B-AMC Project Deliverable D1

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# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>3G</td>
<td>Third Generation</td>
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<tr>
<td>ACP</td>
<td>Aeronautical Communications Panel</td>
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<tr>
<td>AGC</td>
<td>Automatic Gain Control</td>
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<td>ATC</td>
<td>Air Traffic Control</td>
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<td>ATM</td>
<td>Air Traffic Management</td>
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<tr>
<td>B-AMC</td>
<td>Broadband - Aeronautical Multi-Carrier Communication</td>
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<tr>
<td>B-VHF</td>
<td>Broadband VHF</td>
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<tr>
<td>COCR</td>
<td>Communications Operating Concept and Requirements</td>
</tr>
<tr>
<td>D/U</td>
<td>Desired to Undesired</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel</td>
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<tr>
<td>DME</td>
<td>Distance Measuring Equipment</td>
</tr>
<tr>
<td>DME/N</td>
<td>DME (Narrowband)</td>
</tr>
<tr>
<td>DME/P</td>
<td>DME (Precision)</td>
</tr>
<tr>
<td>DME/W</td>
<td>DME (Wideband)</td>
</tr>
<tr>
<td>DOC</td>
<td>Designated Operational Coverage</td>
</tr>
<tr>
<td>ERP</td>
<td>Effective Radiated Power</td>
</tr>
<tr>
<td>EUROCAE</td>
<td>European Organisation for Civil Aviation Equipment</td>
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<tr>
<td>FA</td>
<td>Final Approach</td>
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<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
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<tr>
<td>FCS</td>
<td>Future Communication System</td>
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<tr>
<td>FDR</td>
<td>Frequency Dependent Rejection</td>
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<tr>
<td>ft</td>
<td>feet</td>
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<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>GSM</td>
<td>Global System for Mobile Communications</td>
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<tr>
<td>IA</td>
<td>Initial Approach</td>
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<td>ICAO</td>
<td>International Civil Aviation Organisation</td>
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<td>IFR</td>
<td>Instrument Flight Rules</td>
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<td>ILS</td>
<td>Instrument Landing System</td>
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<td>ITU</td>
<td>International Telecommunication Union</td>
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<td>Meaning</td>
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<td>----------------------------------------------</td>
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<tr>
<td>JTIDS</td>
<td>Joint Tactical Information Distribution System</td>
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<tr>
<td>kHz</td>
<td>Kilohertz</td>
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<tr>
<td>MHz</td>
<td>Megahertz</td>
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<tr>
<td>µs</td>
<td>Microseconds</td>
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<tr>
<td>MLS</td>
<td>Microwave Landing System</td>
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<tr>
<td>mW</td>
<td>milliWatt</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<tr>
<td>NDB</td>
<td>Non-Directional Beacon</td>
</tr>
<tr>
<td>NM</td>
<td>Nautical Miles</td>
</tr>
<tr>
<td>pppps</td>
<td>pulse pairs per second</td>
</tr>
<tr>
<td>PRF</td>
<td>Pulse Repetition Frequency</td>
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<tr>
<td>RNAV</td>
<td>Area Navigation</td>
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<td>RNP</td>
<td>Required Navigation Performance</td>
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<td>RR</td>
<td>Radio Regulations</td>
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<tr>
<td>SDES</td>
<td>Short Distance Echo Suppression</td>
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<tr>
<td>SSR</td>
<td>Secondary Surveillance Radar</td>
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<tr>
<td>STATFOR</td>
<td>Statistics and Forecast</td>
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<td>TACAN</td>
<td>Tactical Air Navigation</td>
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<td>TCAS</td>
<td>Traffic Advisory and Collision Avoidance System</td>
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<td>TMA</td>
<td>Terminal Control Area</td>
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<td>U.S.</td>
<td>United States</td>
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<td>UAT</td>
<td>Universal Access Transceiver</td>
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<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
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<tr>
<td>VHF</td>
<td>Very High Frequency</td>
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<td>VOR</td>
<td>VHF Omni-directional Range</td>
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<td>WP</td>
<td>Work Package</td>
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<thead>
<tr>
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<th>Source</th>
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<tr>
<td>I.</td>
<td>Robert J. Kelly and Danny R. Cusick, “Distance Measuring Equipment and its Evolving Role in Aviation”, Advances in Electronics and Electron Physics, Volume 68.</td>
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<tr>
<td>J.</td>
<td>EUROCONTROL/FAA “Communications Operating Concept and Requirements” (COCR) – v1.0, March 2006.</td>
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1 Introduction

1.1 Project Background

The frequency band currently used for air – ground communications (117.975 – 137.000 MHz) is becoming congested. In some parts of Europe, it is extremely difficult to find a frequency to allow an assignment to be made. With the predicted increase in the number of flights, this situation will get worse. Although there is a programme in place to alleviate this problem by reducing channel spacing in the band from 25 kHz to 8.33 kHz, the relief that it will provide in terms of enabling the required assignments to be made will not satisfy demand in the long-term. In addition to voice communications, future Air Traffic Management (ATM) concepts will require a much greater use of data communications than is employed in the current system.

The International Civil Aviation Organisation (ICAO), through its Aeronautical Communications Panel (ACP), is seeking to define a Future Communication System (FCS), to support ATM operations. In response, the Federal Aviation Administration (FAA) and EUROCONTROL initiated a joint study, with support from the National Aeronautics and Space Administration (NASA) and United States (U.S.) and European contractors, to investigate suitable technologies and provide recommendations to the ICAO ACP Working Group C (WG-C). The first stage of the study was to conduct technology pre-screening, which has been completed and the report published [Reference A]. More than 50 candidate technologies were assessed as part of the pre-screening activity. Nine of those technologies will be carried forward to the next stage, which is to perform an in-depth analysis to identify those technologies that will meet the functional, performance and operational communications requirements of a future ATM system. These technology investigations will conclude in Q3 2007.

Within Europe, the ACP members agreed to adopt a two step approach to technology selection. Step 1 was to identify potential technologies, based upon their ability to meet a subset of the criteria contained in the EUROCONTROL / FAA Communications Operating Concept and Requirements (COCR) document [Reference J]. The Step 1 report can be found at Reference K. In Step 2, additional considerations / investigations addressing the concerns covered by the other initial selection criteria will be applied to the Step 1 selected technologies, aiming to produce a further short list and recommendations for implementation.

The FCS will be the key enabler for new ATM services and applications that will bring operational benefits in terms of capacity, efficiency and safety. The FCS will support both data and voice communications with an emphasis on data communications in the shorter term. It must support the new operational concepts, as well as the emerging requirements for communications of all types (both voice and data) with a minimum set of
technologies deployed globally. The FCS will incorporate new technologies as well as the legacy systems that will continue to be used.

This project, of which this report is part, will contribute to the ongoing work of FCS investigations by providing an in-depth evaluation of one of the technologies carried forward from the Step 1 activity. The technology under consideration is Broadband – Very High Frequency (B-VHF).

The B-VHF project was a research project co-funded by the European Commission 6th Framework Programme. The project investigated the feasibility of a new multi-carrier-based wideband communication system to support aeronautical communications, operating in the VHF communication band. The B-VHF project has already completed a substantial amount of work in developing and designing the system for operation in the VHF band. However the “overlay” implementation option is regarded as feasible only if considerable effort were to be spent implementing all proposed measures for mitigating the strong interference. Since there is no spectrum available in the VHF band for a dedicated B-VHF implementation, the investigation is now considering the implementation of a similar technology but in a different band. The candidate bands are:

- VHF navigation band: [112 or 116] – 118 MHz;
- L band: 960 – [1024 or 1164] MHz;
- C band: [5030 or 5091] – 5150 MHz.

Each of the above bands is already being used by other systems. Therefore, before deciding whether or not to allow any new system to operate, detailed compatibility analyses between the new and existing systems must be undertaken.

The band under consideration in this project is the L-band. Several civil and military systems operate, or will operate, in parts of the 960 – 1215 MHz band, as shown in Figure 1.

![Figure 1: Systems Operating in the 960 – 1215 MHz Band](image-url)
1.2 Specific Context

The project, of which this report is part, will evaluate the possibility of implementing a system using similar technology to B-VHF but in the L-band of 960 – 1164 MHz. The generic name given to the system is Broadband - Aeronautical Multi-Carrier Communication (B-AMC).

At the project kick-off meeting, EUROCONTROL suggested that Work Package 1 (WP1) of this project should investigate three options with regard to the spectrum that could be used for the B-AMC technology. Those options, listed in the order of preference expressed by EUROCONTROL, are described below.

1.2.1 Option 1

Study the feasibility of utilising spectrum between successive Distance Measuring Equipment (DME) channels for B-AMC. This would allow for B-AMC frequency planning that is “independent” from DME planning. If “enough” spectrum is available, the B-AMC would be deployed as an “inlay” system in the L-band (960 - 1164 MHz).

1.2.2 Option 2

If option 1 proves to be not feasible, study the feasibility of assigning frequencies to B-AMC channels in areas where they are not used locally by DME. This would require the establishment of a relationship between potential B-AMC assignments and existing DME assignments.

1.2.3 Option 3

If neither option 1 nor option 2 proves to be feasible, investigate the feasibility of utilising the lower part of the band (960 – 978 MHz) for B-AMC. In that case, inference with the Global System for Mobile Communications (GSM), which is operated in the lower adjacent band, would need to be considered.

1.3 Objectives of Work Package 1

The main objective of WP1 is to determine whether there is sufficient spectrum available in the 960 – 1164 MHz band to allow the proposed B-AMC technology to operate without causing harmful interference to, or receiving harmful interference from, other systems in the band.

