AERONAUTICAL COMMUNICATIONS PANEL

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Agenda Item 5: New Technologies

Report of FAA-JCAB VDL Mode 3 Interoperability Testing

Presented by Satoshi Kato, ENRI
Prepared by Yasuyoshi Nakatani, ENRI

SUMMARY

The Federal Aviation Administration (FAA) and the Civil Aviation Bureau of Japan (JCAB) / the Electronic Navigation Research Institute (ENRI) carried out interoperability testing of VHF Digital Link Mode 3 (VDLM3) voice communication and Aeronautical Telecommunication Network (ATN) data communication over a VDLM3 sub-network at the ENRI facility in Tokyo, Japan. The aim of the tests was to examine interoperability between the FAA VDLM3 ground system and avionics and the ENRI ground/airborne test system infrastructure. The tests were performed with a successful completion. This working paper outlines the objectives, methods and results of the testing as well as discrepancies between both systems and some issues identified by the testing.

1 Introduction

1.1 Objectives

During the verification process of VDLM3 Interoperability Testing, the FAA and JCAB/ENRI demonstrated digital voice and data functionality with end-to-end system operation, including the use of vendors avionics. The Interoperability Testing also verified the operational compatibility of the end-to-end system. The following are the primary Interoperability Testing objectives:

- Interoperability
  Interoperate JCAB/ENRI ground/aircraft stations suite with FAA ground station and Avidyne avionics suite.

- System Maturity
  Identify the technical maturity of ICAO Standards and Recommended Practices (SARPs) through testing independently-developed VDLM3 components.

1.2 Background

1.2.1 FAA NEXCOM Program

The FAA has been moving ahead with a replacement program for air-ground communication systems called Next Generation Air/Ground Communication (NEXCOM), centering on VDLM3. NEXCOM introduces a digital voice and data communication capability into the air/ground communications environment and will reduce maintenance costs of legacy systems, provide increased security/channel control, alleviate future frequency spectrum congestion, and establish a communications path for ATC and non-ATC data link applications.

The NEXCOM program has been successfully carrying out a series of three System Demonstrations, which began in 2002 and will end in 2004. In October 2002, System Demonstration I demonstrated the technical feasibility of the VDLM3 system using a simulated air traffic control facility and three aircraft. System Demonstration II, which was carried out in November 2003 at the FAA William J. Hughes Technical Center, demonstrated the viability of the system architecture and future commercialization of NEXCOM avionics. The Operational Demonstration, which will take place in late 2004, will incorporate commercial production avionics, and show interoperability, and operational viability of digital communications.

1.2.2 ENRI VDLM3 Research Activities

The ENRI in Japan has been conducting VDLM3 research and development activities since 2000. The objectives of the R&D activities are to develop and evaluate a VDLM3 test system compliant with ICAO SARPs and manual (Doc 9805), and to study and consider possible operational issues regarding implementing VDLM3 system in Japanese airspace. In this five-year research program, ENRI has developed four sets of VDLM3 ground/aircraft stations in addition to a ground center station, and has carried out series of tests such as radio interference, voice and data performance, voice quality and flight tests, using the test systems.

1.2.3 Testing Development

The maturity of the two VDLM3 systems being developed by FAA and ENRI was discussed at ICAO ACP Working Group M 8th Meeting in Bangkok in November 2003. As a result of these conversations, FAA personnel visited the ENRI facility in late January 2004 to discuss potential Interoperability Testing between the FAA and ENRI VDLM3 equipment. Subsequently, in spring 2004 ENRI engineers visited the WJHTC and the facilities of some of the contractors related to the NEXCOM program in the United States to learn about the NEXCOM system and to discuss the test procedures and methods for the Interoperability Testing with the FAA.

1.3 Preparatory Work

The FAA and JCAB/ENRI prepared an Interoperability Coordination Plan (ICP) to outline and discuss the coordination required to execute VDLM3 Interoperability Testing between them. The ICP described the organizational roles and responsibilities, ground infrastructure equipment and configuration, and the VDLM3 Interoperability Test structure.

Prior to the implementation of the testing, FAA VDLM3 ground and avionics and hardware and software necessary for the Interoperability Testing were shipped to the ENRI facility. This allowed ENRI engineers to perform preliminary interoperability testing to identify issues between the FAA and ENRI systems that would affect interoperability. Based on the results of the preliminary testing, the ENRI VDLM3 test system was modified to ensure interoperability, and ENRI engineers reported issues to the FAA engineers to ask for modification of the FAA system.

1.4 Formal Interoperability Testing

The FAA and JCAB/ENRI carried out formal Interoperability Testing of VDLM3 voice transmission and ATN data transmission over a VDLM3 sub-network at the ENRI facility in Tokyo, Japan during the week of July 26th, 2004. The testing was attended by personnel from FAA Headquarters, FAA Technical Center, Basic Commerce and Industries, Inc.(BCI), CIE Engineering, Inc., JCAB, ENRI, NEC Corporation and Oki Electric Industry Company. Interoperability between the independently-developed VDLM3 systems was confirmed to a large extent, and significant results were obtained.

