameters | Units | 969 MHz carrier | 981 MHz carrier | >981 MHz carriers |
|---|---|---|---|---|
| | | | | |
| Receive interference peak power | dBm | -26.6 | -81.6 | -86.6 |
| Transmitter duty cycle | % | 10.6% | 10.6% | 10.6% |
| Carrier duty cycle | % | 2.0% | 2.0% | 96.1% |
| Combined duty cycle | % | 0.2% | 0.2% | 10.2% |
| Mean power | dBm | -53.4 | -108.4 | -96.5 |
| Allowed interf. threshold (w/o margin) | dBm | -108.0 | -108.0 | -108.0 |
| Power over the allowed threshold | dB | **54.6** | **-0.4** | **11.5** |
| Distance at which interf. power will be at the threshold | km | | **0.3** | **1.1** |

**Table 11: JTIDS/MIDS Tx -> UMTS UE Rx pulsed interference link budget**

The link budget in Table 11 is based on the following assumptions:

- JTIDS/MIDS pulse duration is 6.4 μs.
- Maximal allowed activity factor from one aircraft is 198,144 pulses in a 12 s period (TSDF 100/50). This results in the overall duty factor of a single aircraft of 10.6%.
- In the area of several nautical miles surrounding the airborne UMTS receiver, the duty factor of JTIDS/MIDS pulses will be limited to 10.6% (one fully active aircraft).
- JTIDS/MIDS uses frequency hopping. As a result, each individual carrier activity will be 1/51.

The interference power budget given in Table 11 shows that the effects of JTIDS/MIDS interference can be divided into the following cases:

- In-band interference. Carrier at 969 MHz falls into the UMTS receive band. It is characterised by 6.4 μs long pulses with a duty cycle of 0.21% from one source (aircraft).
- Out-of-band interference. Carriers at 972, 975 and 978 MHz fall into this region.
- Carriers at 981 MHz and above. This interference is in the worst case 11.5 dB above the UMTS receiver noise floor. The solution to overcome this interference is to keep the separation distance between the military and the commercial aircraft at 1.1 km minimum.

### 4.10.2 In-Band and Out-of-Band Interference

The lowest JTIDS/MIDS carrier frequency is 969 MHz, so a JTIDS/MIDS transmitter will appear as an in-band interferer at the airborne UMTS receiver input.

The effects of in-band interference are addressed in the third column of the interference link budget given in Table 10. As it can be seen there, the in-band JTIDS/MIDS transmitter will effectively jam any UMTS receiver in a wide area when transmitting at the 969 MHz. It is assumed that the airborne JTIDS/MIDS transmitters in the same operational area (100 nmi) as the civil aircraft will be dealt by receiver blanking, while interferers further away will add to UMTS receiver noise floor.

Addressing the interferers within the JTIDS/MIDS operational area the civil aircraft is in, receiver blanking will cause a brief signal interruption, 6.4 μs long and with the duty cycle of 0.82%. It is assumed that signal protection, i.e. coding and interleaving, is capable of coping with pulse interference of such short duration and low duty cycle. However, the UMTS receiver has to be capable of interference sensing, receiver blanking and fast recovery.

The similar conclusion holds for JTIDS/MIDS carriers that fall on three frequencies that represent JTIDS/MIDS out-of-band region. JTIDS/MIDS transmissions will interfere with UMTS reception. UMTS receiver should cope with these strong interference pulses by receiver blanking. The effect of pulses on these frequencies has to be addressed through computer simulation.

### 4.10.3 ICAO Coexistence Study

In the study of UAT receiver performance in the presence of DME/TACAN, JTIDS/MIDS and self-interference ([19], Appendix D), ICAO has assumed that the JTIDS interference as seen at the UAT victim antenna port will consist of the sum of:

- TSDF 50% at -39 dBm,
- TSDF 50% at -60 dBm, and
- TSDF 300% at -84.5 dBm.

Taking these values as input to the JTIDS/MIDS and UMTS interference scenario and reapplying the methodology used in Table 11 leads to the results presented in Table 12.

| Parameters | Units | 969 MHz carrier @ -39dBm | 969 MHz carrier @ -60dBm | 969 MHz carrier @ -84.5dBm | 972 MHz carrier @ -60Bm | 978 MHz carrier @ -39dBm |
|---|---|---|---|---|---|---|
| | | | | | | |
| Receive interference peak power (after UMTS duplexer) | dBm | -39.0 | -60.0 | -84.5 | -76.5 | -82.0 |
| Transmitter duty cycle | % | 10.6% | 10.6% | 63.4% | 10.6% | 10.6% |
| Carrier duty cycle | % | 2.0% | 2.0% | 2.0% | 2.0% | 2.0% |
| Combined duty cycle | % | 0.2% | 0.2% | 1.2% | 0.2% | 0.2% |
| Mean power | dBm | -65.8 | -86.8 | -103.6 | -103.3 | -108.8 |
| Allowed interf. threshold (w/o margin) | dBm | -108.0 | -108.0 | -108.0 | -108.0 | -108.0 |
| Power over the allowed threshold | dB | **42.2** | **21.2** | **4.4** | **4.7** | **-0.8** |
| Distance at which interf. power will be at the threshold | km | | **3.5** | **0.5** | **0.5** | **0.3** |

**Table 12: JTIDS/MIDS Tx -> UMTS UE Rx pulsed interference budget based on [19]**

Results presented in Table 12 lead to the conclusion that only some combinations of carrier frequency and receive power will overcome the allowed interference threshold. These combinations are shown in Table 13.

| **Power (dBm) and duty cycle (%) vs. carrier frequency (MHz)** | -39dBm, 0.2% | -60dBm, 0.2% | -84.5dBm, 1.2% |
|---|---|---|---|
| 969 MHz | | | |
| 972 MHz | | | |
| 975 MHz | | | |
| >=978 MHz | | | |

**Table 13: Combinations of JTIDS/MIDS hopping frequencies and levels that interfere with airborne UMTS reception**

It can be seen from Table 13 (fields in red) that high and medium power JTIDS/MIDS interferer at 969 and 972 MHz is disruptive to UMTS signal reception. The combined duty cycle of this interference is 0.6%.