To meet the above objective, it has been proposed that the following tasks are required:

- Inspect the characteristics (spectrum) of the DME signal-in-space for both uplink and downlink DME transmissions;
- Examine the current DME channel allocation plan and provide comment upon the expected future DME environment;
• Determine and quantify the amount of available spectrum for the B-AMC system implementation assuming dense (worst-case) DME channel deployment;
• Identify the position (with respect to nominal DME channels) of any available spectrum blocks.
2 DME System Overview

2.1 Types of DME

There are two types of DME, namely DME/N (where the N stands for narrow spectrum characteristics) and DME/P (where the P stands for precise distance measurement). DME/P is an integral part of the Microwave Landing System (MLS) for aircraft approach, landing and missed approach operations. Thus, DME/P must be capable of providing high accuracy range information in a potentially severe multipath environment such as that encountered during landing operations. The accuracy required (30 metres) for such operations is at least an order of magnitude better than that provided by DME/N systems.

However, there are very few, if any, DME/Ps in operation. This is mainly because there are very few MLS in operation, and the DME/P was designed to work specifically with MLS. However, in the future we may see an expansion in the use of MLS, with possibly a corresponding increase in the use of DME/P. For this reason, it would be inappropriate to discount DME/P from this study at this time.

When the standards for DME were written, they included provision for a DME/W system (where W stands for wide spectrum characteristics). However, in the latest version of the standards, all reference to DME/W has been removed. DME/W is no longer operated and as such can be discounted from this study.

2.2 Functional Overview

The DME system comprises two main components; an interrogator and a transponder. The interrogator is located on the aircraft and the transponder is ground-based. The interrogator and transponder have similar main functional elements, each having an encoder, transmitter, receiver and decoder. A simplified process flow diagram for a DME system is given in Figure 2.
The purpose of the DME system is to calculate how far an aircraft is from a selected ground transponder. The interrogator interrogates a single transponder which then transmits a reply following a calibrated fixed time delay (shown in Table 1). The airborne unit then computes the slant range to that ground facility by measuring the elapsed time between the interrogation and the reception of the transponder reply. The measured range is then provided to the pilot and other aircraft systems, as required.

Each interrogation consists of a pair of pulses. The spacing of the pulses defines the ‘code’ of the channel, in accordance with Table 1. The code, along with the transmit frequency, defines the operating channel, thereby allowing the interrogations to be addressed to a specific ground facility. Similarly, the transponder reply consists of a pair of pulses with a code and frequency corresponding to the channel in use, thereby allowing the airborne unit to distinguish desired ground facility transmissions from those of other transponders operating on different channels that are within line-of-sight of the interrogator. The spacing of reply pulses is in accordance with Table 1. The reply frequency of the channel is different to the interrogation frequency, being offset by 63 MHz.
### Table 1: DME Channel Codes and Pulse Delays

The DME interrogator and transponder are similar in that both must identify valid DME signals by using the three discriminates of **pulse duration, frequency and code**. The frequency and code of interrogations and replies define the operating channel. The pulse duration check is used to discriminate DME pulses from pulses from other sources.

Figure 3 shows the timing of interrogation and reply cycles for X and Y channels.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Operating mode</th>
<th>Pulse pair spacing (µs)</th>
<th>Time Delay (µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Interr.</td>
<td>Reply</td>
</tr>
<tr>
<td>X</td>
<td>DME/N</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>DME/P IA</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>DME/P FA</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>Y</td>
<td>DME/N</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>DME/P IA</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>DME/P FA</td>
<td>42</td>
<td>30</td>
</tr>
<tr>
<td>W</td>
<td>DME/N</td>
<td>-</td>
<td>-</td>
</tr>
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<td></td>
<td>DME/P IA</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>DME/P FA</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>Z</td>
<td>DME/N</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>DME/P IA</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>DME/P FA</td>
<td>27</td>
<td>15</td>
</tr>
</tbody>
</table>

1 When the DME is associated only with a VHF facility, the transponder fixed time delay is measured between the leading edge of the second pulse of the interrogation and the leading edge of the second pulse of the reply. When the DME is associated with an MLS facility, the transponder fixed time delay is measured between the leading edge of the first pulse of the interrogation and the leading edge of the first pulse of the reply.
**X-Channel Timing**

- Interrogation: 12µs
- SDES*: SDES
- Decoder: Dead Time (~60µs)
- Delay: 50µs Delay Time
- Reply: 12µs

**Y-Channel Timing**

- Interrogation: 36µs
- SDES*: SDES
- Decoder: Dead Time (~60µs)
- Delay: 56µs Delay Time
- Reply: 30µs

*Short Distance Echo Suppression (SDES) is not implemented by all transponders and its duration, where implemented, may be different to that indicated in the diagram.

**Figure 3: Timing of Pertinent Events for X and Y-channel Operation**

W channels use the same frequencies as X channels and Z channels use the same frequencies as Y channels. For these same frequency / different code combinations, the same planning rules apply as for same frequency / same code assignments. The desired channel should always have an 8 dB advantage over all undesired channels.

Note that W channels are not the same as DME/W. DME/W was a type of DME that is no longer operated. W channels, along with Z channels, are defined by the spacing between the pulses of interrogations and replies. These channels are assigned exclusively for use by DME/P systems.
3  DME Standards

The standards and recommended practices for aeronautical radionavigation aids, including DME, are defined in ICAO Annex 10 Volume 1 [Reference B]. This section provides extracts from ICAO Annex 10 that are pertinent to this study. References to the sections from which the information was taken are shown in square brackets.

3.1.1  Characteristics of the Transmitted DME Signal

3.1.1.1  DME Pulse Shape and Spectrum

![Figure 4: DME Pulse Envelope](image-url)
The following definitions [3.5.1] are used in the specification of the pulse shape and spectrum:

**Pulse rise time:**

The time as measured between the 10 and 90 per cent amplitude points on the leading edge of the pulse envelope, i.e. between points a and c on Figure 4.

**Pulse decay time:**

The time as measured between the 90 and 10 per cent amplitude points on the trailing edge of the pulse envelope, i.e. between points e and g on Figure 4.

**Pulse amplitude:**

The maximum voltage of the pulse envelope, i.e. point a in Figure 4.

**Pulse duration:**

The time interval between the 50 per cent amplitude point on leading and trailing edges of the pulse envelope, i.e. between points b and f on Figure 4.

**Virtual origin:**

The point at which the straight line through the 30 per cent and 5 per cent amplitude points on the pulse leading edge intersects the 0 per cent amplitude axis (see Figure 5).

The following criteria apply to all radiated pulses: [3.5.4.1.3]
• For DME/N, pulse rise time shall not exceed 3 microseconds.
• For DME/P, pulse rise time shall not exceed 1.6 microseconds. For the Final Approach (FA) mode, the pulse shall have a partial rise time of 0.25 plus or minus 0.05 microseconds. With respect to the FA mode and accuracy standard 1, the slope of the pulse in the partial rise time shall not vary by more than plus or minus 20 per cent. For accuracy standard 2, the slope shall not vary by more than plus or minus 10 per cent. **Recommendation.**— *Pulse rise time should not exceed 1.2 microseconds.*
• Pulse duration shall be 3.5 microseconds plus or minus 0.5 microseconds.
• Pulse decay time shall nominally be 2.5 microseconds but shall not exceed 3.5 microseconds.
• The instantaneous amplitude of the pulse shall not, at any instant between the point of the leading edge which is 95 per cent of maximum amplitude and the point of the trailing edge which is 95 per cent of the maximum amplitude, fall below a value which is 95 per cent of the maximum voltage amplitude of the pulse.
• To ensure proper operation of the thresholding techniques, the instantaneous magnitude of any pulse turn-on transients which occur in time prior to the virtual origin shall be less than one per cent of the pulse peak amplitude. Initiation of the turn-on process shall not commence sooner than 1 microsecond prior to the virtual origin.

The following applies to the transponder reply signal: [3.5.4.1.3]
• The spectrum of the pulse modulated signal shall be such that during the pulse, the effective radiated power contained in a 0.5 MHz band centred on frequencies 0.8 MHz above and 0.8 MHz below the nominal channel frequency in each case, shall not exceed 200 mW, and the effective radiated power contained in a 0.5 MHz band centred on frequencies 2 MHz above and 2 MHz below the nominal channel frequency in each case, shall not exceed 2 mW. The effective radiated power contained within any 0.5 MHz band shall decrease monotonically as the band centre frequency moves away from the nominal channel frequency.

The following applies to the interrogation signal: [3.5.5.1.3]
• The spectrum of the pulse modulated signal shall be such that at least 90 per cent of the energy in each pulse shall be within 0.5 MHz in a band centred on the nominal channel frequency.
The following guidance material relating to the pulse spectrum measurement is provided: [Attachment C Section 7.1.11]

The effective radiated power contained in the 0.5 MHz measurement frequency bands [around the first and second adjacent channels] can be calculated by integrating the power spectral density in the frequency domain or, equivalently, by integrating the instantaneous power per unit time in the time domain using the appropriate analogue or digital signal processing techniques. If the integration is performed in the frequency domain then the resolution bandwidth of the spectrum analyser must be commensurate with the 5 per cent duration interval of the DME pulse. If the integration is performed in the time domain at the output of a 0.5 MHz five pole (or more) filter then the time sample rate must be commensurate with the pulse spectrum width.

