Research & Development of VDL Mode 3 Test System

VDL Research Group
Aeronautical Systems Division

Independent Administrative Institution
Electronic Navigation Research Institute
Presentation Overview

1. Electronic Navigation Research Institute
2. VDL Mode 3 Research Activities in ENRI
3. Feature of VDL Mode 3 System
4. VDL Mode 3 Test System
5. Tests and Evaluation
Electronic Navigation Research Institute

Mission
To carry out research and development in order to ensure safe and efficient transport systems as the leading institute of electronic navigation in Japan

Organization
- President
- Executive Director
- Auditor
- General Affairs Division
- Planning Office
- Development Division
- Aeronautical Systems Division
- Traffic Management Systems Division
- Satellite Technology Division
- VDL Research Group
- Iwanuma Branch

Number of Personnel
- President: 1
- Executive Director: 1
- Auditor: 1
- Part-Time Auditor: 1
- Office Staff: 16
- Research Staff: 48
- Total: 68

As of April 2003

http://www.enri.go.jp
Overview of VDL-3 R&D Activities

1. Objectives
   - Development and evaluation of VDL Mode 3 test system compliant with ICAO SARPs
   - Study and consideration on possible operational issues to implement VDL Mode 3 system in Japanese airspace

2. Duration
   - 2000-2004 (based on fiscal year in Japan)
   - 2005-2009 (additional research activities, TBD)
Overview of VDL-3 R&D Activities (cont.)

3. **Detail Activities**
   - Development of VDL Mode 3 test system
   - Evaluation of the test system
     - Radio interference
     - Communication performance
     - Voice quality
     - ATN connection (compatibility with ATN)
   - Computer simulation
     - VDL Mode 3 performance under various traffic models
# Overall Plan for VDL-3 R&D Activities

<table>
<thead>
<tr>
<th>Year</th>
<th>Development of VDL Mode 3 Test System</th>
<th>Evaluation of Radio Interference</th>
<th>Evaluation of the Test System</th>
<th>Performance Evaluation by Computer Simulation</th>
<th>Test &amp; Evaluation of VDL Mode 2</th>
<th>Summarization Report</th>
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<tbody>
<tr>
<td>FY2002</td>
<td>Evaluation of the Test System</td>
<td>Performance Evaluation by Computer Simulation</td>
<td>Test &amp; Evaluation of VDL Mode 2</td>
<td>Summarization Report</td>
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<td>FY2003</td>
<td>Performance Evaluation by Computer Simulation</td>
<td>Test &amp; Evaluation of VDL Mode 2</td>
<td>Summarization Report</td>
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<tr>
<td>FY2004</td>
<td>Summarization Report</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>FY2005</td>
<td>Summarization Report</td>
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</table>

**Future works**
- System requirement
- Application software
- Operational issues
- Implementation procedure
## Overall Plan for VDL-3 Tests & Evaluation

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Vocoder Evaluation</td>
<td>x SEP-NOV</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Radio Interference Test</td>
<td></td>
<td>x OCT</td>
<td>x SEP</td>
<td>x DEC</td>
<td>x SEP</td>
</tr>
<tr>
<td>Evaluation for Data Communication</td>
<td></td>
<td></td>
<td>x FEB</td>
<td>x DEC</td>
<td>x x NOV JAN</td>
</tr>
<tr>
<td>Evaluation for Voice Communication</td>
<td>x FEB</td>
<td>x SEP</td>
<td></td>
<td></td>
<td>x x NOV JAN</td>
</tr>
<tr>
<td>Flight Test</td>
<td></td>
<td></td>
<td></td>
<td>x x x</td>
<td>x SEP</td>
</tr>
<tr>
<td>ATN Connection Test</td>
<td></td>
<td></td>
<td></td>
<td>x x x</td>
<td>x x NOV</td>
</tr>
<tr>
<td>Interoperability Test</td>
<td></td>
<td></td>
<td></td>
<td>x x x</td>
<td>x JUL</td>
</tr>
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</table>
Research Activities in FY2004

- Improvement of VDL-3 Test System
- ATN Connection Test
- Interoperability Test (FAA NEXCOM System)
- Overall Evaluation of Test System
- Co-site Radio Interference Test
- Controller Evaluation (Voice & Data)
- Study of Diversity Site Group Operation
- Summarization of Report to JCAB
## VHF Digital Link (VDL)