Carrier / power combinations shown in yellow in Table 13 refer to interference that is below the noise floor, but above the allowed interference level. The combined duty cycle of this interference is 1.6%.

Green marks the carrier / power level combinations of JTIDS/MIDS interference that are below the set interference threshold.

As a conclusion, it can be said that JTIDS/MIDS interference with power levels consistent to ICAO JTIDS/MIDS and UAT coexistence study ([19], Appendix D) would, in the worst case, cause 2.2% loss of UMTS signal due to airborne receiver blanking. It is expected that this amount of signal loss will have no adverse effect on UTMS system capacity.

### 4.10.4 JTIDS/MIDS Operation Without Frequency Hopping

In the analysis of MIDS to UMTS interference scenario and coexistence, it is assumed that JTIDS/MIDS is employing frequency hopping. The system also has two communication modes (mode 2 and 4) where hopping is not used, and all transmissions are made at 969 MHz. In such operational scenario a JTIDS/MIDS transmitter will appear as an in-band interferer (1 MHz away form the centre frequency) at the UMTS receiver input. The duty cycle of that interferer is 10.6% for TSDF 100/50, as discussed in Section 4.10.2. This interferer is expected to have an impact on UMTS signal reception and system capacity. The exact effect of interference has to be established through computer simulation.

## 4.11 Summary

Summary of interference issues for the eight investigated scenarios is given in Table 14. The table lists individual interference scenarios, together with an assessment of how critical a particular scenario is, what effects the interference will have on the interfered receiver, and what measures should be considered in order to protect the interfered receiver.

| Scen. | Interf. source (Tx) | Interfered system (Rx) | Criticality | Key issues | Solutions |
|---|---|---|---|---|---|
| 1 | Airborne UMTS | Onboard DME | High | In-band jamming of DME Rx; DME Rx blocking. | Freq. relocation of 1% of DME channels; custom duplexer; UMTS Tx blanking |
| 2 | Airborne UAT | Airborne UMTS | Low | UMTS Rx jammed by a low duty cycle pulsed spurious interference | Custom duplexer; Rx blanking; sync and decoding resilient to pulses; interference cancellation |
| 3 | Ground UAT | Airborne UMTS | Low | Low duty cycle interference when aircraft close to a ground UAT Tx | Custom duplexer; spreading gain; UMTS receiver resilient to pulsed interference |
| 4 | Ground UMTS | Ground UAT | Moderate | Rx desensitisation | Tx-Rx antenna separation; improved filtering; antenna nulling; interference cancellation |
| 5 | Airborne UMTS | Airborne GNSS | Moderate | Rx desensitisation | UMTS reverse link frequency moved at or below 1147 MHz; Tx power reduction. |
| 6 | Airborne UMTS | Airborne DME | Low | Rx desensitisation | Freq. relocation of 1% of DME channels; custom cavity Tx filter. |
| 7 | Ground UMTS | Ground DME | Low | Rx desensitisation caused by receive spurs | Tx-Rx antenna separation; improved filtering; antenna nulling; interference cancellation |
| 8 | Airborne JTIDS/MIDS | Airborne UMTS | Moderate | In-band blocking; adjacent band desensitisation | Spreading gain; receiver blanking; sync and decoding resilient to pulsed interference. Co-existence is a problem when JTIDS/MIDS does not use frequency hopping (modes 2 and 4). |
| N/A | Ground GSM BS | Airborne UMTS | Low | Receiver desensitisation | Guard band, custom duplexer |

**Table 14: Summary of interference issues**

# 5 OTHER EFFECTS OF INTERFERENCE

Beside the receiver desensitisation that strong in-band, adjacent and out-of-band and spurious interference may cause, which is analysed in Section 4, there are other effects that very strong out-of-band interference may have on the interfered receiver. Some of these effects are:

- Receiver blocking;
- Intermodulation products generated in transmitters and receivers;
- Reciprocal mixing;
- Power amplifier noise.

The amount in which these effects may influence the signal reception depend on numerous parameters of the interfered receiver, such as the receiver architecture, front-end filtering, LNA and mixer linearity, etc. In general, these effects should be minimised as part of the receiver design, e.g. by selecting appropriate RF stage filters, sufficiently linear front end stages and by careful selection of intermediate frequency. A detailed analysis of these "secondary" types of interference effects is seen as out of scope of this report; where appropriate, these effects have already been discussed in Section 4. However, for the sake of completeness, a general discussion of these additional effects of interference is presented here.

## 5.1 Receiver Blocking

Very strong out-of-band interferer can desensitise, or even block the receiver. A generic interference level plan addressing the level of interference that might cause blocking is given in Table 15.

| Parameters | Units | Tx noise |
|---|---|---|
| | | |
| **Transmitter** | | |
| Power | dBm | 58.0 |
| | | |
| **Receiver** | | |
| Receiver desensitisation threshold | dBm | -10.0 |
| Safety margin | dB | 6.0 |
| Allowed out-of-band interference at the receiver input | dBm | -16.0 |
| Tx + Rx antenna gains | dBi | 7.0 |
| | | |
| **Blocking** | | |
| Blocker suppression required | dB | 88.0 |
| Carrier frequency | MHz | 1000.0 |
| Rx roofing filter out-of-band suppression | dB | 30.0 |
| Path length required | m | 19.0 |

**Table 15: Receiver blocking link budget**

The assumptions made in derivation of the level plan in Table 15 were:

- Receiver desensitisation threshold (including LNA and mixer 1dBCP) is -10 dBm.

- With a safety margin and the receiver back-off from the saturation point, allowed blocker at the receiver input is set at -16 dB.

In the case of a blocker with 58 dBm of peak power and with 7 dBi of transmit and receive antenna gains, the blocker would have to be suppressed by 88 dB. This suppression should be achieved by a combination of Rx stage filtering (some of it placed before the LNA) and propagation loss between the interferer's and the receive antennas. As an example, assuming that the roofing filter provides 30 dB of out-of-band suppression, required propagation loss is achieved at approximately 19 metres of distance at 1 GHz frequency.