3.1.1.2 Transponder Peak Power Output

[3.5.4.1.5.2] For DME/N, the peak equivalent isotropically radiated power shall not be less than that required to ensure a peak pulse power density of minus 89 dBW/m$^2$ under all operational weather conditions, at any point within the specified coverage.

*Recommendation.*— The peak effective radiated power should not be less than that required to ensure a peak pulse power density of approximately minus 83 dBW/m$^2$ at the maximum specified service range and level.

[3.5.4.1.5.3] For DME/P, the peak equivalent isotropically radiated power shall not be less than that required to ensure the following peak pulse power densities under all operational weather conditions:

a) minus 89 dBW/m$^2$ at any point within the coverage specified in 3.5.3.1.2, at ranges greater than 13 km (7 NM) from the transponder antenna;

b) minus 75 dBW/m$^2$ at any point within the coverage specified in 3.5.3.1.2, at ranges less than 13 km (7 NM) from the transponder antenna;

c) minus 70 dBW/m$^2$ at the MLS approach reference datum;

d) minus 79 dBW/m$^2$ at 2.5 m (8 ft) above the runway surface, at the MLS datum point, or at the farthest point on the runway centre line which is in line of sight of the DME transponder antenna.

3.1.2 Characteristics of the DME Receiver

The standards specified in ICAO Annex 10 refer almost exclusively to intra-system performance. Therefore, the standards do not specify the requirements for receiver performance in the presence of non-DME signals. For example, in the section titled “Protection against interference” [3.5.4.2.10], which is actually a recommendation and not mandatory, it is simply stated that “Protection against interference outside the DME
frequency band should be adequate for the sites at which the transponders will be used".

However, the following extracts from ICAO Annex 10 are provided since they describe the characteristics of the transponder and interrogator receivers.

3.1.2.1 Transponder Sensitivity

[3.5.4.2.3] In the absence of all interrogation pulse pairs, with the exception of those necessary to perform the sensitivity measurement, interrogation pulse pairs with the correct spacing and nominal frequency shall trigger the transponder if the peak power density at the transponder antenna is at least:

a) minus 103 dBW/m² for DME/N;
b) minus 86 dBW/m² for DME/P Initial Approach (IA) mode;
c) minus 75 dBW/m² for DME/P FA mode.

The minimum power densities specified above shall cause the transponder to reply with an efficiency of at least:

a) 70 per cent for DME/N;
b) 70 per cent for DME/P IA mode;
c) 80 per cent for DME/P FA mode.

DME/N dynamic range. The performance of the transponder shall be maintained when the power density of the interrogation signal at the transponder antenna has any value between the minimum specified above, up to a maximum of minus 22 dBW/m² when installed with an Instrument Landing System (ILS) or MLS, and minus 35 dBW/m² when installed for other applications.

DME/P dynamic range. The performance of the transponder shall be maintained when the power density of the interrogation signal at the transponder antenna has any value between the minimum specified above, up to a maximum of minus 22 dBW/m².

The transponder sensitivity level shall not vary by more than 1 dB for transponder loadings between 0 and 90 per cent of its maximum transmission rate.

3.1.2.2 Transponder Receiver Bandwidth

[3.5.4.2.6] The minimum permissible bandwidth of the receiver shall be such that the transponder sensitivity level shall not deteriorate by more than 3 dB when the total receiver drift is added to an incoming interrogation frequency drift of plus or minus 100 kHz.

DME/N. The receiver bandwidth shall be sufficient to allow compliance with [the stated accuracy requirements] when the input signals [have correct pulse shape and spectrum].
**DME/P — IA mode.** The receiver bandwidth shall be sufficient to allow compliance with [the stated accuracy requirements] when the input signals [have correct pulse shape and spectrum]. The 12 dB bandwidth shall not exceed 2 MHz and the 60 dB bandwidth shall not exceed 10 MHz.

**DME/P — FA mode.** The receiver bandwidth shall be sufficient to allow compliance with [the stated accuracy requirements] when the input signals [have correct pulse shape and spectrum]. The 12 dB bandwidth shall not exceed 6 MHz and the 60 dB bandwidth shall not exceed 20 MHz.

Signals greater than 900 kHz removed from the desired channel nominal frequency and having power densities up to [minus 22 dBW/m² for DME/N installed with ILS or MLS and minus 35 dBW/m² when installed for other applications, and minus 22 dBW/m² for DME/P], shall not trigger the transponder. Signals arriving at the intermediate frequency shall be suppressed at least 80 dB. All other spurious response or signals within the 960 MHz to 1215 MHz band and image frequencies, shall be suppressed at least 75 dB.

### 3.1.2.3 Interrogator Sensitivity

[3.5.5.3.2] DME/N. The airborne equipment sensitivity shall be sufficient to acquire and provide distance information to the accuracy specified [in the appropriate section of the standard] for a signal power density of minus 89 dBW/m².

**Note.** Although the above paragraph relates to DME/N interrogators, the receiver sensitivity is better than that necessary in order to operate with the recommended power density of minus 83 dBW/m² for DME/N transponders, in order to assure interoperability with the IA mode of DME/P transponders.

**DME/P.** The airborne equipment sensitivity shall be sufficient to acquire and provide distance information to the accuracy specified [in the appropriate sections of the standard] for the DME/P signal power densities of [minus 89 dBW/m² at ranges greater than 7 NM from the transponder, minus 75 dBW/m² for ranges less than 7 NM from the transponder, minus 70 dBW/m² at the MLS approach reference datum and minus 79 dBW/m² at 8 ft above the runway surface].

**DME/N and DME/P.** The performance of the interrogator shall be maintained when the power density of the transponder signal at the interrogator antenna is between [minus 89 dBW/m² for DME/N and minus 89 dBW/m² at ranges greater than 7 NM from the transponder, minus 75 dBW/m² for ranges less than 7 NM from the transponder, minus 70 dBW/m² at the MLS approach reference datum and minus 79 dBW/m² at 8 ft above the runway surface for DME/P] and a maximum of minus 18 dBW/m².
3.1.2.4 Interrogator Receiver Bandwidth

[3.5.5.3.3] DME/N. The receiver bandwidth shall be sufficient to allow compliance with [the stated accuracy requirements], when the input signals [have correct pulse shape and spectrum].

DME/P — IA mode. The receiver bandwidth shall be sufficient to allow compliance with [the stated accuracy requirements] when the input signals [have correct pulse shape and spectrum]. The 12 dB bandwidth shall not exceed 2 MHz and the 60 dB bandwidth shall not exceed 10 MHz.

DME/P — FA mode. The receiver bandwidth shall be sufficient to allow compliance with [the stated accuracy requirements] when the input signals [have correct pulse shape and spectrum]. The 12 dB bandwidth shall not exceed 6 MHz and the 60 dB bandwidth shall not exceed 20 MHz.
4 **Option 1 – B-AMC between DME Channels**

4.1 **Overview**

This option will investigate the feasibility of assigning channels for use by B-AMC between channels that are currently assigned to DME, for example at $f_0 + 500$ kHz, where $f_0$ is the nominal frequency of a DME channel. This option is being considered with the understanding that the assignment of the B-AMC channels must not impact DME operation in any way, including causing electromagnetic interference or imposing planning constraints on DME now and in the future. In other words, the operation of B-AMC should be totally compatible with the operation of DME.

If this option is feasible, it offers a number of benefits. Firstly, it will not cause harmful interference to DME and presumably B-AMC design will be such that it does not receive harmful interference from DME. Secondly, no account would need to be taken of DME planning. In other words, if it can be demonstrated that B-AMC is compatible with DME in the worst case conditions (i.e. when B-AMC is utilising spectrum between successive DME channels with no minimum separation requirement), then it might be possible for DME planners and B-AMC planners to operate independently without the need to consider the other system when assigning channels for their system, although this would need to be agreed.

4.2 **Consideration of the Interference Scenarios**

In considering the 960 – 1215 MHz band for an allocation to B-AMC, a number of interference scenarios must be taken into account. Figure 6 shows the principle paths of interference between B-AMC and DME. Since it is a pre-requisite of this study that B-AMC must not cause interference to DME, this WP focuses primarily upon interference from B-AMC to DME, i.e. the interference paths shown in red in Figure 6. WP4 of the project will study in more detail interference between the two systems.
4.2.1 Interference to the DME Interrogator

The interference paths numbered 2, 7 and 10 involve the DME interrogator. For each interference scenario, details of the interrogator receiver characteristics are required. Figure 7 and Figure 8 show graphically the receiver bandwidth requirements for a DME/P in Initial Approach and Final Approach mode respectively. These diagrams have been created using values taken from ICAO Annex 10 section 3.5.5.3.3. (It should be noted that the bandwidth requirements are the same for the DME/P transponder).
In Figure 7 and Figure 8, the bandwidth of the receiver passband is shown as being estimated. This is because the bandwidth is not stated in ICAO Annex 10. Furthermore, in the research conducted during the preparation of this report, it was not possible to find any other form of specification or example of the bandwidth for either DME/P or DME/N. The bandwidth...
figures shown in the diagrams are taken from a very reliable but slightly dated document [Reference I] that was written in the late 1980’s. That document states that the bandwidth of a DME/P interrogator receiver is around 800 kHz for IA mode and 4 MHz for FA mode. These are example figures based upon technology at that time.

The same document states that the bandwidth of a DME/N interrogator receiver is between 400 – 800 kHz which is also an example. Whilst these figures are not definitive, they could be considered as good working approximations for use in this study.