<table>
<thead>
<tr>
<th>Application</th>
<th>VDL Mode 2</th>
<th>VDL Mode 3</th>
<th>VDL Mode 4</th>
</tr>
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<tbody>
<tr>
<td>Data</td>
<td>Data</td>
<td>Voice/Data</td>
<td>Surveillance</td>
</tr>
<tr>
<td>AOC ATC</td>
<td>AOC ATC</td>
<td>ATC</td>
<td>ADS-B</td>
</tr>
<tr>
<td>Modulation</td>
<td>D8PSK</td>
<td>D8PSK</td>
<td>GFSK</td>
</tr>
<tr>
<td>Media Access</td>
<td>CSMA</td>
<td>TDMA</td>
<td>STDMA</td>
</tr>
<tr>
<td>Rate</td>
<td>31.5 kbps</td>
<td>31.5 kbps</td>
<td>19.2 kbps</td>
</tr>
<tr>
<td>ICAO SARPs</td>
<td>1997</td>
<td>2001</td>
<td>2001</td>
</tr>
</tbody>
</table>

ICAO SARPs 1997, 2001 2001
VDL-3 Key Features (for Voice)

- **Anti Blocking**
  - First come, first served
  - Resolution for stepped-on transmission

- **Controller Override**
  - Controller can preempt ongoing aircraft transmission

- **Next Channel Uplink**
  - Uplink of next frequency

- **Urgent Downlink Request**
  - Pilot can inform controller of necessity of urgent voice transmission by downlink data message
VDL-3 Key Features (for Data)

- Priority control for data transmission
  - Supports up to four priority of data
- Slot allocation based on reservation request
  - Avoids simultaneous data transmission
- Secures received data by FEC
  - Up to 5 byte error in received data can be corrected by Reed Solomon Code, RS(72,62)
VDL-3 System Configuration
VDL-3 Operational Concept
ENRI VDL-3 Test System

Legend:
- RF: RF Unit
- MODEM: MODEM Unit
- TDMA: TDMA Control Unit
- CCU: Communication Control Unit
- VOICE: Voice Processing Unit
- GCS: Ground Center Station
## Major Specifications

<table>
<thead>
<tr>
<th>Subject</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Compliant with ICAO SARPs and VDL-3 Manual (Doc 9805)</td>
</tr>
<tr>
<td>TX Power</td>
<td>15 w (42 dBm)</td>
</tr>
<tr>
<td>TX/RX Frequency</td>
<td>Lab Test : 118(^\sim) 136.975MHz (25kHz step)</td>
</tr>
<tr>
<td></td>
<td>Flight Test : 136.900 / 136.925MHz</td>
</tr>
<tr>
<td>System Configuration</td>
<td>2V2D : Two Voice / Two Data</td>
</tr>
<tr>
<td></td>
<td>3V1D : Three Voice / One Data</td>
</tr>
<tr>
<td>Min. Receiving Sensitivity</td>
<td>-103.2 dBm (at BER=10(^{-3}) before FEC)</td>
</tr>
<tr>
<td>Number of Equipment</td>
<td>Ground/Aircraft Station : Two sets each</td>
</tr>
<tr>
<td></td>
<td>Ground Center Station : One set</td>
</tr>
</tbody>
</table>
Additional Functions

- Simple Link Monitor
- Graphical Display
- Received Data Status Log
- Predefined Scenario  
  (for data performance test)
- Aircraft Position Display

Upper: GCS main display
Lower: CCU main display
External View of Test Equipment

VOICE
RF
MODEM
TDMA
CCU
Tests and Evaluation of VDL-3 Test System

- Radio Interference Test
- Laboratory Test for Data Transfer
- Laboratory Test for Voice Quality
- Flight Test
- Lab Test for Co-site Radio Interference
Lab Test for Radio Interference

Test Items

- Interference from VDL-3 to DSB-AM
  - SINAD
  - S/P Ratio
  - Test Results were submitted to ACP WGB/12

- Interference from DSB-AM to VDL-3
  - Bit Error Rate (BER)
  - Adjacent Channel Rejection (ACR)
  - Test Results were submitted to ACP WGB/14
ACR Characteristic: SINAD=15dB
ACR Characteristic : S/P=18dB
D/U Ratio vs. BER Characteristic
ACR Characteristic: BER=1x10^{-3}