As a conclusion, receiver blocking is only an issue when a transmitter and receiver are co-located. Therefore, blocking is addressed in interference scenarios in Section 4 that included co-siting of the transmitter and the receiver.

## 5.2 Intermodulation Products

When two strong signals are present at the input of a non-linear receiver, they can combine to create intermodulation products. Since interfering signals have to be strong enough to generate intermodulation products, two interfering transmitters and the interfered receiver have to be placed close to each other, e.g. they can be co-sited on the same aircraft.

There is a similar mechanism of IM product generation that involves transmitters. When two transmitters are co-sited, strong signals generated by one transmitter can enter the other transmitter's non-linear power amplifier and create harmonics that can fall into the neighbouring receiver's receive band.

The question of receive intermodulation products has to be addressed by appropriate receiver design, in particular by providing sufficient front end filtering and linearity in the receiver. Also, the power and frequency of intermodulation products generated in a transmitter depend on the transmit filter selectivity, linearity of the amplifiers and other effects. The issues of receiver and transmitter design are seen as out of scope of this report. However, some initial comments appropriate to the nature of interfering systems and their carrier frequencies can be made.

There are two intermodulation scenarios that may affect transmitters and receivers onboard an aircraft:

- 3$^{rd}$ order IM products (IP3), and

- 2$^{nd}$ Order IM products (IP2).

These two scenarios are commented in the following text in more detail.

### 5.2.1 3$^{RD}$ Order Products

In the IP3 scenario, strong signals on frequencies $f_1$ and $f_2$ combine to create products at frequencies $2f_1-f_2$ and $2f_2-f_1$. One of the frequencies, $f_1$ or $f_2$, is the onboard UMTS transmitter at 1149 MHz. Both the other frequency and the intermodulation product frequency have to fall into the airborne ARNS band 960-1215 MHz to become a possible source of intermodulation interference. The possible interference scenarios are:

- UMTS Tx combining with DME Tx generating IP3 products in the GNSS receiver: $f_1$ = 1149 MHz, $f_2$ = 1157…1168 MHz; $2f_2$-$f_1$ = 1165…1187 MHz. Onboard DME interrogator is a pulsed interference, and GNSS receiver can tolerate pulsed interference with up to 10% of duty cycle; this is not seen as a potential interference problem.

- UMTS Tx combining with DME Tx generating IP3 products in the DME receive band: it is assumed that onboard DME reception is suppressed during the DME transmission, so this is not seen as a problem.

- UMTS Tx combining with SSR Tx generating IP3 products in the SSR receive band: $f_1$ = 1090 MHz, $f_2$ = 1149 MHz, $2f_1$-$f_2$ = 1031 MHz. It is assumed that onboard SSR reception will be suppressed during SSR transmission, so this is not a problem.

- UMTS Tx combining with DME Tx generating IP3 products in the UAT receive band: $f_1$ = 1063 or 1064 MHz, $f_2$ = 1149 MHz, $2f_1$-$f_2$ = 977 or 979 MHz. Not an issue because interference falls 1 MHz away from the UAT carrier, where UAT receiver will provide some suppression.

As an illustration of levels of IP3 that might be experienced in a co-sited airborne scenario, the following interference link budget is developed.

| Parameters | Units | Tx noise |
|---|---|---|
| | | |
| **Transmitter** | | |
| Power | dBm | 33.0 |
| | | |
| **Receiver** | | |
| Receiver NF | dB | 7.0 |
| kT | dBm/Hz | -174.0 |
| Receiver noise PSD | dBm/MHz | -107.0 |
| Safety margin | dB | 6.0 |
| Interference margin to accommodate other sources | dB | 6.0 |
| Receiver BW | MHz | 1.0 |
| Allowed IM products power | dBm | -119.0 |
| IIP3 | dBm | 0.0 |
| Allowed interference power at the Rx input | dBm | -39.7 |
| | | |
| **IP3** | | |
| Interference suppression required | dB | 72.7 |
| Isolation between Tx and Rx antennas | dB | 35.0 |
| Additional filtering required | dB | 37.7 |
| | | |
| Carrier frequency | MHz | 1000.0 |
| Tx + Rx antenna gains | dBi | 7.0 |
| Rx roofing filter out-of-band suppression | dB | 30.0 |
| Path length required | m | 7.3 |

**Table 16: IP3 link budget**

The link budget in Table 16 shows that IP3 products can only be an issue when ACS of the interfered receiver is less than 38 dB. Combination of sufficient roofing filtering and pulsed nature of the interference creating intermodulation products indicates that IP3 is not an issue in collocating UMTS airborne equipment with the existing ARNS.

### 5.2.2 2ND ORDER PRODUCTS

In the IP2 scenario, strong signals on frequencies $f_1$ and $f_2$ combine to create products at frequencies $f_1$-±$f_2$. At least one of the signals creating intermodulation products are far out of band of the interfered system; therefore it is expected that roofing filter of the interfered receiver will suppress the products sufficiently so IP2 will not be an issue in practice.

The reason why this scenario is nevertheless mentioned here is the fact that combination of the UMTS and ARNS signals in the 960-1215 MHz band can create 2nd order products in the VHF aeronautical band.

## 5.3 RECIPROCAL MIXING

Reciprocal mixing is an effect in superhet receivers when a strong adjacent band interferer is present at the mixer (i.e. down-converter) input. Although this strong adjacent band interferer will be suppressed by IF filters after down-conversion, it may combine with the LO phase noise to generate noise in the IF band. This noise is added to the thermal noise, thus desensitising the receiver.