2 <u>Equipment Tested</u>

2.1 FAA Ground System

The FAA Ground System evaluated in the testing consisted of ITT Multi-mode Digital Radios (MDR), a Real Time Platform (RTPF), a Radio Interface Unit (RIU) and a Ground Network Interface (GNI) as well as ATN Air-Ground (A/G) Router. The equipment is listed in table 1.

The FAA Technical Center developed the RTPF, RIU and additional ground system to make available a working VDLM3 system compliant with international standards. The RTPF and peripheral components had been utilized during VDLM3 Avionics & System Demonstration activities, and has also been provided to Avionics and ground system vendors in the United States to aid in VDLM3 development efforts. The RTPF simulates an Air Traffic Control (ATC) ground station by combing MDR TX and RX with VDLM3 functionality.

Table 1 FAA Ground System Configuration

Equipment	Vendor	Remarks
MDR TX	ITT	VDLM3/DSB-AM(25k/8.33k)
MDR RX	ITT	
RTPF	CIE	
Octal T1 Module (OTM)	CIE	
Voice Channel Module (VCM)	CIE	Four modules
RIU	BCI	
Link Monitor Tool/PXI Radio	Veridian	For monitoring
GNI	BCI	Installed on one PC
ATN A/G Router	BCI	

2.2 FAA Airborne System

Pre-production Avidyne VDLM3 avionics were provided for testing as the FAA airborne system. The avionics had been utilized during FAA Avionics Interoperability Testing, as well as in subsequent System Demonstration II activities in November 2003. The FAA airborne system consists of equipment listed in table 2.

Table 2 FAA Airborne System Configuration

Equipment	Vendor	Remarks
VDLM3 Avionics	Avidyne	Prototype
Airborne Network Interface (ANI)	BCI	Installed on one PC
ATN Airborne (A/B) Router	BCI	

2.3 ENRI Ground/Airborne System

The ENRI system consists of equipment listed in table 3. The ENRI VDLM3 test system is being developed in compliance with the ICAO SARPs and manual (Doc 9805) and was operated in the 2V2D (two voice and two data channels) configuration throughout the duration of the test activities. This test system is also capable of operating in the 3V1D configuration. The ENRI ground/airborne system has the same configuration, which contains the units listed in the table below.

Table 3 ENRI Ground/Airborne System Configuration

Equipment	Vendor	Remarks
VDLM3 Ground/Airborne System	NEC	Test System Three sets used for the test
RF Unit	NEC	
Modulation/Demodulation Unit	NEC	MODEM Unit
TDMA Control Unit	NEC	TDMA Unit
Communication Control Unit	NEC	COMM Unit
Voice Processing Unit	NEC	VOICE Unit
VDLM3 Ground Center Station	NEC	For ground systems control
ATN A/G Router	OKI	Two sets

3 Test Description and Results

3.1 Test Schedule

The FAA and JCAB/ENRI conducted the formal Interoperability Testing at the ENRI facility in Tokyo, Japan during the week of July 26th. The test schedule is shown in table 4.

Table 4 Test Schedule

Day 1	Day 2	Day 3	Day 4
Briefing/Discussions ENRI(G) ⇔ FAA(A) - Basic & Enhanced Voice Test - Next Channel Uplink	FAA(G) ⇔ ENRI(A) - Basic & Enhanced Voice Test - Next Channel Uplink FAA(A) ⇔ ENRI(A) - Timing State 2	FAA(G) ⇔ ENRI(A) ENRI(G) ⇔ FAA(A) - ATN Data Test Digital Voice Quality Test by PESQ tool	FAA(G) ⇔ ENRI(A) - Additional Test Summarization and Discussions

(G): Ground system (A): Airborne system

3.2 Test Environment

The test approach was designed to incorporate Air-to-Ground testing via an attenuated circuit in the ENRI laboratory environment. VDLM3 digital voice/data transmission was carried out in a 2V2D system configuration via specifically allocated test frequencies in the VHF band.

3.3 Digital Voice Communication Test

3.3.1 Test Summary

During the digital voice communication test, FAA and ENRI engineers participated in Air-to-Ground procedural tests of the avionics and ground test systems. A mock pilot and mock air traffic controller communicated while reading scripts that were representative of actual air traffic control communications.

For both VDL Mode 3 Avionics and Ground Test System (FAA & ENRI) combinations, both Basic and Enhanced Voice operations were validated by digital voice transmission and reception confirmation. The Next Channel Uplink function was also validated by management burst transmission and reception confirmation. The results of these voice tests indicate that total interoperability was achieved between the FAA and ENRI VDLM3 systems.

3.3.2 Test Items

The following tests were conducted to verify voice communication interoperability.

a) Verify net entry sequences for voice communication

b) Exchange and validate basic voice functionality
  - Digital voice quality
  - Stuck microphone resolution
  - Controller override
  - Anti-blocking

c) Exchange and validate enhanced voice functionality
  - Urgent downlink request

d) Validate next channel uplink functionality

e) Exchange and validate truncated voice functionality in Timing State 2

3.3.3 Test Procedure and Result

3.3.3.1 ENRI Ground System with FAA Airborne System

(1) Digital Voice Quality

a) Test Setup: See Figure 1

b) Reading Script: ICP Appendix D, Script 1

c) Test Result: Confirmed with each other that voice was received clearly.

