DME Enhancements in Support of NextGen Performance Based Navigation and Surveillance

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DME CONOPS within NextGen

4 Pillars of APNT CONOPS:

1. **Safe recovery** (landing) of aircraft flying in Instrument Meteorological Conditions (IMC) under Instrument Flight Rule (IFR) operations,

2. **Strategic modification** of flight trajectories to avoid areas of interference and manage demand within the interference area,

3. **Continued dispatch** of air carrier operations to deny an economic target for an intentional jammer,

4. **Flight operations continue without a significant increase in workload** for either the pilot or the Air Navigation Service Provider (ANSP) during an interference event.
# PBN and ADS-B Surveillance Performance in Support of TBO


<table>
<thead>
<tr>
<th>Flight Operation</th>
<th>Navigation (≥99.0% Availability)</th>
<th>Surveillance (≥99.0% Availability)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accuracy* (95%)</td>
<td>Containment (10-7)</td>
</tr>
<tr>
<td>Taxi-out</td>
<td>Visual</td>
<td>Visual</td>
</tr>
<tr>
<td>Takeoff</td>
<td>Visual</td>
<td>Visual</td>
</tr>
<tr>
<td>Climb to Cleanup</td>
<td>0.3 nm</td>
<td>0.6 nm</td>
</tr>
<tr>
<td>Departure / Climb</td>
<td>1 nm</td>
<td>2 nm</td>
</tr>
<tr>
<td></td>
<td>0.3 nm</td>
<td>0.6 nm</td>
</tr>
<tr>
<td>Cruise</td>
<td>10 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td></td>
<td>4 nm</td>
<td>8 nm</td>
</tr>
<tr>
<td></td>
<td>2 nm</td>
<td>4 nm</td>
</tr>
<tr>
<td></td>
<td>1 nm</td>
<td>2 nm</td>
</tr>
<tr>
<td>Top of Descent</td>
<td>2 nm</td>
<td>4 nm</td>
</tr>
<tr>
<td></td>
<td>1 nm</td>
<td>2 nm</td>
</tr>
<tr>
<td>Arrival</td>
<td>1 nm</td>
<td>2 nm</td>
</tr>
<tr>
<td></td>
<td>0.3 nm</td>
<td>0.6 nm</td>
</tr>
<tr>
<td>Approach</td>
<td>LNAV RNP (AR)</td>
<td>0.3 nm</td>
</tr>
<tr>
<td></td>
<td>0.3-0.1 nm</td>
<td>0.6 nm</td>
</tr>
<tr>
<td>Taxi –in</td>
<td>Visual</td>
<td>Visual</td>
</tr>
</tbody>
</table>

* Navigation Accuracy expressed as a Total System Error (TSE), which is the RSS of the Navigation System Error (NSE) and the Flight Technical Error (FTE). For a TSE of 0.3 nm (RNP 0.3), assuming 0.25 nm FTE, the NSE has to be better than 0.17 nm (307 m) 95%
NextGen Time & Frequency Requirements

By 2025: “APNT will provide backup timing services for navigation and positioning and possibly other aviation applications”
(from: APNT CONOPS 2012)

Proposed requirements: (from: APNT CONOPS 2012)

– From expected future communication needs:
  • Time: $1 \mu$s (advanced communications)
  • Frequency: **Stratum 1 (1e-11)** (Digital comm., Mobile wideband)

Note: 10-100 ns time synchronization requirement only applies to pseudoranging & multilateration APNT architectures, not to proposed DME/N-Recap and DME/Next architectures.
Potential Future DME Architectures

Enabling Technologies & Infrastructure
- Increased coverage
- Improved transponder timing
- Improved transponder capacity
- Improved interrogator performance
- Integration with IRU
- Improved multipath mitigation
- DME beat signal broadcast
- Data broadcast
- Transponder synchronization
- Carrier phase processing
- Alternate modulation

Potential Architectures
- **DME/N-Recap**
  Upgraded transponder & interrogator performance, and improved coverage

- **DME-Next**
  Transponder beat signal, carrier phase, data broadcast
  No transponder synchronization

- **DME-Sync**
  Synchronized transponders
  Precise time

- **DME-AltMod**
  Alternate modulation
  Transponder beat signal & data bc
  Synchronized transponders
## Potential future DME Architectures

**DME/N-Recap**
Leverage performance enhancements of state-of-the-art interrogators and transponders.

<table>
<thead>
<tr>
<th>FAA-E-2996</th>
<th>State-of-the-art</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interrogator</td>
<td>0.17 nmi</td>
</tr>
<tr>
<td>Propagation</td>
<td>0.04 nmi</td>
</tr>
<tr>
<td>Transponder</td>
<td>0.10 nmi</td>
</tr>
<tr>
<td>TSE (2σ)</td>
<td>0.20 nmi</td>
</tr>
</tbody>
</table>