Reciprocal mixing should be addressed by adequate measures in the receiver design. In particular, adequate selectivity of the RF stage and LO with low phase noise has to be selected. To help assess the potential severity of reciprocal mixing in the analysed scenarios, a preliminary link budget is given in Table 17.

| Parameters | Units | Tx noise |
|---|---|---|
| | | |
| **Transmitter** | | |
| Power | dBm | 33.0 |
| | | |
| **Receiver** | | |
| Receiver NF | dB | 7.0 |
| kT | dBm/Hz | -174.0 |
| Receiver noise PSD | dBm/MHz | -107.0 |
| Safety margin | dB | 6.0 |
| Interference margin to accommodate other sources | dB | 6.0 |
| Allowed reciprocal mixing noise PSD | dBm/MHz | -119.0 |
| Mixer noise PSD | dBc/MHz | -85.0 |
| Allowed interference power at the Rx input | dBm | -34.0 |
| | | |
| **Mixer noise** | | |
| Interference suppression required | dB | 67.0 |
| Isolation between Tx and Rx antennas | dB | 35.0 |
| Out-of-band suppression required | dB | 32.0 |
| | | |
| Carrier frequency | MHz | 1000.0 |
| Tx + Rx antenna gains | dBi | 7.0 |
| Rx roofing filter out-of-band suppression | dB | 30.0 |
| Path length required | m | 3.8 |

**Table 17: Receiver reciprocal mixing link budget**

The interference link budget is based on the assumption that the reciprocal mixing noise is -145 dBm/Hz. This is within the range of values for COTS mixers used in base stations and handsets.

The results of link budget given in Table 17 show that, for typical power of the interferer, reciprocal mixing is only an issue with collocated transmitters and receivers. In that case, required out-of band suppression is of the order of 30 to 35 dB, which can be easily achieved by RF stage filtering.

## 5.4 Power Amplifier Noise

The power amplifier (PA) in the transmitter will generate wideband thermal noise, and some of that noise will fall in the receive band of the collocated receiver. Depending on the PA noise figure, gain, and isolation between the transmitter and the receiver, this noise can add to the thermal noise floor of the receiver.

The analysis of effects of PA noise on the collocated receiver is presented in the following Table as an interference link budget.

| Parameters | Units | Tx noise |
|---|---|---|
| | | |
| **Transmitter** | | |
| PA noise figure | dB | 7.0 |
| Driver stage noise figure | dB | 10.0 |
| PA gain | dB | 40.0 |
| kT | dBm/Hz | -174.0 |
| Tx noise PSD | dBm/MHz | -57.0 |
| | | |
| **Receiver** | | |
| Receiver NF | dB | 7.0 |
| Receiver noise PSD | dBm/MHz | -107.0 |
| Safety margin | dB | 6.0 |
| Interference margin to accommodate other sources | dB | 6.0 |
| Allowed PA noise PSD | dBm/MHz | -119.0 |
| | | |
| **Noise** | | |
| Noise suppression required | dB | 62.0 |
| Carrier frequency | MHz | 1000.0 |
| Tx + Rx antenna gains | dBi | 7.0 |
| Path length required | m | 67.3 |

**Table 18: PA Tx noise link budget**

The link budget in Table 18 is based on typical values of gain and NF of PA used in mobile communications in the same frequency band.

It can be seen from Table 18 that, for parameters assumed selected in Section A.1, PA noise is 50dB above the receiver thermal noise floor, and 62dB above the level that is includes protection margins. This amount of PA noise suppression may be provided by a combination of Tx filtering and isolation between the transmit and receive antennas. For example, assuming that combined gain of transmit and receive antennas is 7dBi, 62+7dB of free space loss is achieved at 67 metres of distance. Therefore, PA noise is seen as a potential issue only in situations where co-sited transmitter and receiver share the same antenna.

# 6 CONCLUSIONS

Roke Manor Research Ltd. (Roke) has been tasked by Eurocontrol to perform a study of interference issues between a 3G (UMTS) air-to-ground communication system and other aeronautical communication and navigation systems that would operate in the L-band, [1]. This report contains the output of the activities undertaken during the study.

The results presented here refer to the worst case scenarios, with maximal transmit powers, an aircraft located at the edge of UMTS cell coverage, peak transmit power of pulsed transmitters etc. The study has also considered analogue receiver stages; possible effects of digital processing, FEC, etc on interference suppression and data recovery in a pulsed environment has not been taken into account.

The conclusions derived during the study are:

- The UMTS carrier frequencies that provide the best allocation of guard bands are 968 MHz in the forward link (ground to air) and 1149 MHz in the reverse link (air to ground).

- Due to the spread-spectrum transmission in UMTS FDD, the effect of the UMTS transmitter on other systems is equivalent to an increase in the noise floor.

- Due to the pulsed nature of transmissions of other L-band systems, the effect of ARNS systems on UMTS is equivalent to pulsed jamming.

- Coexistence of UMTS with the ARNS (e.g. DME, UAT) and GNSS (e.g. GPS) systems operating in the L band on the same platform requires additional cross-system interference suppression. Signal acquisition and AGC techniques robust to pulsed jamming should also be implemented in the UMTS receiver.

- In most cases, effects of interference may be reduced with a custom duplexer in UMTS equipment.

- Additional suppression of interference generated by an UMTS airborne transmitter may be achieved by implementing better (i.e. more linear) up-converter and power amplifier stages in the UMTS transmitter.

- Also, careful selection of the UMTS antenna location on the aircraft fuselage may help to reduce the effects of interference in some scenarios.

- Frequency reallocation of DME stations operating on channels close to 1150 MHz is necessary in order to avoid excess interference caused by UMTS airborne transmission into the onboard DME receiver. The percentage of DME stations in Europe that need to be refarmed is estimated to be around 1%.

- Interference in the GNSS (i.e. GPS and Galileo) band caused by a co-sited UMTS transmitter is below the GNSS noise floor, but it can overcome the allowed interference level when safety margins are included in some extreme scenarios (e.g. at the edge of UMTS coverage). This interference may be reduced if reverse link is set at 1147 MHz but at the expense of refarming a larger number of DME stations.

- Interference from airborne UAT may cause loss of UMTS packets in forward link and can affect quality of service. In the worst case, one UMTS frame per second can be lost. The quantitative estimation of block error rate in UMTS would require computer simulation.

- Initial investigation of JTIDS/MIDS interference effects on airborne UMTS reception show that the receiver can be desensitised during JTIDS/MIDS dwells on the 969 MHz carrier or when the military aircraft is in close proximity to a civil aircraft. Quantification of the effects of this fast hopping interference on UMTS needs to be performed through computer simulation.

- The UMTS receiver has to be protected from strong pulsed interference with receiver blanking. The UMTS receiver also has to be capable of fast recovery from moderately strong interference pulses.