(2) Stuck Microphone Resolution

a) Test Setup: See Figure 1

b) Reading Script: ICP Appendix D, Script 2

c) Test Result: Confirmed that stuck microphone condition was deactivated by a mock air traffic controller.

(3) Controller Override

a) Test Setup: See Figure 1

b) Reading Script: ICP Appendix D, Script 4

c) Test Result: Confirmed a priority override access by a mock air traffic controller.

(4) Urgent Down Link Request (UDR)

a) Test Setup: See Figure 2

b) Reading Script: ICP Appendix D, Script 5

c) Test Result: Confirmed that UDR message was transferred from Avidyne radio to ENRI ground system correctly.

(5) Anti-Blocking

a) Test Setup: See Figure 2

b) Reading Script: ICP Appendix D, Script 6

c) Test Result: Confirmed that voice transmission was inhibited when the voice channel was busy.

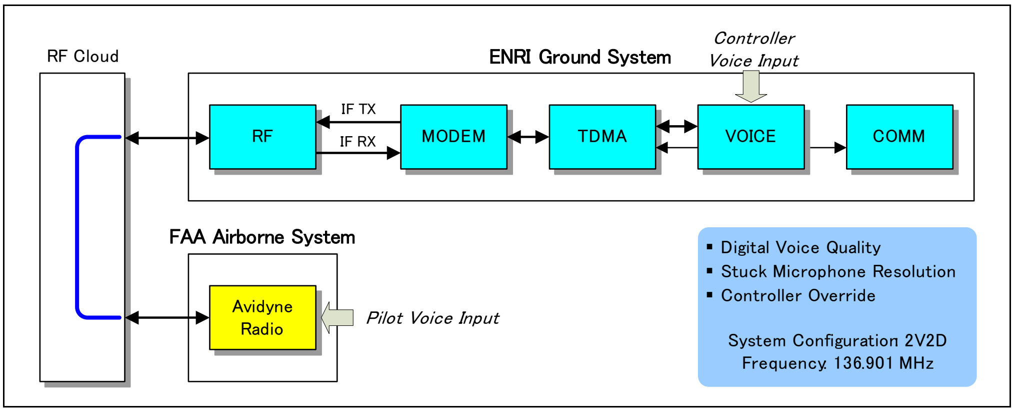

Figure 1 Test Setup (ENRI GND <=> FAA AIR)

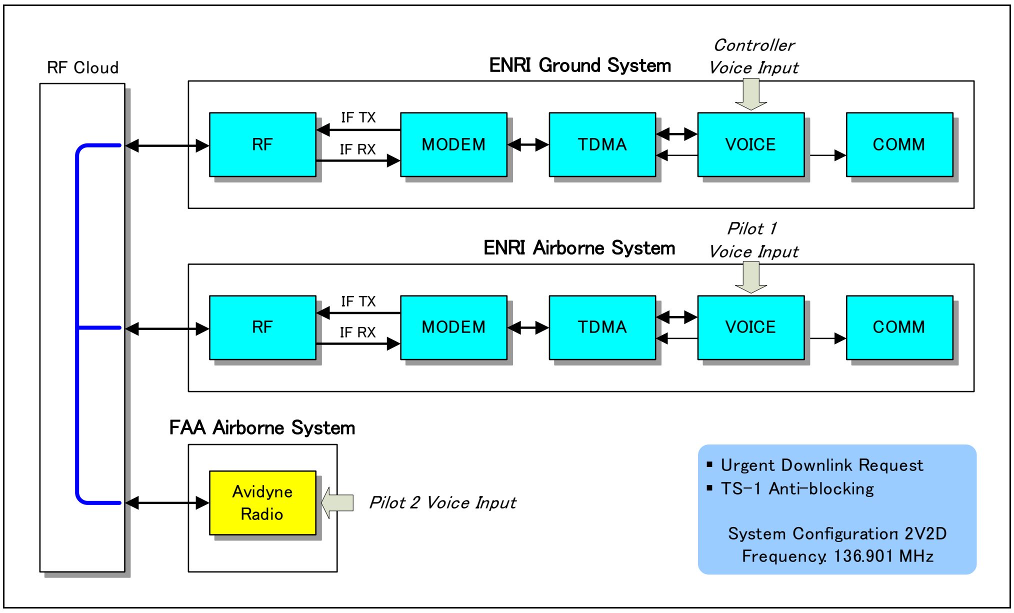

Figure 2 Test Setup (ENRI GND/AIR <=> FAA AIR)