Assuming these example figures to be correct, a B-AMC transmitter using a frequency offset of 500 kHz from the nominal frequency of the DME channel (i.e. the reply frequency) may benefit from a limited amount of Frequency Dependent Rejection (FDR) in the case of a DME/N interrogator. The centre frequency of the B-AMC channel would be between 100 kHz and 300 kHz from the DME interrogator receiver passband. For a DME/P in IA mode, the B-AMC centre frequency would be around 100 kHz from the interrogator receiver passband. However, for a DME/P in FA mode, the B-AMC centre frequency would be within the passband of the interrogator.

Of the interference paths involving the DME interrogator, the co-site scenario (i.e. path 2 in Figure 6) is likely to give the greatest potential for interference to the interrogator. Although the proposed location of the B-AMC airborne antenna is not yet known, it is likely that it will be located on the underside of the aircraft. Therefore it is likely to be within metres of the DME interrogator antenna, which means that the path loss between the two antennae is likely to be relatively small. In a study conducted by Roke Manor [Reference H], a figure of 35 dB is assumed as the isolation between a Universal Mobile Telecommunications System (UMTS) antenna and a DME antenna on the same aircraft.

For the air-to-air and ground-to-air scenarios (i.e. paths 10 and 7 in Figure 6), path loss between the B-AMC transmitter and the DME interrogator receiver will provide greater attenuation of the B-AMC signal than in the co-site scenario. The minimum separation distance between the B-AMC transmitter and the interrogator will be dictated by normal Air Traffic Control (ATC) separation distances.

4.2.2 Interference to the DME Transponder

The interference paths numbered 4 and 6 in Figure 6 involve the DME transponder. The DME/P transponder receiver characteristics that are stated in ICAO Annex 10 are the same as for the DME/P interrogator receiver, as shown in Figure 7 and Figure 8. For DME/N, ICAO Annex 10 states that “the receiver bandwidth shall be sufficient” to allow compliance with the stated accuracy requirements. Therefore, for the purpose of this study, it is reasonable to assume that the bandwidths of DME/N and DME/P transponders are similar to those of DME/N and DME/P interrogators.
The worst case scenario involving the DME transponder is when a nearby B-AMC unit is transmitting on a channel whose centre frequency is offset by 500 kHz from the interrogation frequency that the transponder is receiving.

4.3 Option 1 Conclusions

In WP4 of this project, an extensive investigation has been conducted that studies the potential for interference between B-AMC and several systems, as reported in Reference L. WP4 has provided a significant number of results and conclusions from the many scenarios considered. It is not the objective of this section to re-iterate those results and conclusions, so the reader is advised to read the report at Reference L, if such information is required. The purpose of this section is to draw conclusions that are pertinent to the scenario considered in Option 1.

From studies performed to date, particularly under WP4, it can be concluded that it is not feasible to implement B-AMC channels between successive nominal DME channels, whilst preserving the current minimum spatial distances between systems.

Note:

The above conclusion applies to the B-AMC system operating in both A/G and A/A mode.

Under the technical and operational conditions assumed within WP4, the results indicate that the minimum required frequency separation between a B-AMC terminal on one aircraft and a DME interrogator on a neighbouring aircraft, at a 600 m vertical separation distance, would be 2.5 MHz. Between an airborne B-AMC terminal and a DME ground transponder, the minimum required frequency separation would also be 2.5 MHz. Between a ground B-AMC terminal and an airborne DME interrogator, the required separation distance would be 2 MHz.

There will be at least 16 MHz frequency separation between a ground B-AMC terminal and a DME ground transponder, which means that it should be possible to plan ground stations so as to avoid interference between these elements.

The worst case is that where a B-AMC terminal and a DME interrogator are situated on the same aircraft. In this case, it is likely that no amount of frequency separation (within the band under consideration) would be able to prevent harmful interference from B-AMC to the DME.

It should be noted that the scenarios considered in deriving these results were worst case. Whilst it can be expected that normal operational conditions would result in less interference to the DME, it is appropriate for the purpose of this study to consider the worst case.
5 Option 2 – Interleaving with DME Channels

5.1 Overview

If it is demonstrated that a B-AMC channel cannot be assigned with a 500 kHz offset from a DME channel without causing unacceptable interference to either DME or B-AMC, then additional protection will be required. Such protection could be achieved by greater attenuation of the B-AMC signal. This could be implemented by introducing frequency and / or physical separation between DME and B-AMC. To implement such a solution would require knowledge of the physical location and the operating channels of both DME and B-AMC equipment.

Like with Option 1, it is a pre-requisite of Option 2 that the assignment of B-AMC channels must not impact DME operation in any way. Therefore, B-AMC channels must “fit around” the DME assignments.

5.2 DME Frequency Planning

5.2.1 Channel Definition

The DME channel plan defines 352 distinct operating channels. A channel is defined by an interrogation / reply frequency pair and a pulse code. There are 126 interrogation frequencies with corresponding reply frequencies. The interrogation and reply frequencies in a pair are separated by 63 MHz. The channel code is determined by the spacing between the pulses of an interrogation or reply and is designated by a letter W, X, Y or Z. Therefore, a channel is designated by a number in the range 1-126, followed by a letter, for example 32X. It should be noted that W and Z channels were reserved for use exclusively by DME/P equipment. There are no DME/P systems within Europe and there are no known plans to install them. Therefore, there are currently no operational W and Z channels.

This channel plan structure is shown in Figure 9.
Interrogation Frequencies (Air to Ground)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 63X</td>
<td>960 MHz</td>
</tr>
<tr>
<td>64 - 126X</td>
<td>962 MHz</td>
</tr>
<tr>
<td>1 - 63Y</td>
<td>1213 MHz</td>
</tr>
<tr>
<td>64 - 126Y</td>
<td>1215 MHz</td>
</tr>
<tr>
<td>1 - 63Z</td>
<td>1025 MHz</td>
</tr>
<tr>
<td>64 - 126Z</td>
<td>1088 MHz</td>
</tr>
<tr>
<td>1 - 63W</td>
<td>1151 MHz</td>
</tr>
<tr>
<td>64 - 126W</td>
<td>1215 MHz</td>
</tr>
</tbody>
</table>

Reply Frequencies (Ground to Air)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 63X</td>
<td>960 MHz</td>
</tr>
<tr>
<td>64 - 126X</td>
<td>962 MHz</td>
</tr>
<tr>
<td>1 - 63Y</td>
<td>1213 MHz</td>
</tr>
<tr>
<td>64 - 126Y</td>
<td>1215 MHz</td>
</tr>
<tr>
<td>1 - 63Z</td>
<td>1025 MHz</td>
</tr>
<tr>
<td>64 - 126Z</td>
<td>1088 MHz</td>
</tr>
<tr>
<td>1 - 63W</td>
<td>1151 MHz</td>
</tr>
<tr>
<td>64 - 126W</td>
<td>1215 MHz</td>
</tr>
</tbody>
</table>

X Channels

\[
\begin{align*}
  I &= 1025 + (CH-1) \\
  R &= I - 63 \\
  R &= I + 63 \\
  12 \, \mu s &= \text{Interrogation Code} \\
  12 \, \mu s &= \text{Reply Code} \\
  50 \, \mu s &= \text{Transponder Reply Delay}
\end{align*}
\]

Y Channels

\[
\begin{align*}
  I &= 1025 + (CH-1) \\
  1 &= CH \leq 63 \\
  64 &= CH \geq 64 \\
  36 \, \mu s &= \text{Interrogation Code} \\
  30 \, \mu s &= \text{Reply Code} \\
  56 \, \mu s &= \text{Transponder Reply Delay}
\end{align*}
\]

\[CH = \text{Channel Number (1 to 126)}\]
\[I = \text{Interrogation Frequency (MHz)}\]
\[R = \text{Reply Frequency (MHz)}\]

Figure 9: DME / Tactical Air Navigation (TACAN) Channel Plan
5.2.2 Channel Assignment Criteria

A minimum Desired to Undesired (D/U) signal ratio is required to protect the desired transponder reply signal at the airborne DME receiver from the various co-frequency / adjacent frequency, same code / different code ground DME transponder reply signals that may exist. DME channel assignments are made so as to ensure that the D/U ratio throughout the operational coverage volume of the transponder is in accordance with the relevant standards. The international standard that specifies DME performance is ICAO Annex 10 Volume 1 [Reference B]. The following table is taken from Table C-4 of Attachment C to ICAO Annex 10 Volume 1 and shows the D/U ratios at the input of an airborne DME interrogator receiver that are required to protect the desired transponder signal from the unwanted signals from other DMEs:

<table>
<thead>
<tr>
<th>Type of Assignment</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-frequency:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same code</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Different code</td>
<td>8</td>
<td>-42</td>
</tr>
<tr>
<td>First Adjacent Frequency:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same code</td>
<td>-(P_u - 1)</td>
<td>-42</td>
</tr>
<tr>
<td>Different code</td>
<td>-(P_u + 7)</td>
<td>-75</td>
</tr>
<tr>
<td>Second Adjacent Frequency:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same code</td>
<td>-(P_u + 19)</td>
<td>-75</td>
</tr>
<tr>
<td>Different code</td>
<td>-(P_u + 27)</td>
<td>-75</td>
</tr>
</tbody>
</table>

**Note 1:** The D/U ratios in column A protect those DME/N interrogators operating on X or Y channels. Column A applies to decoder rejection of 6 microseconds.

**Note 2:** The D/U ratios in column B protect those DME/N or DME/P interrogators utilising discrimination in conformance with 3.5.5.3.4.2 and 3.5.5.3.4.3 of Chapter 3 and providing a decoder rejection conforming to 3.5.5.3.5 of Chapter 3.