- There is a potential loss in forward link capacity and coverage in UMTS when the aircraft is in proximity to a terrestrial UAT transmitter. Initial analysis shows that one UMTS frame per second may be lost. Accurate estimation of the effect of interference has to be established through computer simulation.

- On the ground, collocation of a UMTS NodeB with other ARNS terrestrial equipment is impractical.

- The required protection zone surrounding UMTS NodeB may be reduced using techniques such as custom duplexer filters in UMTS and antenna nulling techniques.

- Possible synchronisation of UMTS transmissions with other airborne equipment is seen as not practical due to the continuous transmission nature of the UMTS FDD. Modification of the standard into slotted (TDD-like) mode would require significant departure from the current standard.

- UMTS transmission blanking is a potentially attractive technique of protection of co-sited ARNS equipment on the same aircraft. The optimal trade-off between the achieved protection level and loss of UMTS reverse link performance needs to be established through computer simulation.

As a conclusion, the operation of the new UMTS air to ground communication link in the L-band may be possible if protection measures listed above are introduced. The issue of in-band interference into the co-sited airborne DME receivers remains a concern, as airborne UMTS transmissions can potentially desensitise the co-sited DME receiver front end. However, it is expected that this conclusion would apply to any continuously transmitting communication system with similar transmit power and bandwidth that operates in the DME band.

UMTS transmitter and receiver blanking are seen as potentially promising techniques to overcome the problem of coexistence with DME. The effects of this scheme on UMTS system capacity requires further investigation.

# 7 REFERENCES


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# 8 GLOSSARY

| | |
|---|---|
| ACL | Adjacent Channel Leakage |
| ACLR | Adjacent Channel Leakage Ratio |
| ACS | Adjacent Channel Selectivity |
| ADS-B | Automatic Dependant Surveillance-Broadcast |
| ARNS | Aeronautical Radio Navigation Service |
| AWGN | Additive White Gaussian Noise |
| BLER | Block Error Rate |
| BS | Base Station |
| COTS | Commercial Off-The-Shelf |
| CW | Continuous Wave |
| DME | Distance Measuring Equipment |
| DoD | Department of Defence |
| FH | Frequency Hopping |
| FIS-B | Flight Information Services – Broadcast |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| GSM | Global System for Mobile Communications |
| IF | Intermediate Frequency |
| IIP3 | Input Intercept Point for 3$^{rd}$ order intermodulation |
| IP2 | 2$^{nd}$ order intermodulation products |
| IP3 | 3$^{rd}$ order intermodulation products |
| IM | Intermodulation |
| ITU | International Telecommunications Union |
| JTIDS | Joint Tactical Information Distribution System |
| LNA | Low Noise Amplifier |

| | |
|---|---|
| LO | Local Oscillator |
| MIDS | Multifunction Information Distribution System |
| NATO | North Atlantic Treaty Organisation |
| NMI | Nautical Mile |
| PA | Power Amplifier |
| PSD | Power Spectral Density |
| RNSS | Radionavigation Satellite Service |
| SCH | Synchronisation Channel |
| SSR | Secondary Surveillance Radar |
| TACAN | Tactical Air Navigation |
| TDMA | Time Division Multiple Access |
| TIS-B | Traffic Information Service Broadcast |
| TSDF | Time Slot Duty Factor (in JTIDS/MIDS) |
| UAT | Universal Access Transceiver |
| UE | User Equipment |
| UMTS | Universal Mobile Telecommunications System |
| WRC | World Radio Congress |

# APPENDIX A SYSTEM PARAMETERS

This section lists values of parameters for five systems (UMTS, DME, UAT, GNSS and MIDS) that have been identified for this study. This section is based on the intermediate Working Paper, [2], with some of the parameters added and values updated. The five systems will jointly cover all eight interference scenarios as listed in Section 2.

Section A.1 provides a list of general parameters applicable to all eight scenarios whilst Sections A.2-A.6 list parameters for each of the five systems.

## A.1 GENERAL PARAMETERS

This section provides a list of general parameters that are applicable for all scenarios to be investigated.

| Parameters | Units | Value | Ref | Notes |
|---|---|---|---|---|
| Isolation between co-sited antennas on the same side of the aircraft | dB | 35 | | Both on top or at the bottom of the aircraft, typical case. |
| Isolation between co-sited antennas on the opposite aircraft sides | dB | 45 | | One antenna placed at the top, another at the bottom, so there is the airframe between them |
| Isolation between co-sited antennas on the ground | dB | 20 | | Values between 20 and 40dB typically experienced |
| Propagation loss | | | | Free space assumed in all cases as a worst-case (minimal loss) scenario where antennas are not co-sited. |
| Polarisation mismatch loss | dB | 3 | | E.g. between vertical and right-hand circular polarisation |
| Receiver input 1dB compression point (1dBCP) | dBm | -10 | | Includes effects of LNA and mixer saturation and intermediate RF filter stage. |
| Receiver 3$^{rd}$ order input intercept point (IIP3) | dBm | 0 | | 1dBCP+10dB |
| Safety margin | dB | 6 | [6] | Additional S/I margin for safety-critical systems. Includes a back-off margin |
| Apportionment of interference to all the interference sources | dB | 6 | [6] | Additional S/I margin to accommodate other sources of interference |
| UMTS power amplifier noise figure | dB | 7 | | |
| Power amplifier driver stage noise figure | dB | 10 | | |
| UMTS PA gain | dB | 40 | | |
| Receiver noise figure | dB | 7 | | |

**Table 19: General parameters**

## A.2 UMTS

Table 20 lists UMTS system parameters. UMTS FDD Release 6 standards and, where deemed appropriate, any relevant documents from previous work carried out for Eurocontrol were used to source the parameters required for the 3G communication system. The UMTS parameters listed cover:

Airborne UMTS transmitter: *Scenarios 1-3*

Ground UMTS transmitter: *Scenarios 4-5*

Airborne UMTS receiver: *Scenarios 6-8*

| Parameters | Units | Value | Ref | Notes |
|---|---|---|---|---|
| Airborne transmit power | dBm | 33 | [10], Table 6.1 | Nominal maximum output power i.e. the output power of the UE |
| Ground station transmit power | dBm | 48 | [4], Table 11.2 | Recommended value for wide area BS |
| Reverse link frequency band | MHz | 1145 - 1156 | [1], p11 | Air to ground |
| Forward link frequency band | MHz | 960-977 | [1], p11 | Ground to air |
| Airborne antenna gain | dBi | 0 | | |
| Ground antenna gain | dBi | 7 | | |
| Antenna polarisation | n/a | Vertical | | |
| Allowed interference threshold *(without margin)* | dBm | -108 for in-band<br>-56 for ±10MHz<br>-44 for ≤-15MHz and ≥15MHz | [10], Table 7.6 | |

**Table 20: UMTS system parameters**

## A.3 GNSS

Table 21 lists GNSS system parameters used in this study. The parameters listed cover:

Airborne GNSS receiver: *Scenario 3*

Parameters for airborne GNSS receivers, namely GPS L5 and Galileo E5a, are taken from [18], [21], and [22]. Galileo E5b signal will not be considered as its carrier frequency is further away from the 1150 MHz band that is planned for the UMTS system.

| Parameters | Units | Value | Ref | Notes |
|---|---|---|---|---|
| Airborne receive frequency | MHz | 1176.45 | [21], Section 3.3.1.1; [22] Table 1 | GPS L5 and Galileo E5a. |
| Receive signal bandwidth | MHz | 24 | [21], Sect 3.1.1.1; [22], Sect 5.1 | |
| Receive antenna gain | dBi | 7 | [23] | This is max. gain in upper hemisphere when the minimum antenna is at 5° elevation towards satellite. |
| Antenna polarisation | n/a | RHCP | [21], Sect 3.3.1.9; [22], Sect 5.2 Table 2 | |
| Allowed interference threshold *(without margin)* | dBm | -90 | [18], Fig. 3 | |
| Adjacent channel selectivity | dB | 78.7 | [18] Fig. 3 | |

**Table 21: GNSS system parameters**

## A.4 DME

Table 22 lists DME system parameters used in this study. The parameters listed cover:

Airborne DME receiver: *Scenario 1*

Ground DME receiver: *Scenario 5*

| Parameters | Units | Value | Ref | Notes |
|---|---|---|---|---|
| Airborne antenna gain (max) | dBi | 7 | | |
| Airborne antenna gain (0deg elevation) | dBi | -1.5 | | |
| Antenna polarisation | n/a | Vertical | | |
| Allowed interference threshold *(without margin)* | dBm | -99 for airborne receiver | [18], Sect 2.2.1, Table 1 | |
| | | -95 for ground receiver | [24], Table 1, p3 | Value quoted is -125dBW for TACAN/DME transponder |
| Ground and airborne receiver adjacent channel selectivity | dB | 60 | [14], Sect. 3.5.4.2.6.3 | For more than 10 MHz away |

**Table 22: DME system parameters**

## A.5 UAT

Table 23 lists UAT system parameters used in this study. The parameters listed cover:

Ground UAT transmitter: *Scenario 7*

Ground UAT receiver: *Scenario 4*

Airborne UAT transmitter: *Scenario 6*

| Parameters | Units | Value | Ref | Notes |
|---|---|---|---|---|
| Transmit power | dBm | 54 | [17] Sect. 12.1.2.3.2 | Assumes a 4 dBi antenna |
| Transmit EIRP | dBm | 58 | [17], Sect. 12.1.2.3.2 | Maximum transmit power for high aircrafts shall not exceed this value |
| Transmit and receive frequency | MHz | 978 | [17], Sect. 12.1.2.1 | |
| Receive signal bandwidth | MHz | 1.3 | [19], Sect. B.3.1 | Values of 0.8 and 1.2 MHz are also suggested |
| Airborne pulse duration | µs | 265<br>403.2 | [17], Sect. 8.2 | Short and long ADS-B |
| Receiver antenna gain | dBi | 7 | | |
| Antenna polarisation | n/a | Vertical | [17], Sect. 12.1.2.5 | |
| Allowed interference threshold *(without margin)* | dBm | -98 | [19], Sect. 2.5 | |
| Adjacent channel selectivity | dBc | 10 for -1.0MHz | [17], Sect. 12.3.2.2, Table 3 | |
| | | 15 for +1.0MHz | | |
| | | 50 for ±2.0MHz | | |
| | | 60 for ±10MHz | | |

**Table 23: UAT system parameters**

## A.6 JTIDS/MIDS

Table 24 lists MIDS system parameters used in this study. The parameters listed cover:

Airborne MIDS transmitter: *Scenario 8*

| Parameters | Units | Value | Ref | Notes |
|---|---|---|---|---|
| Transmit frequency | MHz | 969–1008<br>1053-1065<br>1113-1206 | [25] | Pseudorandom hopping, 51 carrier frequencies, 3 MHz spacing |
| Dwell period | μs | 13 | [25] | Time spent on one frequency |
| Airborne transmit power | dBm | 53 | [25] | Maximum power measured at the terminal output |
| Airborne transmit antenna gain | dBi | 7 | [25] | This value is for a large aircraft.<br>NOTE: Ground Station = 9 dBi and Fighter Aircraft = 5 dBi |
| Antenna polarisation | n/a | Vertical | [25] | |

**Table 24: MIDS system parameters**

## APPENDIX B TERRESTRIAL GSM BS TO AN AIRBORNE UMTS RX INTERFERENCE

In this interference scenario the signal generated by a terrestrial GSM base station transmitter is interfering with UMTS signal receiver onboard an airborne aircraft. This scenario is illustrated in Figure 24.