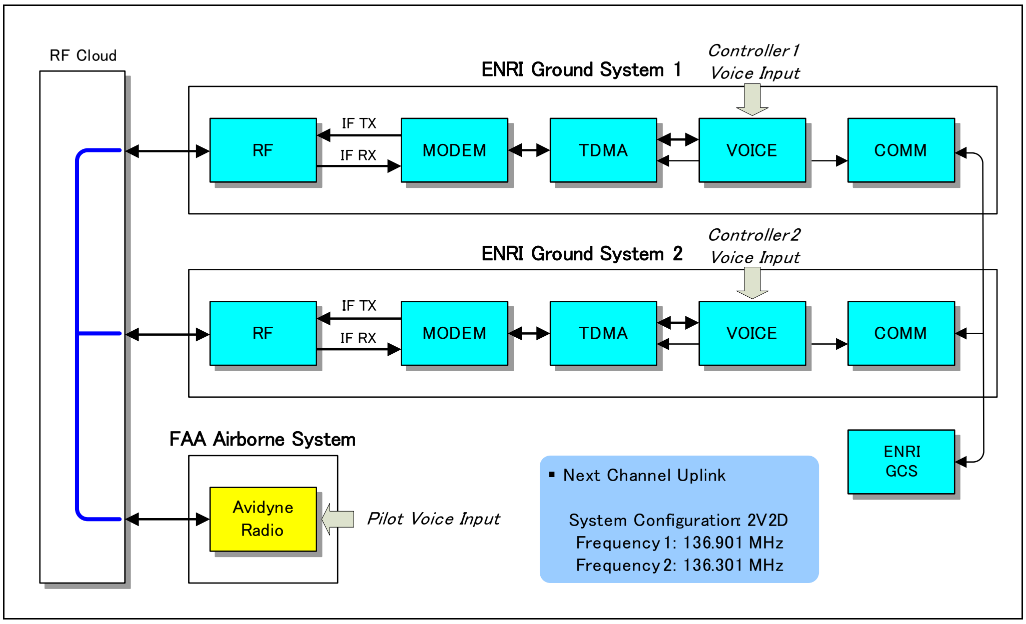

Figure 3 Test Setup (ENRI GND/GND <=> FAA AIR)

(6) Next Channel Uplink

a) Test Setup: See Figure 3

b) Reading Script: ICP Appendix D, Script 3

c) Test Result: Confirmed that a net handoff was correctly executed after a Next Channel message was uplinked and a mock pilot took action to execute the transfer.

3.3.3.2 FAA Ground System with ENRI Airborne System

(1) Digital Voice Quality

a) Test Setup: See Figure 4

b) Reading Script: ICP Appendix D, Script 1

c) Test Result: Confirmed with each other that voice was received clearly.

(2) Stuck Microphone Resolution

a) Test Setup: See Figure 4

b) Reading Script: ICP Appendix D, Script 2

c) Test Result: Confirmed that stuck microphone condition was deactivated by a mock air traffic controller.

(3) Controller Override

a) Test Setup: See Figure 4

b) Reading Script: ICP Appendix D, Script 4

c) Test Result: Confirmed a priority override access by a mock air traffic controller.

(4) Urgent Down Link Request (UDR)

a) Test Setup: See Figure 5

b) Reading Script: ICP Appendix D, Script 5

c) Test Result: Confirmed that UDR message was transferred from ENRI airborne system to FAA RIU correctly.

(5) Anti-Blocking

a) Test Setup: See Figure 5

b) Reading Script: ICP Appendix D, Script 6

c) Test Result: Confirmed that voice transmission was inhibited when the voice channel was busy.

(6) Next Channel Uplink

a) Test Setup: See Figure 6

b) Reading Script: ICP Appendix D, Script 3

c) Test Result: Confirmed that a net handoff was correctly executed after a Next Channel message was uplinked and a mock pilot took action to execute the transfer.

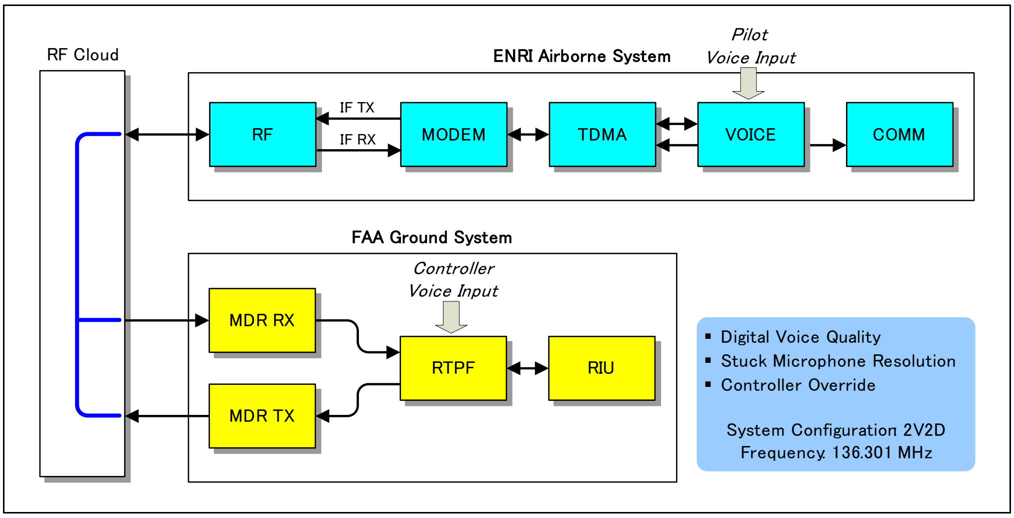

Figure 4 Test Setup (FAA GND <=> ENRI AIR)