**Note 3:** P_u is the peak effective radiated power (ERP) of the undesired signal in dBW.

**Note 4:** The frequency protection requirement is dependent upon the antenna patterns of the desired and undesired facility and the ERP of the undesired facility.

**Note 5:** In assessing adjacent channel protection, the magnitude of D/U ratio in column A should not exceed the magnitude of the value in column B.

Table 2: Desired to Undesired Ratios Required at the Interrogator to Protect the Transponder Signal
Note: As the above values are for the case of DME to DME interference, they should be used with caution (i.e. they may not be directly applicable) when considering interference between non-DME systems towards an airborne DME receiver.

For completeness, the paragraphs of ICAO Annex 10 referenced in Note 2 to Table 2 are given below:

3.5.5.3.4.2 DME/N signals greater than 900 kHz removed from the desired channel nominal frequency and having amplitudes up to 42 dB above the threshold sensitivity shall be rejected.

3.5.5.3.4.3 DME/P signals greater than 900 kHz removed from the desired channel nominal frequency and having amplitudes up to 42 dB above the threshold sensitivity shall be rejected.

3.5.5.3.5.1 The interrogator shall include a decoding circuit such that the receiver can be triggered only by pairs of received pulses having pulse duration and pulse spacings appropriate to the transponder signals, as described in 3.5.4.1.4.

3.5.5.3.5.2 DME/N Decoder rejection: A reply pulse pair with spacing of plus or minus 2 µs, or more, from the nominal value and with any signal level up to 42 dB above the receiver sensitivity, shall be rejected.

3.5.5.3.5.3 DME/P Decoder rejection: A reply pulse pair with spacing of plus or minus 2 µs, or more, from the nominal value and with any signal level up to 42 dB above the receiver sensitivity, shall be rejected.

Within the ICAO European region, the rules that apply to DME frequency planning are defined in Chapter 5 of the EUR Frequency Management Manual [Reference E]. They are as follows:

- "Co-frequency:
  
  Same code: D/U = -8 dB
  
  Different code: D/U = -8 dB
  
- The first and second adjacent channel protection requirements are governed by the spurious emission criteria of the transponder. These are:
  
  200 mW (-7 dBW) on the first adjacent frequency
  
  2 mW (-27 dBW) on the second adjacent frequency
The D/U ratios are as in the co-frequency case and the minimum signal level at the airborne receiver to be protected is minus 89 dBW/m² within the designated operational coverage.”

The European planning criteria corresponds with the criteria for assignments with different pulse codes in column A of Table C-4 of ICAO Annex 10, as shown in Table 2.

### 5.3 Utilisation of the DME Band

In addition to DME, the following systems operate, or will operate, in parts of the 960 – 1215 MHz band, in accordance with the International Telecommunication Union (ITU) Radio Regulations (RR):

- the Universal Access Transceiver (UAT); a data link that operates on 978 MHz;
- Secondary Surveillance Radar (SSR), Mode-S and the Traffic Advisory and Collision Avoidance System (TCAS) use the frequencies 1030 and 1090 MHz;
- the Global Positioning System (GPS) L5 and Galileo E5a, which are centred on 1176.45 MHz and Galileo E5b, which is centred on 1207.140 MHz.

Although it is not in accordance with the RR allocations, the Joint Tactical Information Distribution System (JTIDS) also operates in the range 969 – 1206 MHz.

Whilst it is not within the scope of this WP to study the compatibility of B-AMC with these systems, each must be considered in the process of identifying suitable spectrum for B-AMC.

### 5.4 Current Utilisation of DME Channels

Figure 10 and Figure 11 show respectively the current distribution of transponder frequency assignments (ground-to-air) and the corresponding interrogation frequencies (air-to-ground) in Europe.
Figure 10: Distribution of DME Reply Frequency Assignments in Europe
Figure 11: Distribution of DME Interrogation Frequencies Used in Europe
5.5 Future DME Environment

5.5.1 Growth in Air Traffic

It is expected that there will be a growth in the number of flights in Europe over the next 20 years or so. The graph in Figure 12 and the accompanying Table 3 show that overall, the number of Instrument Flight Rules (IFR) flights in 2025 is expected to be between 1.7 and 2.1 times the 2005 traffic. This information is taken from the Long Term Forecast of IFR Flights [Reference F], which was produced by the EUROCONTROL Statistics and Forecast (STATFOR) Service.

Figure 12: Predicted Number of IFR Flights in the EUROCONTROL Statistical Reference Area up to the Year 2025
Table 3: Predicted Growth in IFR Flights in the EUROCONTROL Statistical Reference Area up to the Year 2025

The EUROCONTROL STATFOR report predicts that the increase will not be uniform across all States. Calculating the rate of growth is complex, and the reader is advised to refer to the EUROCONTROL STATFOR report to fully appreciate the contributing factors and to understand the different scenarios A to D. However, in its executive summary, the report states: “Growth is not uniform across the region. In terms of numbers of additional flights added to the network, the busiest States continue to add most traffic, but with Turkey and Poland also making a large contribution to flight growth. Looking beyond Europe, it is the longer-haul flows which are forecasted to grow fastest: not just the Far East, but also the regions immediately to the East and South of Europe. There are many factors considered in the forecasting model, but it is the economic factors that dominate. The strong economic growth forecasted for the Far East in particular, but also for North Africa and the Former CIS Region will continue to encourage the trend to longer flights.”

The map in Figure 13 shows the average annual growth for each State, assuming scenario B.
The information can also be presented as an increase in the predicted number of movements, rather than a rate of growth. The report provides a prediction of the IFR traffic added to the European network by 2025 compared with 2005. This is shown in Figure 14.
5.5.2 Navigation Infrastructure

The long term strategy of ICAO for the provision of navigation services sees a progressive move towards satellite-based systems. The ultimate goal is a transition to a Global Navigation Satellite System (GNSS) that would eliminate the requirement for ground-based navigation aids. That is a long term goal, which is not expected to be achievable before the year 2020. Until then, ground-based navigation aids will continue to make an important contribution towards the provision of navigation services. Whilst we will probably see a gradual withdrawal of Non-Directional Beacons (NDB) and VHF Omni-directional Range (VOR) facilities some time after 2015, the use of DME will increase as DME/DME position fixing provides an input to aircraft Flight Management Systems to support Required Navigation Performance (RNP) 1 Area Navigation (RNAV). There will only be a significant reduction in the number of DMEs if GNSS can be certified for “sole service” use for all phases of flight.

Traditional methods of en-route navigation involve aircraft flying from point to point along pre-defined airways. Typically, a combination of VOR and DME would indicate to the pilot the bearing and distance of the next
waypoint from the aircraft. This method would require that the aircraft was within the Designated Operational Coverage (DOC) of just one VOR and DME at any one time. However, to derive the position of an aircraft using only DME requires that the aircraft is within the coverage of at least two DME transponders. In order to achieve the level of accuracy required for RNP 1 RNAV, the position of the DME transponders must be such that the angle between the aircraft path and each transponder is at least 30 degrees and the internal subtended angle at the aircraft is less than 150 degrees.

In addition, coverage redundancy must be considered. A point in space for which a position fix can be calculated from more than one pair of transponders, is considered to have redundancy. Although a single pair of transponders can give a position fix, it offers no redundancy in case one unit in the pair fails. Limited redundancy is provided where three independent transponders are in view and are within the subtended angle limit, i.e. there are two pairs, but they are not independent. Full redundancy is where there are at least two independent pairs (i.e. four or more independent ground stations) in view and within the subtended angle limit.

In order to provide a DME infrastructure with coverage that would support RNP 1 RNAV, additional transponders will be required. Studies have shown [Reference G] that around 329 additional DME transponders will be required, which breaks down as follows:

- for en-route down to 5000ft, an additional 260 transponders will be required. This figure assumes that the DOC of all new transponders would be 200 NM;
- in terminal areas down to 3000ft, an additional 69 transponders will be required. This requirement only considers one major Terminal Control Area (TMA) per state in Europe.

However, a limitation on the amount of spectrum available for new DME assignments means that this number of additional transponders with 200 nautical mile (NM) DOCs cannot be accommodated. Studies have shown that sufficient coverage to support RNP 1 RNAV can still be achieved if a reduced DOC (up to 50 NM) is provided by the additional DMEs. A recent requirement states that transponders should only be used to a maximum of 160 NM for RNP 1 RNAV.

In summary, it is anticipated that around 329 additional DME transponders will be required in order to support RNP 1 RNAV en-route procedures down to 5000 ft and procedures in TMAs down to 3000 ft.

### 5.6 Consideration of Spectrum for B-AMC

The objective of Option 2 is to determine whether it is possible to assign frequencies to B-AMC channels in areas where they are not used locally by DME. The most attractive solution would be if sufficient amounts of clean spectrum could be identified to accommodate B-AMC. If this is not
possible then the investigation would need to address how to plan B-AMC frequencies to ‘fit around’ DME assignments.

5.6.1 Identification of Clear Spectrum

The first approach is to consider whether there are any parts of the 960 – 1215 MHz band that offer clear spectrum, i.e. which contain no assignments to DME or other systems.

We can see from the DME channel plan (Figure 9) that DME interrogators do not transmit in the sub-bands 960 – 1024 MHz and 1151 – 1215 MHz. Therefore, B-AMC transmissions in these sub-bands would present a low probability of interference to DME transponders. However, these sub-bands are used by UAT, GPS and Galileo. Compatibility with each of these systems would need to be assessed. The band 960 – 978 MHz is considered further in Chapter 6.