![Graph showing ACR characteristic with modes and adjacent channel numbers]
Required Separation Distance

![Graph showing required separation distance for different modes and DSB-AM.](image)
Laboratory Test for Data Transfer

Test Items

- Received Level vs. Bit Error Rate (BER)
- BER vs. Transfer Delay
- BER vs. Throughput
- Transfer Delay vs. Traffic Load
- Transfer Delay with Different Data Priorities
Lab Test for Data Transfer (1)

Test Items  (a) Received Level vs. BER  (b) BER vs. Transfer Delay & Throughput

Test Setup
Received Level vs. BER

![Graph showing BER vs. Received Power (dBm)]

- Min Rx Sensivity: -103.2 dBm

@ CIE Engineering Inc. Washington, DC on APR 26th 2004
BER vs. Transfer Delay

Note:
(1) Channel Load: more than 94%
(2) Transfer Delay: except for the time of ACK transfer
BER vs. Throughput

Total Throughput between GND and AIR
Downlink: 1seg Data repeatedly Tx
Uplink: 15seg Data Tx with 1.5sec interval

- Total throughput: 459.1byte/s
- Failure Rate for Downlink: 67.3byte/s
- Failure Rate for Uplink: 12.7byte/s
- Throughput (byte/s): 322.8byte/s

Graph shows BER vs. Throughput with Sleep=1.5 MSG=100.
Definition for Transfer Delay

Aircraft Station
- TX Data
- Random Access
- Reservation Request
- Reservation Response
- M Burst
- Slot Allocation

Ground Station
- V/D Burst
- Data
- ACK
- V/D Burst
- RX Data

Transfer Delay (except for the time for ACK transfer)
Total Transfer Delay

* Repeat 15 times for 15 seg data
Lab Test for Data Transfer (2)

Test Items
(a) Transfer Delay vs. Traffic Load
(b) Transfer Delay with Different Data Priorities

Test Setup

- **TX Data**
  1. Length: 15seg
  2. ACK: No
  3. Priority: 0 (Low)
  4. Number of data: 100
  5. TX interval: 1~3sec (0.5 step)

- **Downlink**

- **Uplink**

- **ATT**

- **VDL3 GS**
  - TX Data:
    1. Length: 15seg
    2. ACK: No
    3. Priority: 0 (Low)
    4. Number of data: 100
    5. TX interval: 1~3sec (0.5 step)

- **VDL3 AS 1**
  - TX Data:
    1. Length: 15seg
    2. ACK: Yes
    3. Priority: 0 (Low)
    4. Number of data: 100
    5. TX interval: 1~3sec (0.5 step)

- **VDL3 AS 2**
  - TX Data:
    1. Length: 15seg
    2. ACK: Yes
    3. Priority: 0 (Low) or 1 (Mid)
    4. Number of data: 100
    5. TX interval: 1~3sec (0.5 step)

- **VDL3 AS 3**
  - TX Data:
    1. Length: 15seg
    2. ACK: Yes
    3. Priority: 0 (Low) or 1 (High)
    4. Number of data: 100
    5. TX interval: 1~3sec (0.5 step)
## Test Scenarios for Data Transfer Tests (2)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Data Length</th>
<th>TX Interval for Uplink</th>
<th>Priority for AS 1</th>
<th>Priority for AS 2</th>
<th>Priority for AS 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 seg</td>
<td>1.0 sec</td>
<td>0 (Low)</td>
<td>0 (Low)</td>
<td>0 (Low)</td>
</tr>
<tr>
<td>6</td>
<td>1 seg (62 bytes)</td>
<td>1.0</td>
<td>0 (Low)</td>
<td>1 (Mid)</td>
<td>2 (High)</td>
</tr>
<tr>
<td>7</td>
<td>1 seg (62 bytes)</td>
<td>1.5</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>1 seg (62 bytes)</td>
<td>2.0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>1 seg (62 bytes)</td>
<td>2.5</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>1 seg (62 bytes)</td>
<td>3.0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>15 seg (930 bytes)</td>
<td>1.0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>15 seg (930 bytes)</td>
<td>1.5</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>15 seg (930 bytes)</td>
<td>2.0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>19</td>
<td>15 seg (930 bytes)</td>
<td>2.5</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>15 seg (930 bytes)</td>
<td>3.0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Traffic Load vs. Transfer Delay

