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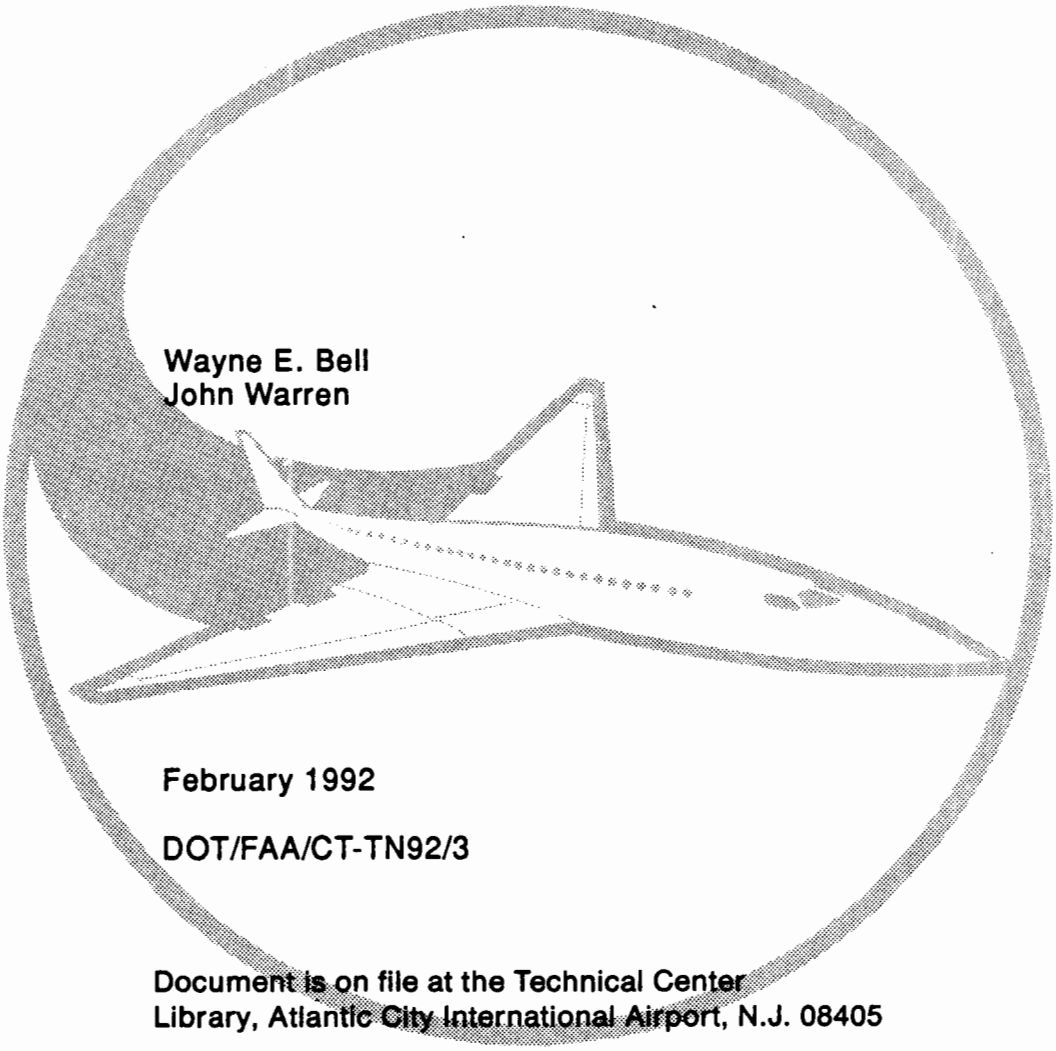
ECP-27 Final Test Report



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February 1992

DOT/FAA/CT-TN92/3

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16. Abstract

This test report contains the results of the Operational Test and Evaluation (OT&E)/Integration testing of Engineering Change Proposal No. 27 (ECP-27) equipment. This report is based on the test results derived from five separate test efforts associated with ECP-27 and performed from March 1989, to October 1991. Based on the test results, it is concluded that ECP-27 equipment performed its function of providing data exchange between National Airspace System (NAS) Radio Communications Link (RCL) facilities and is considered qualified for operational deployment.