Interrogators, however, are designed to receive replies from the transponder across the whole 962 – 1213 MHz band. We can see from Figure 10 that there are no DME assignments in the ranges 962 – 977 MHz, 1025 – 1034 MHz and 1088 – 1103 MHz. This is because these sub-bands are reserved, in order to prevent interference between DME and SSR. DME channels within the bands 1021 – 1040 MHz and 1085 – 1093 MHz are not normally used. If these bands were to be used by B-AMC, compatibility with SSR would need to be demonstrated.

Outside of the SSR ‘guard bands’, there is at least one assignment on every other frequency. It can be concluded, therefore, that there is no spectrum in this range that is clear of DME assignments.

5.6.2 B-AMC Co-located and Co-channel with DME

This scenario considers co-locating the B-AMC ground-based transmitter with the DME transponder and using the same uplink and downlink frequencies as the DME channel. Furthermore, the operational range of the B-AMC is to be considered equal to that of the DME with which it is co-located.

If B-AMC and DME shared the same uplink and downlink frequencies, the interference would be in-band and therefore no frequency dependent rejection is provided. However, if compatibility between the two systems can be demonstrated in this scenario, then the main advantage of this approach is that it offers simplified frequency planning for B-AMC and could potentially avoid the need to co-ordinate frequency assignments.

The criteria for compatibility is likely to require that the DME transponder signal is at least 8 dB higher than the B-AMC signal, plus additional margins are likely to be required, probably in the order of 6 dB, to protect the incumbent DME because it is a safety service, and a further 6 dB as a budget for allocating dissimilar systems in the same band. This would mean that the transmitted B-AMC forward link signal would be required to be around 20 dB below the transmitted DME transponder signal. For a
typical en-route DME, the effective radiated power is around 67 dBm, which means that the radiated power of a co-located B-AMC terminal would need to be below 47 dBm.

There is an important difference between this scenario and Option 1. In Option 1, the airborne B-AMC would transmit on a frequency just 500 kHz removed from the DME interrogator receive frequency, resulting in in-band interference. In this Option 2 scenario, the DME interrogator receive frequency would be 63 MHz away from the airborne B-AMC transmit frequency, thus some FDR would be provided. However, the studies conducted in WP4 [Reference L] of this project show that in the co-site scenario, it is not possible to achieve the required amount of frequency dependent rejection necessary to protect the DME interrogator receiver, even with 63 MHz separation between nominal channels.

One issue that must be considered very carefully is the effect that this scenario could have upon scanning and multi-channel DME interrogators. Such units will be receiving replies on several channels. It is possible, therefore, that the B-AMC downlink would not be separated from the DME reply frequency by 63 MHz, which could result in even less FDR.

Another issue to consider is the effect that high power, out-of-band emissions could have upon the interrogator receiver. Whilst the B-AMC transmission would be outside of the passband of the interrogator receiver IF filter, it would be within the passband of the RF ‘roofing filter’ of the receiver front end. High power B-AMC transmissions could affect the Automatic Gain Control (AGC) of the receiver, resulting in a reduction of receiver sensitivity.

5.6.3 B-AMC Co-located but Different Channel to DME

In this scenario, the B-AMC ground-based transmitter would be co-located with the DME transponder, but using a different frequency to that of the DME channel. The main benefit of this scenario is that the interfering B-AMC signal would be out-of-band and therefore some FDR would be provided. Also, since B-AMC would not be co-frequency with the DME, it may not be necessary to impose the 8 dB D/U ratio, although the 12 dB protection margin may be required.

The main disadvantage of this approach is that it would require full frequency planning and frequency co-ordination. The first step would be to determine the criteria for compatibility between the two systems, such as the frequency and geographical separations required. Then, the planning rules would need to be agreed by the appropriate international authority, probably ICAO. Once agreed, the planning rules would need to be implemented in frequency planning software that takes into account the DME assignments. If a suitable frequency could be found for the B-AMC station, it would need to be co-ordinated internationally before it could be used. Furthermore, because the planning of B-AMC and DME would be linked in this scenario, any changes to the DME plan would impact the B-
AMC plan. Therefore, communication between the authorities responsible for planning and operating each system would be necessary.

Furthermore, the fact that the number of DME ground stations is likely to increase significantly to support RNAV operations in the future, as described in Section 5.5.2, will make finding frequencies for B-AMC more difficult in the future.

5.6.4 B-AMC Independent of DME Location and Channel

In this scenario, the B-AMC ground-based transmitter would not be co-located with the DME transponder, it would not use the same frequencies as the DME channel and it would not be constrained to using the same DOC as the DME. The main advantage of this scenario is that the B-AMC planners would be able to plan a more efficient deployment of B-AMC ground stations, probably by utilising large operational coverage volumes.

The implementation of this scenario would require full frequency planning and co-ordination, as described in Section 5.6.3. Finding frequencies for B-AMC will become more difficult as the number of DME increases. However, the level of difficulty would be increased if large DOCs are required.

5.7 Option 2 Conclusions

There is currently no clear spectrum in the 978 – 1213 MHz band that offers the potential for making a dedicated allocation to B-AMC to support the required number of channels.

It is theoretically possible to achieve protection of DME, UAT and SSR systems (with the exception of the aircraft co-site scenario), using a combination of frequency and distance separations.

Note:

The above conclusion applies to the B-AMC system operating in both A/G and A/A mode.

Please see the report of WP4 [Reference L] for details of the frequency and distance separation requirements for the airborne and ground elements for each of the systems under consideration. For the purpose of summarising WP1, it can be concluded that it is theoretically possible to protect DME, SSR and UAT systems using a combination of frequency and distance separation. However, to meet such requirements would demand frequency planning and the enforcement of B-AMC operating restrictions.

A pre-requisite of frequency planning would be the determination of appropriate protection criteria, which would need to be agreed by the appropriate international authorities.
Only when frequency planning analysis has been performed will it be possible to state whether it is practically possible to implement protection of these systems via frequency and distance separation.

The acceptability of the necessary B-AMC operating restrictions should be the subject of further investigation.

It is not possible to provide a sufficient amount of FDR to protect the DME interrogator and other airborne systems from the transmissions of co-site B-AMC. Additional measures (e.g. usage of the suppression bus) would be required to physically protect the receivers of those systems.

Note:

Even with a frequency separation of 63 MHz, the emissions from B-AMC are likely to cause harmful interference to a co-site DME interrogator. The most effective solution to this problem is likely to be utilisation of the aircraft suppression bus. However, suppressing the DME receiver can reduce the DME system reply efficiency. Before this can be recommended as a feasible solution, it should be investigated in further detail. The maximum B-AMC duty cycle that could be tolerated by the co-located airborne systems would need to be specified. The duty-cycle of the B-AMC system is relatively low.

Similarly, B-AMC transmissions are also likely to affect SSR and UAT. As a result, it is expected that each of the systems operating in the band will need to utilise the aircraft suppression bus in order to avoid interference. The cumulative effect of all systems sharing the bus should be studied.
6 Option 3 – Discrete Allocation to B-AMC in the 960 – 978 MHz Band

6.1 Factors to Consider

The objective of Option 3 is to investigate the technical feasibility of utilising the frequency band 960 – 978 MHz for B-AMC implementation.

6.1.1 DME

It can be seen from Figure 10 that there are no DME assignments in the band 962 MHz to 976 MHz. These channels are reserved in order to protect airborne SSR equipment (that is receiving on 1030 MHz) from the corresponding DME interrogation frequencies that are transmitted in the band 1025 MHz to 1040 MHz. ICAO Annex 10 states that these channels may be used for national allotment on a secondary basis.

Regarding compatibility with DME, this sub-band may offer some potential for B-AMC, but an uplink / downlink separation of a value other than 63 MHz should be used in order to protect SSR. One option that should be considered is having the B-AMC uplink and downlink within the 962 – 1024 MHz sub-band, for example, uplinks between 1010 MHz and 1024 MHz with corresponding downlinks between 962 MHz and 976 MHz.

6.1.2 Other Users in the Band

Since this sub-band can be used for national allotment, States may make use of it for other purposes. In particular, it is understood that the military may utilise this sub-band. However, it would be difficult to get details of any such activity since it would be classified. Whilst this appears to be an institutional issue, it also has technical implications since inter-system interference with the other systems that are operated in the sub-band would need to be taken into account. Furthermore, those systems may vary from State to State, making an assessment of compatibility very difficult. Further investigation is needed, possibly in conjunction with the EUROCONTROL military domain, to better understand the existing uses of this sub-band.

6.1.3 Adjacent Band Operations

The GSM-900 downlink frequency band is 925 – 960 MHz. Utilisation of the 960 – 978 MHz band for B-AMC would need to consider adjacent band interference.

6.1.4 UAT

978 MHz is used by UAT in the U.S., and in the future this may be implemented in Europe. Protection of the UAT will need to be ensured, which may preclude the use of one or more channels just below 978 MHz. The studies of WP4 have shown that, in theory, it is possible to protect UAT through a combination of frequency and distance separation.
6.2 Option 3 Conclusions

Taking into account only the FDR investigations conducted in WP4 [Reference L], B-AMC transmissions in the 960 – 978 MHz range could, in some cases, cause unacceptable interference to UMTS and GSM. However, taking into account the specified GSM/UMTS receiver blocking performance characteristics, it can be concluded that neither mobile GSM/UMTS RX nor the GSM/UMTS base station RX should be affected by interference caused by an aircraft equipped with a B-AMC transmitter, even at relatively close distances.

Note:

Further studies are required to confirm whether this conclusion is correct or not, and to determine more accurately the frequency and distance separations required to mitigate any harmful interference.