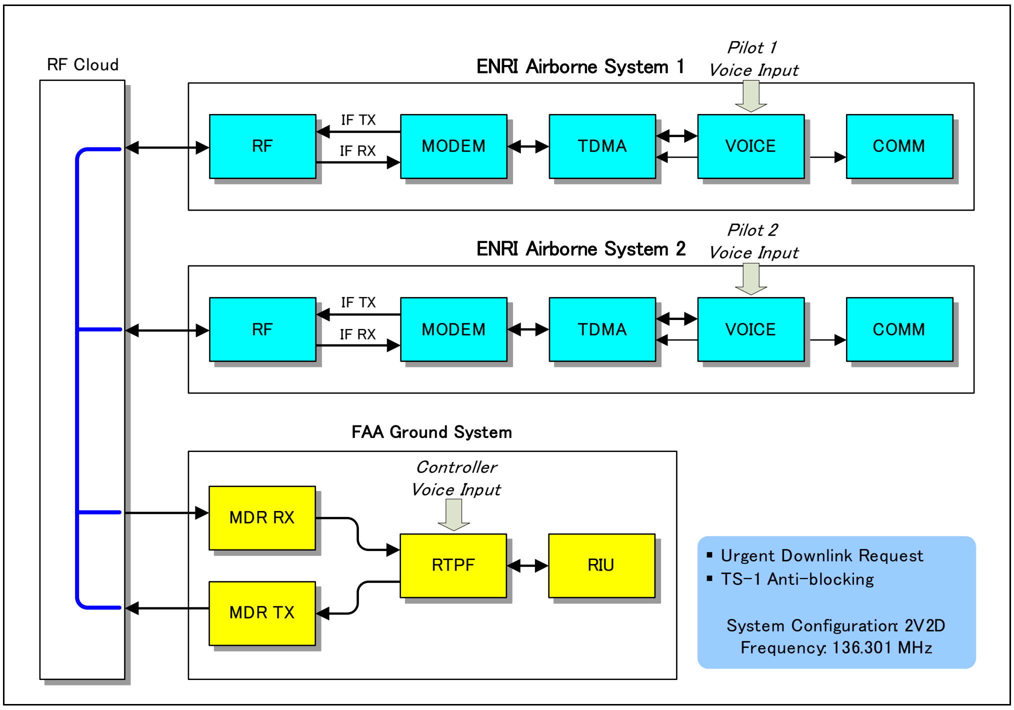

Figure 5 Test Setup (FAA GND <=> ENRI AIR/AIR)

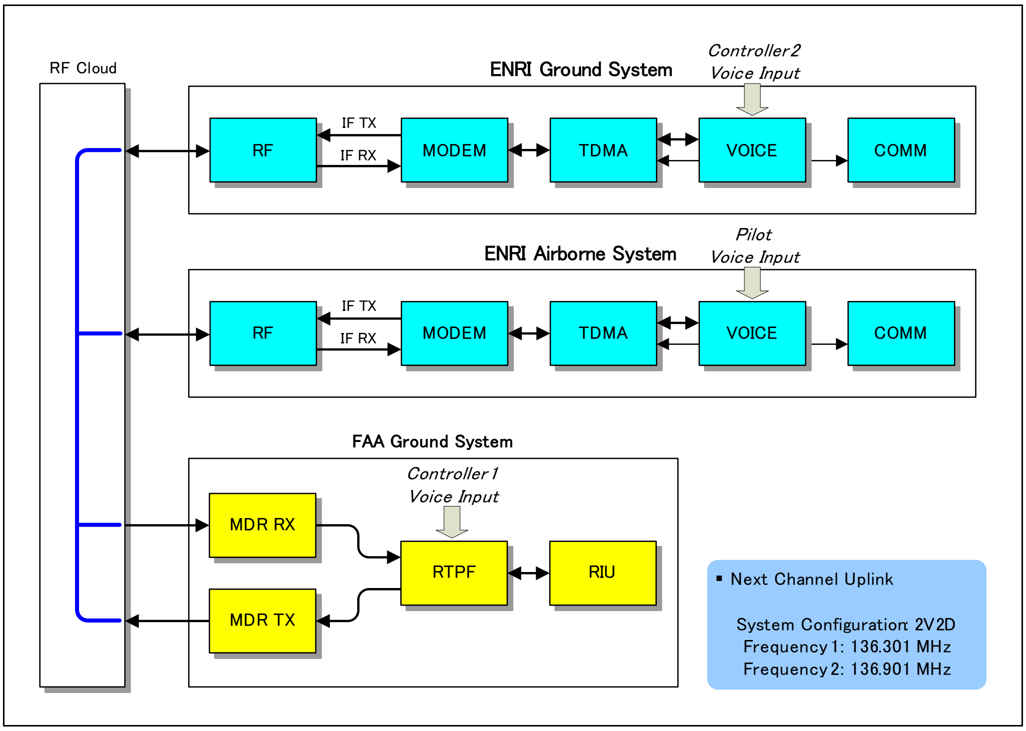

Figure 6 Test Setup (FAA GND/ENRI GND <=> ENRI AIR)

3.3.3.3 FAA Airborne System with ENRI Airborne System

(1) Truncated Voice Communication in Timing State 2

a) Test Setup: See Figure 7

b) Reading Script: ICP Appendix D, Script 7

c) Test Result: Confirmed with each other that truncated voice was received clearly.