**Synchronize transponders**
- Synchronized beat signal broadcast
  - Transponders time & frequency sync
  - passive ranging → **unlimited capacity**
  - Precise time & frequency distribution
- Carrier phase tracking
  - Ultra precise displacement measurement (mm/s)

**DME-Next**

- **Beat signal broadcast**
  - Transponders NOT time synchronized
  - Resolve transponder time offset by occasional 2-way ranging
  - Significant **capacity increase**
  - Coarse frequency distribution

- **Data broadcast**
  - Coarse time sync for advanced comm.

**Broadcast beat signal**
- Synchronize transponders

**Remain legacy compliant**
- Broadcast of alternative modulation signal
  - Spread Spectrum: CDMA or OFDM
  - Spread Spectrum bursts in DME channel, or
    - 1 MHz Bandwidth
  - All transponders use same frequency
    - Wide-band (>> 1 MHz, e.g. 10 MHz)
    - TDMA to mitigate near-far
  - Superior multipath mitigation and ranging accuracy

**DME-AltMod**

- Broadcast beat signal
- Add Alternate Modulation
- Remain legacy compliant
Unique Architecture Elements

DME Carrier Phase

Combination of 1-way and 2-way ranging

Increased Capacity
Significant reduction of interrogation rate

Improved Accuracy
Range smoothing
Precise Velocity

Enhanced Integrity
Multipath bound

References:
01/30/2012 - ION-ITM: Flight Test Performance Assessment of eDME

Technology Feasibility Demonstration Flight Tests:
05/27/2011 - DME software radio, one-way ranging, instrumentation aircraft
01/04/2012 - Dedicated DME transponder, DME carrier phase, precise truth
04/05/2012 - Carrier phase tracking, multipath mitigation & bounding
DME Architecture Development Cost-Benefit

DME-N-Recap
Upgraded transponder & interrogator performance, improved coverage

DME-Next
Transponder beat signal, carrier phase, data broadcast
No transponder synchronization

DME-AltMod
Alternate modulation

DME-Sync
Synchronized transponders
Precise time

Required Investment

Navigation & Surveillance Performance

Incremental Transition Path
Technology Feasibility Demonstration Flight Tests

Method:
- UTC time-stamped RF data recording of transponder transmissions (TOT) and received signal at airplane (TOA)
  - Allows usage of unmodified DME transponder for Tx
  - Pulse pseudoranging and DME carrier phase in post-processing

Assets:
- Customized RF data collection platform and in-house developed DME post-processing software
- In-house developed GPS/IMU/Rubidium truth system for ultra-precise high update rate position, velocity, time, and frequency
- Thales 415SE low-power DME transponder and dB-Systems 510A DME antenna
- Multiple aircraft: Piper Saratoga, Baron-58, King-Air C90

Flight tests:
- May 27, 2011: DME software radio, one-way ranging, instrumentation aircraft
- January 4, 2012: Dedicated transponder, DME carrier phase, precise truth
- April 5-6, 2012: Carrier phase tracking, multipath mitigation & bounding

Funding:
- FAA Joint University Program (Grant 10-G-018), OU-AEC & EECS internal funding

References:
07/08/2010 - FAA/JUP: Enhanced DME in support of APNT
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01/21/2011 - FAA/JUP: eDME and How to Determine the TOA of a Pulse
07/14/2011 - FAA/JUP: Robust GNSS Timing: Characterization of Error Sources
10/06/2011 - FAA/JUP: GNSS satellite and propagation anomaly detection for robust timing
01/30/2012 - ION-ITM: Flight Test Performance Assessment of eDME
02/02/2012 - FAA/JUP: Flight Test Performance Assessment of enhanced DME
02/02/2012 - FAA/JUP: From Legacy to eDME in support of APNT.
04/13/2012 - COUNT: Time and Frequency Transfer for Terrestrial-Based Sadian nav Systems
04/13/2012 - COUNT: eDME Carrier Phase Tracking
04/20/2012 - FAA/JUP: Enhanced Distance Measuring Equipment Carrier Phase Tracking
04/20/2012 - FAA/JUP: Rubidium Ensemble Algorithms and Performance
Flight Test Configuration with 5 ns Truth System

GROUND

RF data recorder
GPS
PPS

DME transponder

RF signal gen.

10 MHz

Rb oscillator

AIR

GPS/IMU/Rb

PPS

RF data recorder

CW @ 1107 MHz

RF signal gen.

10 MHz

1 ms CW cal. burst

Freq spectrum

DME pulses

Real-time quality monitoring