Although [Reference L] does not provide information about the potential interference caused in the A/A B-AMC mode of operation, Option 3 may be applicable to the B-AMC system operating in the A/A mode, as long as it uses a single RF channel. In such a case, an analogy may be drawn with the UAT system that also uses a single RF channel and was demonstrated to be able to operate at relatively close frequency distances from DME, UMTS and GSM channels.

The studies performed under WP4 have made the assumption that the B-AMC uplink will be in the range 985 – 1009 MHz and the B-AMC downlink will be in the range 1048 – 1072 MHz. From the information provided in the report of WP4 [Reference L], it is difficult to extrapolate results for the effects to UMTS and GSM from B-AMC transmissions in the 960 – 978 MHz range. If it is believed that Option 3 may present a feasible solution, then this should be studied further.
7 Conclusions

From the work conducted to date under this project, it is clear that it is not feasible to implement B-AMC utilising channels between successive DME channels (i.e. Option 1), without employing B-AMC frequency planning.

It appears to be theoretically possible to avoid causing interference to DME, SSR and UAT by a combination of selecting B-AMC channels with a certain frequency offset from nearby DME systems, and ensuring that a minimum separation distance is maintained (i.e. Option 2). Whether this can be implemented in practice would require a full frequency planning exercise to be conducted. As a pre-requisite to such a planning exercise, compatibility criteria would need to be determined and agreed by the appropriate international bodies.

There is currently insufficient information available to determine whether it is technically feasible to implement B-AMC in the 'lower' band of 960 – 978 MHz (i.e. Option 3). It may be applicable to the B-AMC system in the A/A mode. However, such an option presents a number of institutional issues that would need to be addressed.

The scenario where B-AMC and other equipment (DME, SSR and UAT) are both located on the aircraft presents the greatest risk of interference. The risk of interference cannot be resolved by the use of frequency and distance separation. It appears that a solution could be found by ensuring that all systems in the band make use of the aircraft suppression bus. However, that solution itself carries other risks, such as reducing the reply efficiency of the DME system.

Further detailed investigations are required to prove whether B-AMC can share the L-band without causing unacceptable interference to the legacy systems. From such investigations, the criteria and conditions of sharing should be established.
8 Further Work

In order to determine whether either of the two remaining options presents a feasible solution for implementation of B-AMC in the 960 – 1215 MHz band, the following work needs to be conducted:

- The potential for interference between B-AMC and GNSS in the band needs to be investigated;
- The potential for interference from Ultra Wideband systems should be considered;
- The potential for interference between B-AMC and UMTS, GSM, DME, SSR and UAT for B-AMC operations in the 960 – 978 MHz band should be investigated in greater depth;
- The cumulative effects upon each system, caused by B-AMC, DME, SSR and UAT utilising the aircraft suppression bus, should be investigated;
- Compatibility criteria between B-AMC and DME should be determined and agreed internationally;
- Software should be developed that will allow frequency planning of B-AMC channels, taking into account the other systems operating in the band;
- Discussions should be held to determine the acceptability of the B-AMC operating restrictions that may need to be established;
- There should be discussions at the appropriate international fora regarding the institutional feasibility of utilising the 960 – 978 MHz band for B-AMC.
Annex A – Description of DME Operation

A.1 Interrogator Operation

A.1.1 Overview

A simplified functional block diagram of a DME interrogator is shown in Figure 15.

![Functional Diagram of an Interrogator](image)

Figure 15: Basic Functional Diagram of an Interrogator

When a channel is first selected by the pilot or flight management system (as described in Section A.1.2), the interrogator enters ‘search’ mode. In search mode, the interrogator transmits up to 150 pulse pairs per second (ppps) on the designated channel. Once valid replies from the transponder have been identified, the interrogator enters ‘track’ mode. In track mode, the interrogator transmits at a lower rate, up to 30 ppps, in order to maintain lock in search mode. Whilst these are the maximum permissible transmission rates, most modern interrogators utilise lower rates.

ICAO Annex 10 [Reference B] states “When, after a time period of 30 seconds, tracking has not been established the pulse pair repetition
frequency shall not exceed 30 pulse pairs per second thereafter". It also recommends that “After 15,000 pairs of pulses have been transmitted without acquiring indication of distance, the Pulse Repetition Frequency (PRF) should not exceed 60 pairs of pulses per second thereafter, until a change in operating channel is made or successful search is completed”.

If the interrogator cannot enter track mode on the selected channel, it will continue to interrogate on the same channel until the operating channel is changed. A channel change could be initiated by the pilot, the flight computer, or by the interrogator itself if it is a scanning DME in free-scan mode (see Section A.1.3).

Although a reply to an interrogation will only be transmitted by the desired transponder, the interrogator unit will ‘hear’ all of the replies to other aircraft that are being transmitted on the same channel by the desired transponder, plus the replies on different channels from the undesired stations that are within line-of-sight. Consequently, the interrogator must distinguish the replies to its own interrogations from the thousands of pulse pairs that it may actually receive. It does this by identifying those beacon transmissions that arrive at the interrogator at consistent intervals after the transmission of the interrogations. Replies that have a carrier frequency different to that of the channel being used, and replies whose pulse code is different to that of the desired channel, are considered to be invalid and are eliminated from consideration by the interrogator signal processor.

Other sources of undesired signals arriving at the antenna include non-DME systems, such as JTIDS, other pulsed systems and noise.

In addition to performing range measurements, the interrogator must also recognise an identification signal transmitted by the transponder. The identification signal consists of on-channel pulse pairs sent at a periodic rate of 1350 ppps, which can be decoded by the interrogator and converted into an audible tone for use by the pilot. The identification is a three or four letter Morse code that uniquely identifies the transponder to which the interrogator is tuned.

A.1.2 Functional Components of an Interrogator

Receiver

The interrogator receiver determines which of the pulses at the antenna meet the specification for valid replies. It does this by checking the frequency and duration of received pulses. It also measures the amplitude of the pulses.

Correlator

In search mode, the interrogator transmits an interrogation and then “listens” for a reply. The interrogator does not transmit and receive simultaneously. At this stage, it does not know when (or if) the reply will arrive, so it listens for approximately 2500 µs, which corresponds to a 400
NM round trip time, and stores all on-channel signals it receives during this period. Over successive interrogations, it attempts to identify the replies to its own interrogations by a process of correlation, recognising pulses that are consistently synchronous with its own interrogations. Once the correct reply is found, the correlator narrows the period over which it expects the reply because it knows, to within a few microseconds, when the reply should arrive. At this point, the interrogator enters “track mode”. For modern interrogators, the search process can be as short as half a second if there is a valid transponder signal present.

**Decoder**

The decoder in an interrogator performs a similar function to the decoder in a transponder. From the valid pulses received, it checks for pulse spacing corresponding to the code of the channel in use, as shown in Table 1.

**Range Calculator**

The range from the aircraft to the ground transponder is derived from the total round trip time. A clock in the interrogator is started at the 50% point on the rising edge of the first pulse of an interrogation. The clock is stopped at the 50% point on the rising edge of the first pulse of the received reply. The total round trip time includes the fixed transponder processing delay, which is 50 µs for an X-channel and 56 µs for a Y-channel. Since the pulses travel at the speed of light, it takes 6.18 µs to cover 1 NM. Therefore, the range to the beacon is calculated using the following equation:

\[
\text{Range(nmi)} = \frac{\text{Total Round Trip Delay} - \text{Transponder Delay}}{12.36}
\]

**Equation 1**

The reference point for range calculation in DME/P equipment is different, as described in Section A.3.

**Display and Ident**

The calculated range can be output from the interrogator and displayed in the aircraft cockpit. The interrogator output can also be sent to the aircraft flight control computer if one is installed. If the interrogator is a scanning DME (as described in Section A.1.3) then the range to several ground transponders can be determined and used by the flight computer to calculate the position of the aircraft.

In addition to calculating the range to the transponder, the interrogator decodes the Morse code identifier of the transponder, which is output to audio equipment so that it can be heard by the pilot. This allows the pilot to check that the interrogator is tuned to the correct transponder.
Channel Selector
DME can be paired with VOR, ILS and MLS. When the pilot or flight computer selects the required VOR, ILS frequency or MLS channel, the corresponding DME channel will be automatically selected. The reason for such pairing is to reduce the workload of the pilot in that he only has to make one channel selection, rather than two or three. The pairing is in accordance with a fixed channel plan that is published in ICAO Annex 10.

Encoder and Transmitter
The encoder ensures that the spacing of the pulses generated by the interrogator corresponds to the channel in use. The interrogation transmission start time is varied randomly (jittered) to eliminate the chance of the interrogator synchronising with the replies of any other transponder.

A.1.3 Types of Interrogator
There are three main types of interrogator; single channel, multi-channel and scanning. On a single channel unit, the interrogator will be tuned to one channel and will interrogate just one transponder at a time. A multi-channel interrogator can be tuned to more than one channel and therefore interrogate / track multiple stations. A scanning interrogator can also interrogate more than one channel, but it can operate in three different modes.

- In **single channel mode**, the interrogator functions like a single channel interrogator.

- In **directed scan mode**, the flight control computer directs the interrogator as to which channels it should interrogate, based upon the position (stored in the flight computer database on the aircraft) of the desired transponders, relative to the aircraft. If one of the desired transponders is not available, the interrogator will continue its attempt to acquire a signal on the same channel as the desired transponder. If a signal on the same channel but from a different transponder is found, the interrogator would lock onto that transponder. A scanning DME does not utilise the identifier signal to validate that the acquired signal is from the desired transponder.