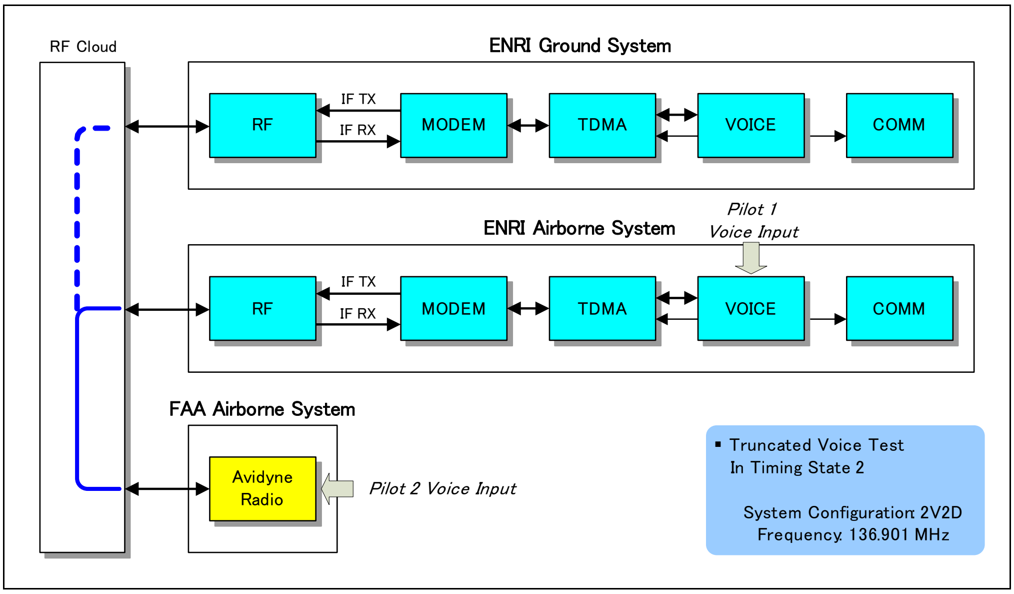

Figure 7 Test Setup (ENRI GND/AIR <=> FAA AIR)

3.4 ATN Data Communication Test

3.4.1 Test Summary

As a risk mitigator, a preliminary router connection test was conducted between Japan and the United States on June 29th and 30th to verify interoperability between the FAA A/G Router and the ENRI A/G Router using a standard ISO 8208 sub-network interface. The routers were connected using the public Internet with encapsulation of X.25 over TCP/IP (XOT) by Cisco 2600 IP routers.

ATN/VDLM3 data tests were carried out between an ENRI airborne and an FAA ground system, and an FAA airborne and an ENRI ground system. The routers exchanged CLNP PDUs over an X.25 Virtual Circuit (VC) using the ATN SNDCF for mobile ISO/IEC 8208 sub-networks. X.25 packets were encapsulated in VDLM3 frames for transmission over the VDLM3 sub-network. The tests confirmed basic connectivity and interoperability between the ENRI and FAA VDLM3 data communication sub-systems and ATN routers. Minor implementation differences were identified between the ATN routers that do not affect interoperability, but which merit clarification. It was discovered, however, that the FAA and ENRI routers handle loss of communication link and router failure/recovery in different ways that affects interoperability; communication will not always recover if a router is reset or is otherwise temporarily unable to communicate with its corresponding VDL network interface. These issues warrant further examination.

3.4.2 FAA Ground System with ENRI Airborne system

(1) Test Setup: See Figure 8

(2) Test Items

- a) Route Initiation
- b) Route Termination
- c) Echo Request/Response between ATN Routers
- d) Echo Request to Unknown Destination Address
- e) Circuit Failure at airborne side

(3) Test Result

Interoperability was confirmed between the ENRI and FAA router protocols: IDRP, CLNP, ISO/IEC 8208 mobile SNDCF with LREF PDU header compression, and ISO/IEC 8208 Packet Layer Protocol. Router-router communication in a simulated air-ground environment transmitting X.25 packets in VDL Mode 3 frames was also successfully demonstrated.

Implementation differences between the ATN routers were identified as summarized in 4.2

3.4.3 ENRI Ground System with FAA Airborne System

(1) Test Setup: See Figure 9

(2) Test Items

a) Route Initiation
b) Route Termination
c) Echo Request/Response between ATN Routers
d) Echo Request to Unknown Destination Address

(3) Test Result:

See 3.4.2 (3) Test Result.

Some data tests in this configuration experienced problems due to the corruption of VDL data frames caused by a grounding issue with the Avidyne airborne radio. This corrupted data was verified with the data logs obtained during the tests.