![Graph showing the relationship between traffic load and transfer delay for different priority levels. The graph indicates that as traffic load increases, the transfer delay also increases. The graph has three lines representing low priority, mid priority, and high priority.]
Transfer Delay with Different Data Priorities

![Chart showing delay with different data priorities](chart.png)

- Data Priority
- AS No.
- Scenario No.
- Traffic Load

- (1)-(2): Reservation Request
- (2)-(3): Slot Assignment
- (3)-(4): Data Transfer
- (4)-(5): Acknowledgment
Laboratory Test for Voice Quality

Test Items

■ Vocoder Processing Delay
■ Total Transfer Delay (end to end)
■ Voice Quality with Radio Interference
■ Voice Quality by PESQ Tool
Vocoder Processing Delay

BER=0%

BER=2%

BER=4%

BER=6%

Befor Encoding

After Decoding

Not deteriorated

Not deteriorated

Deteriorated

Voice Processing Delay (except for delay in vocoder test equipment)

VOICE Encoding

Vocoder Test Equip Error inserted

VOICE Decoding
Total Voice Transfer Delay (end to end)

 Specifications on system transfer delay in ICAO Manual Doc9805
  • Transmit delay <= 175ms : Delay from voice input to RF transmission
  • Receive delay <= 40ms : Delay from RF reception to voice output
  • End-to-end voice delay = max 250ms : Total transfer delay

VDL-3 GS

136.9MHz

VDL-3 AS

Voice Input

Voice output

Total Voice Transfer Delay

208ms
# Voice Quality with Radio Interference

<table>
<thead>
<tr>
<th>D/U</th>
<th>BER</th>
<th>Quality of Received Voice</th>
</tr>
</thead>
<tbody>
<tr>
<td>10dB</td>
<td>6.0E-02</td>
<td>Very little audio output (close to “step on” situation)</td>
</tr>
<tr>
<td>11dB</td>
<td>4.7E-02</td>
<td>A very little part of voice message understandable</td>
</tr>
<tr>
<td>12dB</td>
<td>4.6E-02</td>
<td>Considerable part understandable</td>
</tr>
<tr>
<td>13dB</td>
<td>3.1E-02</td>
<td>Interference recognized but voice message was understandable, in particular bass is partly unclear</td>
</tr>
<tr>
<td>14dB</td>
<td>1.7E-02</td>
<td>Interference obviously recognized but voice message was understandable</td>
</tr>
<tr>
<td>15dB</td>
<td>4.5E-03</td>
<td>Some interference recognized</td>
</tr>
<tr>
<td>16dB</td>
<td>2.0E-03</td>
<td>No interference identified</td>
</tr>
</tbody>
</table>
Voice Quality by PESQ Tool

Test Setup

Reference Voice
(1) Prepared by Agilent
(2) ATC Phrase by Japanese Controller

PESQ: Perceptual Evaluation of Speech Quality
ITU-T Recommendation P.862

Agilent VQT J1981A
Voice Quality by PESQ Tool

![Graph showing voice quality ratings for different conditions.

- Vocoder only
- VDL_BER=0%
- VDL_BER=0.1%
- VDL_BER=1.0%
- VDL_BER=1.8%
- VDL_BER=2.6%
- VDL_BER=3.0%
- VDL_BER=3.2%
- VDL_BER=4.4%
- DSB-AM (1)
- DSB-AM (2)
- Cell Phone_3G
- Cell Phone_TDMA

PESQ LQ scores range from 1.00 to 4.50.]
Flight Test

Aircraft Station

Flight Path

- Flight Path 1
  - Sendai - Misawa
- Flight Path 2
  - Sendai - Omiya
- Flight Path 3
  - SDE R100/150 NM

Radio Horizon from
- Iwanuma GS
- Omiya
- Misawa

No retransmission
Retransmission occurred
Flight Test - Received Level

Sendai <---> Omiya Iwanuma Station ALT=18,000 feet

RCV Power (dBm)

Distance (NM)

Outbound

Inbound