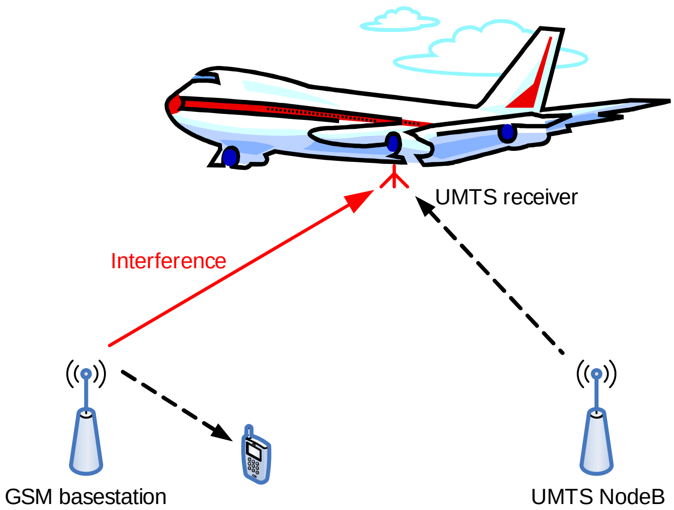


**Figure 24: Terrestrial GSM base station interfering with an airborne UMTS receiver**

The GSM Tx → UMTS Rx interference scenario is important, as it affects the minimal guard band between the two systems.

### B.1 GSM TO UMTS FREQUENCY PLAN

Frequency plan of the band which two systems share is shown in Figure 25. Two frequency allocations of the UMTS forward link are shown; one with no guard band between the GSM and UMTS, and another with 5.5 MHz of guard band.

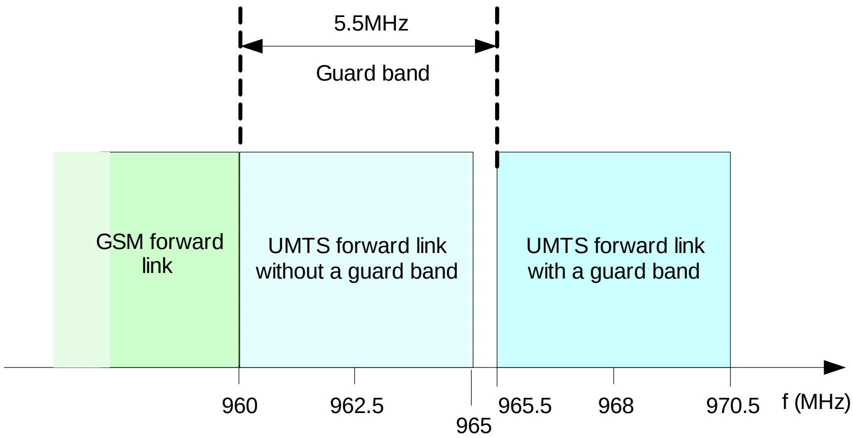


**Figure 25: UAT, GSM forward link and UMTS forward link bands**

Cross-system interference from terrestrial GSM base station transmitter into an airborne UMTS receiver will depend on the guard band between the two systems. In order to see how much guard band is required, the interference link budget has been put together for scenarios without the guard band and with 5.5 MHz of guard band. The link budget is presented in Table 25.

| Parameters | Units | In Tx band w/o guard band (ACS) | In Rx band w/o guard band (ACL) | In Tx band with guard band (ACS) | In Rx band with guard band (ACL) |
|---|---|---|---|---|---|
| | | | | | |
| **Transmitter (GSM)** | | | | | |
| Tx and Rx frequencies | MHz | 959.8 | 962.5 | 959.8 | 968.0 |
| Frequency offset (abs) | MHz | 2.7 | 2.7 | 8.2 | 8.2 |
| Transmit power | dBm | 43.0 | 43.0 | 43.0 | 43.0 |
| Tx power in 30kHz | dBm | N/A | 34.8 | N/A | 34.8 |
| ACLR in 100kHz relative to in-band 30kHz | dBc | N/A | 75.0 | N/A | 80.0 |
| UMTS bandwidth | MHz | 3.8 | 3.8 | 3.8 | 3.8 |
| Duplexer attenuation | dB | | 13.8 | | 44.0 |
| Interference power in UMTS | dBm | N/A | -38.1 | N/A | -73.4 |
| | | | | | |
| **Channel** | | | | | |
| Tx antenna gain (mainlobe) | dBi | 13.8 | 13.8 | 13.8 | 13.8 |
| Tx antenna sidelobe loss | dB | 15.0 | 15.0 | 15.0 | 15.0 |
| Tx-Rx ditance | km | 0.3 | 0.3 | 0.3 | 0.3 |
| Free space loss | dB | 81.8 | 81.8 | 81.8 | 81.8 |
| Polarisation mismatch loss | dB | 0.0 | 0.0 | 0.0 | 0.0 |
| Receve antenna gain | dBi | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | | |
| **Receiver (UMTS)** | | | | | |
| Interference threshold of UMTS receiver (narrowband blocking) | dBm | -57.0 | -108.0 | -56.7 | -108.0 |
| Duplexer attenuation | dB | 1.1 | | 31.4 | |
| Safety margin | dB | 6.0 | 6.0 | 6.0 | 6.0 |
| accommodate other sources | dB | 6.0 | 6.0 | 6.0 | 6.0 |
| | | | | | |
| **Interference** | | | | | |
| Interference allowed | dBm | -67.9 | -120.0 | -37.3 | -120.0 |
| Receive interference peak power | dBm | -40.0 | -121.1 | -40.0 | -156.4 |
| Additional suppression required | dB | 27.9 | -1.1 | -2.6 | -36.4 |
| Distance at which no additional suppression is required | km | 7.6 | 0.3 | 0.2 | 0.0 |

**Table 25: Terrestrial GSM basestation -> UMTS UE Rx interference link budget**

Level plan Table 25 is addressing four interference cases: the Tx and Rx band interference with and without 5.5MHz of guard band between the systems. GSM BS ACLR and UMTS Rx ACS are shown in the following Figure.