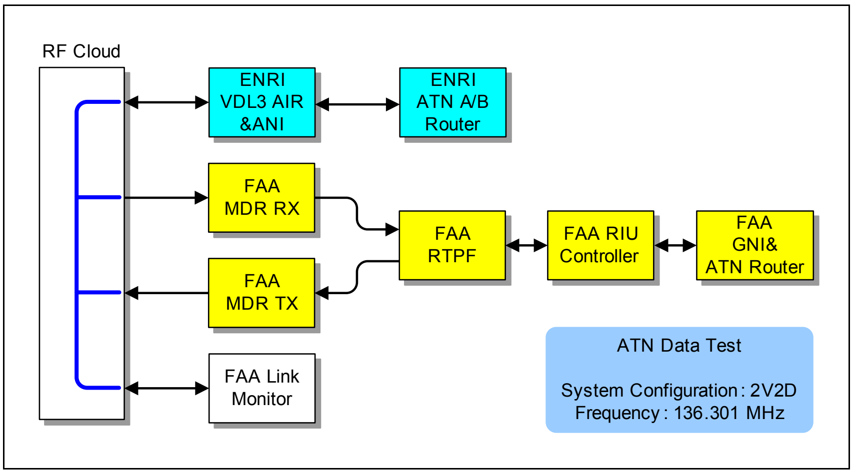

Figure 8 Test Setup (FAA GND <=> ENRI AIR)

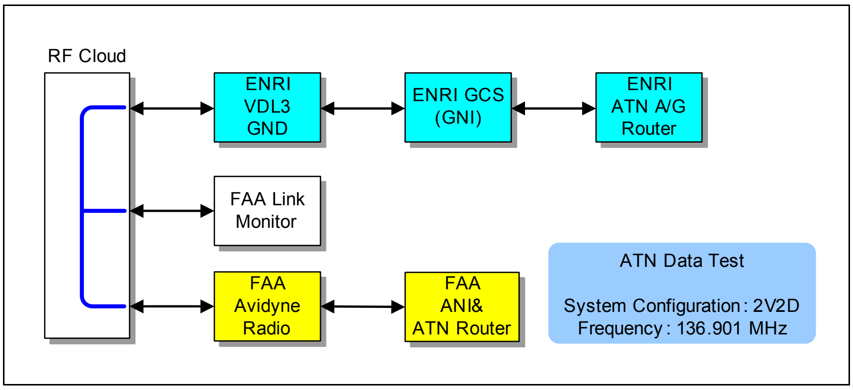

Figure 9 Test Setup (ENRI GND <=> FAA AIR)

3.5 Digital Voice Quality Test by PESQ Tool

During the Interoperability Testing, FAA engineers conducted voice quality tests of ENRI Voice unit incorporating the FAA-20 Vocoder board by the use of a Voice Quality Tester (Agilent VQT J-1981A). The VQT is capable of testing voice quality based on several evaluation methods by Perceptual Speech Quality Measurement (PSQM, ITU-T P.861), Perceptual Analysis Measurement System (PAMS) and Perceptual Evaluation of Speech Quality (PESQ, ITU-T P.862). The results of the tests indicated the following.

- PESQ score was more sensitive to signal level than other measurement scores.

- PESQ scores varied by speaker, especially in the case of truncated mode.

4 Discrepancies between FAA and ENRI Systems

During the preliminary test and the Interoperability Testing, the following discrepancies were identified between the FAA and ENRI VDLM3 systems and ATN routers. While many of these were resolved by modifications to permit interoperability testing, some remain unresolved. Some clarification of relevant ICAO documents will be required for those discrepancies resulting from the ambiguity of ICAO specifications.

4.1 VDL Mode 3 System

Probable Cause	Discrepancy	
Lack of clarity of Doc 9805	4.1.1	Supported Option Message
	4.1.2	Urgent Downlink Request
	4.1.3	Response to UDR Message
	4.1.4	Payload Octet in XID Exchange
Mis-implementation	4.1.5	Bit Ordering of Voice Frame
	4.1.6	Acknowledgment of Data Reception
	4.1.7	Toggle Bit
Function not supported	4.1.8	Sub-network Protocol for ATN Data Transfer
	4.1.9	Voice Communication in Timing State 2
Other reason	4.1.10	DLS Frame Structure
	4.1.11	Message ID
	4.1.12	XID Exchange

4.1.1 Supported Option Message

	ENRI Implementation	FAA Implementation
Discrepancy	Local user ID was set in Polling address field	Local user ID was set in Reservation Response address field
Cause	Lack of clarity of Doc 9805	
Measure	Modified to FAA implementation	---

4.1.2 Urgent Downlink Request

	ENRI Implementation	FAA Implementation
Discrepancy	Random access and polling response	Polling response only
Cause	Lack of clarity of Doc 9805	
Measure	Remain unsolved (not affected interoperability)	

4.1.3 Response to UDR Message

	ENRI Implementation	FAA Implementation
Discrepancy	Return RACK	No response
Cause	Lack of clarity of Doc 9805	
Measure	Modified to FAA implementation	---

4.1.4 Payload Octet in XID Exchange

	ENRI Implementation	FAA Implementation
Discrepancy	"Payload octet" was included in XID exchange	"Payload octet" is not included
Cause	Lack of clarity of Doc 9805	
Measure	Modified to FAA implementation	---

4.1.5 Bit Ordering of Voice Frame

	ENRI Implementation	FAA Implementation
Discrepancy	LSB first	MSB first
Cause	Based on original Doc 9805	Based on latest RTCA DO-224A
Measure	Modified to MSB first	---

4.1.6 Acknowledgment of Data Reception

	ENRI Implementation	FAA Implementation
Discrepancy	Acknowledgment of data reception was designated with each message	Discretely-addressed INFO and CTRL_RSP frames require acknowledgement of correct reception
Cause	Mis-implementation	
Measure	Corrected	---