- In **free scan mode**, the interrogator initially scans all channels and determines which transponders are the closest. The closest one will be the primary channel and the next five nearest will be kept as secondary channels. In the background, the unit continues to scan all channels to determine if any other transponders are closer than its current primary and secondary ones and, if so, they will be replaced.

The European Organisation for Civil Aviation Equipment (EUROCAE) requirement for DME interrogators [Reference C] states the following:
Single Channel Mode

The average PRF, assuming 95% of the time in track and 5% in search, shall not exceed 16 pulse pairs per second, nor the instantaneous rate of 150 pulse pairs per second. The period of search with a PRF of greater than 16 pulse pairs per second shall not exceed 30 seconds.

Multi-channel Mode

The total interrogation rate shall not exceed 48 pulse pairs per second for all frequencies, nor the instantaneous rate of 150 pulse pairs per second.

A.2 Transponder Operation

A.2.1 Overview

A simplified functional block diagram of a DME transponder is shown in Figure 16.

![Basic Functional Diagram of a Transponder](image)

**Figure 16: Basic Functional Diagram of a Transponder**

A transponder may ‘hear’ interrogations, both from aircraft utilising that transponder and from other aircraft within line-of-sight that are utilising other transponders on different channels. To minimise the load on the transponder and to ensure unambiguous range information to the user, the transponder must only respond to those interrogations intended for it, i.e. those having frequency and code corresponding to the assigned channel.

Other sources of undesired signals arriving at the antenna include non-DME systems, such as JTIDS, other pulsed systems and noise.
A.2.2 Functional Components of a Transponder

Receiver

It is a function of the receiver to determine which of the pulses arriving at
the antenna are valid and which are extraneous, and to pass valid pulses
to the decoder. The receiver uses the parameters of frequency and pulse
duration to identify valid pulses. The duration of a DME pulse allows the
receiver to differentiate it from noise pulses that have short duration.
However, not all transponder types employ a maximum pulse duration
check. In such cases, pulses that are wider than DME pulses might
incorrectly be considered valid by the receiver.

Decoder

Pulses having the correct frequency and pulse duration are passed to the
decoder. It is the function of the decoder to identify a valid interrogation by
considering the code, i.e. the spacing between pulses. Once a valid
interrogation has been identified, the decoder ‘dead time’ is started.

Dead Time

The purpose of the dead time is to allow the transponder to transmit the
reply pulse pair following the appropriate reply delay, as the transponder
should not transmit and receive simultaneously. The definition of dead
time given in ICAO Annex 10 is:

“A period immediately following the decoding of a valid interrogation
during which a received interrogation will not cause a reply to be
generated.

Note:- Dead time is intended to prevent the transponder from replying to
echoes resulting from multipath effects.”

Although the minimum performance specification [Reference D] states
that the dead time should normally not exceed 60 µs, it also states that “it
shall be possible to prevent triggering by multipath delayed interrogation
pulse pairs that arrive after the normal transponder dead time period”.
What this means in practical terms is that where the local multipath
environment dictates, the dead time may be longer than 60 µs. The
consequent degradation of reply efficiency should be kept to a minimum.

Short Distance Echo Suppression (SDES)

Since dead time only starts after the second pulse of a pair, it cannot
mitigate the effects of extraneous pulses arriving between the first and
second pulses of a desired interrogation. One possible source of such
extraneous pulses is echoes resulting from multipath of the desired signal
reflecting off objects close to the transponder, such as aircraft hangars on
the airfield. To eliminate the possibility of such occurrences, some
transponders employ SDES. This is implemented by desensitising the
receiver for a period of time following the reception of a valid pulse. The
following two paragraphs, taken from the transponder performance specification [Reference D], refer to SDES:

“Means shall be provided to enable a high percentage of successful interrogations in the presence of first pulse echo signals. These echo signals may appear between the first and second pulse of a pair, or cause distortion of the second pulse.

When the siting makes it necessary, it shall be possible to prevent triggering by multipath delayed interrogation pulse pairs that arrive after the normal transponder dead time period. It is preferred that the system be based upon an automatic desensitisation, the level and duration of which should be adapted to the local multipath characteristics. The consequent degradation of reply efficiency should be kept to a minimum.”

The SDES period ends just prior to the time when the second pulse of a valid pair should arrive. In Figure 17, D1 and D2 are the desired interrogation pulses of the direct signal. R1 and R2 are pulses received as a result of short distance reflections of the desired signal.

![Direct and Reflected DME Pulse Pair](a)

![SDES Suppresses Reception of R1](b)

**Figure 17: Representation of Direct and Reflected Signals and the Implementation of SDES**

**Zero Mile Delay**

The transponder must accurately generate a fixed time delay between receipt of the interrogation and the transmission of a reply. The purpose of the fixed delay, also known as the “zero mile delay”, is to ensure that the delay in the processing path of the transponder is known to the interrogator. Otherwise, the processing delay may vary between transponder types and would be unknown to the interrogator, thus leading to range bias errors.
The fixed delay is implemented by starting a clock upon receipt of the first pulse of an interrogation. The delay is measured between the half amplitude point on the leading edge of the first interrogation pulse and the same point on the first pulse of the reply pair. The round trip propagation delay is therefore extended by a fixed amount. Since the length of the delay is known to the interrogator on the aircraft, it can be subtracted from the total round trip time in the calculation of the range to the transponder.

Encoder and Transmitter

Following the fixed time delay after reception of the interrogation, the transponder generates the reply. The encoder ensures that the spacing of the pulses in a reply pair corresponds to the channel in use.

A.2.3 Types of Transponder

There are two types of transponder; fixed rate and variable rate. As the name suggests, a fixed rate transponder will always transmit a fixed number of pulse pairs per second (except during transmission of identification), typically 2700 ppps. If the total number of transmissions (including replies to aircraft, replies to the monitor and identification) is insufficient to maintain this rate, then additional pulse pairs known as ‘squitter’ are added until the fixed transmission rate is reached. Tactical Air Navigation (TACAN) systems operate at a fixed rate of 3600 ppps.

Variable rate transponders have a minimum transmission rate, normally around 700 ppps. If the total number of transmissions (including replies to aircraft, replies to the monitor and identification) is insufficient to maintain this rate, then squitter pulses are added until the minimum transmission rate is reached. Once the minimum rate has been reached, squitter pulses are no longer added and the transmission rate thereafter varies according to the interrogation rate. This makes variable rate transponders more efficient than fixed rate units in terms of the DME pulse environment. It should be noted, however, that variable rate transponders can also be set to operate at a fixed rate. It is the decision of the air traffic service provider whether to operate at a fixed or variable rate.

Regarding minimum transmission rate, it is a requirement of ICAO Annex 10 that “The transmitter shall operate at a transmission rate, including randomly distributed pulse pairs and distance reply pulse pairs, of not less than 700 pulse pairs per second except during identity. The minimum transmission rate shall be as close as practicable to 700 pulse pairs per second”.

A.3 DME/P Overview

DME/P provides high accuracy in FA mode and full interoperability with DME/N in IA mode. In the final phases of the approach and landing operation, the major source of accuracy degradation is due to multipath. Multipath perturbations, which always occur later in time than the desired signal, are minimised by thresholding the received pulse at a point that
has not been significantly corrupted by multipath. Therefore, the necessary accuracy for DME/P is achieved by thresholding low (about 17 dB below the pulse peak) on the leading edge of a fast rise-time pulse. This is in contrast to the 50% level thresholding and slow rise-time pulses used in DME/N.

By achieving enhanced accuracy in this manner, questions can be raised concerning interoperability with DME/N. Firstly, the use of a low threshold level impacts transmitter power in the sense that more power is required to obtain an adequate threshold-to-noise level throughout the coverage volume. At the same time, a fast rise-time pulse is required which increases the spectral width of the radiated pulse. These two requirements are in conflict with the need to satisfy the adjacent channel spectrum requirements noted earlier. Hence, both the pulse rise-time and the maximum range at which the low-threshold technique can be used, must be restricted. Secondly, conventional interrogators are calibrated assuming that transponder reply delay timing is based on the 50% threshold level. However, transponder reply delay initiation based on low-level thresholding of a conventional DME pulse will be different from that based on the 50% points. Thus, if a conventional interrogator were to interrogate a DME/P transponder which only used the low-level threshold technique, a range bias error could occur.

DME/P utilises a two-pulse / two-mode technique to solve the problem of interoperability between DME/N and DME/P by providing two modes of operation, a wideband final approach mode and a narrowband initial approach mode. The FA mode utilises the low-thresholding technique in both the interrogator and transponder for ranges to 7 NM from the transponder. By limiting the FA mode coverage range to 7 NM, the adjacent channel radiated power constraints on the transponder can be satisfied, while an adequate threshold-to-noise ratio (for low-threshold pulse detection) is maintained throughout this region. Beyond 7 NM, the IA mode is used and its operation is identical to that of DME/N. In addition, a transition between the two modes is provided in the 7 – 8 NM region. Therefore, in the IA mode, no DME/N interoperability bias error occurs because both the interrogator and the transponder threshold on the 50% pulse levels. Further, use of the 50% threshold allows an adequate threshold-to-noise ratio to be maintained to the coverage limit of 22 NM.

The interrogator selects the mode, FA or IA, according to the measured range from the ground facility. The interrogation mode is characterised by the pulse code (i.e. pulse spacing). The transponder reply delay timing is then based on the proper threshold point for the type of interrogation received. Within a channel assignment, the transponder reply code remains the same, regardless of the type of interrogation.