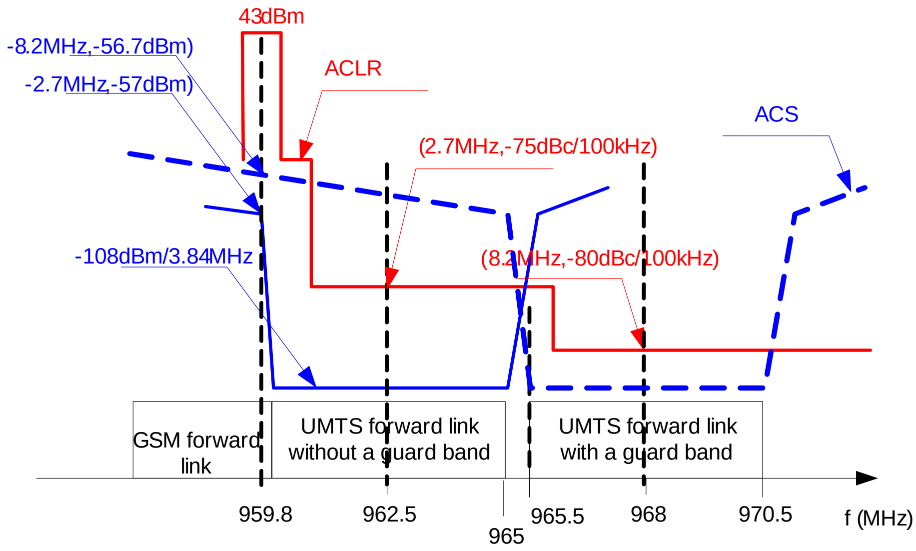


**Figure 26: GSM BS Tx ACLR and UMTS UE Rx ACS**

**Interference without a guard band.** With no guard band between the two systems, UMTS forward link carrier frequency is 962.5 MHz. Values for peak GSM BS power are taken from an ETSI standard [15], while base station antenna gain and sidelobe suppression are taken from Andrew datasheet for a panel antenna DB874G105AXY [16] as typical values for a sectorized antenna. The antenna in question has maximal sidelobe level for elevation of 70 deg, and 20 dB of sidelobe suppression in zenith. Minimal level of sidelobe suppression of that antenna was 15 dB. Interference threshold is taken from UMTS specification for adjacent channel GSM interference, [10]. Duplexer attenuation in transitional band is 5.5 dB/MHz.

The results, shown in the second column of Table 25 show that without a guard band, insufficient adjacent channel selectivity of the UMTS receiver means that the adjacent channel interference coming from a terrestrial GSM basestation is approximately 28 dB above the acceptable level. This is 16 dB above the allowed UMTS receiver blocking by a GSM signal in adjacent band, which is -57 dBm. As a result, the airborne UMTS receiver will in this case be desensitized by the same amount of 16 dB.

UMTS receiver desensitisation caused by GSM interference can be reduced if a guard band is introduced between the GSM band and the UMTS forward link band. In further analysis this guard band is selected to be 5.5 MHz.

**Interference with a guard band.** Performing the same analysis as in the case without a guard band, it can be seen from Table 25 that the guard band gives room for a transitional band of both UMTS and GSM duplexers. The additional suppression provided by the duplexers means that inter-system interference is reduced to the acceptable level.

Conclusions:

- No guard band can reduce receiver sensitivity in worst case by 16dB;
- With the guard band of 5.5 MHz, duplexers provide sufficient suppression of interference even in the situations where aircraft is flying low over a terrestrial GSM station operating close to 960MHz.

# APPENDIX C EFFECTS OF PULSED INTERFERENCE ON UMTS SIGNAL RECEPTION

UMTS technology has been developed for commercial markets. The World Radio Congress (WRC) has established the IMT-2000 spectrum bands to be used worldwide (excl. USA). This block of frequencies was pre-empted for 3G use under the control of ITU. As a result, the UMTS was developed as a spectrally efficient system that would need little margin of safety against pulsed interference and hence little loss of capacity for that reason.

As a result, there are several elements in UMTS FDD that are potentially vulnerable to pulsed interference. For example, the control channels are most vulnerable in UMTS transmission, and their short duration can mean that the significant part of the burst might be masked by an interference pulse. Also, loss of information on the synchronisation channel would mean longer synchronisation time and some associated loss of performance.

If interference has moderate peak power, it will add excess noise but would not cause blocking of the receiver. This is seen as an advantage as UMTS would be additionally protected by available coding and process gain when the receiver operates in the linear region.

Preliminary analysis of pulse interference effects on UMTS FDD done by Roke show that:

- Power control alone can give some resistance to pulse interference, at the cost of increased transmit power and reduced link efficiency;

- Pulsed interference with low duty cycles represents a significant source of interference. The cause is assumed to be high peak power causing irrecoverable block errors in the coding blocks. Interference from UAT is seen as such type of interference (420 μs of burst duration) that will most probably disrupt reception of the affected frame.

- Very narrow, high peak power, pulses are expected to not be so disruptive of UMTS reception due to the error correction capability of the coding against a few wrong bits. JTIDS/MIDS interference (6.4 μs of burst duration) is seen as such type of interference.

In the UMTS system, several techniques of pulsed interference mitigation can be considered:

- Making key transmissions more robust. In a terrestrial UMTS system, the fraction of total power allocated to key channels is balanced to provide maximal capacity and coverage. Robustness of the critical channels can be improved by increasing its power share at the expense of the total capacity.

- Increase the transmit power. This may be a problem, in a way that it might cause increased interference to other co-located ARNS systems (e.g. onboard GPS).

- Custom RF front end. UMTS receiver front end that is more linear and more selective in both ground and airborne equipment is seen as necessary to address other types of interference.

- Receiver blanking is seen as necessary method to protect the UMTS airborne receiver from strong pulsed power.

- UMTS receiver has to be capable of fast recovery from pulsed interference in order to reduce the additional loss of signal;

- Antenna nulling is another technique that should be used to address interference in situations where ground UMTS NodeB is located in proximity of ARNS terrestrial equipment.

- External synchronisation. Vulnerability of UMTS synchronisation channel can be addressed in airborne equipment by using external means (e.g. GPS) to assist synchronisation.

- Modification of the transport channel coding and multiplexing. If further analysis shows that existing UMTS channel coding and multiplexing is particularly vulnerable to the type of pulsed interference that UAT and JTIDS/MIDS represents, the modification of e.g. interleaving scheme or depth may be considered. Interleaving and de-interleaving is most likely to be performed in the DSP software, so it could potentially be tailored to the type of interference Airborne UMTS can experience.

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