4.1.7 Toggle Bit

	ENRI Implementation	FAA Implementation
Discrepancy	Alternate between 0/1 for uplink ACK	Alternate between 0/1 for each unique ACK frame group
Cause	Mis-implementation	
Measure	Corrected	---

4.1.8 Sub-network Protocol for ATN Data Transfer

	ENRI Implementation	FAA Implementation
Discrepancy	ATN frame mode only	ISO8208 compressed and CLNP compressed
Cause	Variation in implementation	
Measure	---	Temporarily accommodated ENRI implementation

4.1.9 Voice Communication in Timing State 2

	ENRI Implementation	FAA Implementation
Discrepancy	Not supported	Supported
Cause	DVSI VC-20 Vocoder limitation	
Measure	Vocoders have been replaced with newly developed FAA-20, which provided by the FAA	---

4.1.10 DLS Frame Structure

	ENRI Implementation	FAA Implementation
Discrepancy	Contains "user data management field" (23 byte)	---
Cause	Due to experimental purposes	
Measure	---	Temporarily accommodated ENRI implementation

4.1.11 Message ID

	ENRI Implementation	FAA Implementation
Discrepancy	Varied depending on data - acknowledged or unacknowledged	MID is fixed to "100"
Cause		?
Measure	ENRI system temporarily accommodated FAA implementation, but essentially remain unsolved.	

4.1.12 XID Exchange

	ENRI Implementation	FAA Implementation
Discrepancy	Option parameters were included	Option parameters were not included
Cause	Variation in implementation?	
Measure	Accommodated FAA implementation	---

4.2 ATN Router

Probable Cause	Discrepancy
Lack of Clarity of Doc 9705	4.2.1 ISH PDU Transmission Timing and Timer Values
Possible mis-implementation/ differing interpretation of Doc 9705	4.2.2 IDRP Connection Termination
	4.2.3 Information retained in case IDRP connection was closed
	4.2.4 Leave Event Generation by the SNDCF

Note. 4.2.3 and 4.2.4 affect interoperability and raise issues of link robustness.

4.2.1 ISH PDU Transmission Timing and Timer Values

	ENRI Implementation	FAA Implementation
Discrepancy	After VC establishment during which ISH-PDUs are exchanged in X.25 CR/CC packets using the Fast Select facility, the ENRI router transmits an additional ISH-PDU. Holding timer value was 65534	After VC establishment during which ISH-PDUs are exchanged in X.25 CR/CC packets using the Fast Select facility, no further ISH-PDU was transmitted. Holding timer value was 65535
Cause	Lack of clarity of Doc 9705	
Measure	Further investigation required.	

4.2.2 IDRP Connection Termination

	ENRI Implementation	FAA Implementation
Discrepancy	Upon receiving "Leave event" from VDLM3, an IDRP CEASE PDU was transmitted, then X.25 VC call clearing was executed.	Upon receiving "Leave event" from VDLM3, X.25 call clearing was carried out without any further transmission of CLNP PDUs.
Cause	Possible mis-implementation/differing interpretation of Doc 9705	
Measure	Further investigation required.	

4.2.3 Information retained in case IDRP connection was closed

	ENRI Implementation	FAA Implementation
Discrepancy	Closing the IDRP connection (CEASE PDU from the peer) causes the air-ground route and configuration information to be deleted. Re-establishing the air-ground route to the same peer DTE requires an exchange of ISH-PDUs.	Configuration information is retained if the IDRP connection is closed without a leave event from VDLM3.
Cause	Possible mis-implementation/differing interpretation of Doc 9705	
Measure	Further investigation required.	

4.2.4 Leave Event Generation by the SNDCF

	ENRI Implementation	FAA Implementation
Discrepancy	Certain events such as detection of circuit failure or call clearing cause the SNDCF to generate a Leave event, and configuration information to be deleted.	The SNDCF does not generate Leave Events; the router deletes routing information only upon receipt of a Leave event from the sub-network.
Cause	Possible mis-implementation/differing interpretation of Doc 9705	
Measure	Further investigation required.	

5 **Issue to be reflected to international standards**

5.1 Polling Sequence in 3V1D/2V1D system configurations

An issue was identified in the course of upgrading the ENRI VDLM3 system which, while it does not affect interoperability between the FAA and ENRI systems, could pose a serious problem in terms of net entry in 3V1D or 2V1D configuration where there are more than 25 aircraft in one user group. If there are 25 aircraft in the net, the M channels associated with the A slots are occupied by polling responses from aircraft radios, and they are not available for net entry requests from any new users. To resolve this issue, polling should be allowed on only half the cycles. It is considered that this should be reflected to the international standards.

6 Conclusions

FAA and JCAB/ENRI have confirmed that this Interoperability Testing was very successful. Validation results from this testing should be reflected in relevant ICAO documents and RTCA MASPS for clarity. A further interoperability test between the FAA and ENRI systems will be planned in the future. This will cover voice communications in various combinations of VDLM3 Timing State 1/2/3, and data communication between multiple aircraft stations. Certificated avionics will be considered as equipment for the second test. Furthermore, additional ATN data testing for other sub-network protocols and full end-to-end testing of CPDLC, CM and FIS applications over VDLM3 will be considered if the FAA and ENRI systems are available and capable of such functions in the future.