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EXECUTIVE SUMMARY

This report describes the results of testing performed on Engineering Change Proposal No. 27 (ECP-27) to the Radio Communications Link (RCL) program which will provide the capability to handle digital data over the RCL.

This report summarizes the results of five separate test efforts associated with ECP-27 and performed from March 1989, to October 1991, by government and contractor personnel at five different locations. A different group of personnel was involved in each test. These tests include Mitre tests; the Operational Capability Demonstration (OCD); field tests from Nashua to Bangor, Maine; Coastcom tests of their Office Channel Unit Data Port (OCUDP) card; and Operational Test and Evaluation (OT&E)/Integration tests.

The test results support the recommendation to deploy ECP-27 for field use on the RCL program.

1. INTRODUCTION.

The Radio Microwave Link (RML) system which was used primarily to transmit radar video in a 5-megahertz (MHz) bandwidth, and voice and digital data over numerous 4-kilohertz (kHz) bandwidth telephone lines, is being replaced by a new interfacility communications system consisting of a Radio Communications Link (RCL), a Routing and Circuit Restoral (RCR) system and a Low Density Radio Communications Link (LDRCL) system. The RCL is an analog microwave radio communications network which operates in the 8-gigahertz (GHz) government band and is licensed by the National Telecommunications and Information Administration (NTIA) for a 20-MHz radio frequency (RF) emission bandwidth.

1.1 BACKGROUND.

This Final Test Report is based on the test results derived from the following five tests performed on Engineering Change Proposal No. 27 (ECP-27) with the participants listed in Section 1.3:

a. MITRE Corporation Tests, March 1989.
b. Operational Capability Demonstration (OCD) Tests, June 1990.
c. Nashua to Bangor, Maine, Field Tests, September 1990.
d. Coastcom Tests, April 1991.
e. Operational Test and Evaluation (OT&E)/Integration Test, October 1991.

1.2 PURPOSE.

The purpose of this report is to consolidate the test results from the five tests listed above and to determine from the test reports if ECP-27 should be recommended for deployment.

1.3 PARTICIPANTS.

MITRE Test:

NAME	ORGANIZATION
Franklin McCutchen	Mitre Corporation
William Washington	Mitre Corporation
Ben Thompson, FAA	ARTCC-Leesburg, Va.
Irvin Solt	Karkar Electronics, Inc.
John Alstatt	Karkar Electronics, Inc.
Jose Waters	Karkar Electronics, Inc.
Steve Eymann	EF Data Corporation
Greg Walker	Fairchild Data Corporation
Don Betts	Fairchild Data Corporation

OCD:

NAME	ORGANIZATION
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Bob Niedzwiecki	FAA
Frank Corpening	SEIC
Stephen Walker	RJO
Don Betts	Fairchild Data Corporation
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Marty Goldenberg	FAA-RCL Project Manager
Doug Bamford	Mitre Corporation
David Hamrick	Mitre Corporation
Malcom Clark	ASM-320
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Saud Negash	SEIC
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H.C. Wang	AT&T
Bob Lindsey	Coastcom
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Charles E. Phillips	DSC Communications
James Leard	SEIC
John Barry	AT&T RCL Project
Jim McNulty	AT&T
Shee Lee	AT&T
Jeff Yarnell	ACE-425

Nashua to Bangor Field Test:

NAME	ORGANIZATION
Joseph Hoffert	ASM-640
James Corbert	AFS-815
Jeffrey Yarnell	ACE-425
David Lee	Mitre Corporation
Douglas Lee Bamford	Mitre Corporation
James Leard	SEIC/ANC-140
Saud Negash	SEIC/ANC-140

Coastcom:

NAME	ORGANIZATION
Jim Leard	SEIC
John Barry	AT&T
John Warren	ACN-260
Jim Sullenberger	Coastcom
Tom Theriot	AT&T
Malcom Clark	FAA
Dragan Konjikusic	Coastcom
Larry Marshall	Coastcom
Ken Holt	Coastcom

OT&E/Integration:

NAME	ORGANIZATION
John Warren	ACN-260
Mike Melillo	Raytheon Corporation
Tuan Tran	ACN-260

2. TEST APPROACH AND CONCEPT.

The test concept for ECP-27 is to ensure that the digital capability added to the RCL by this system performs according to specification. The approach to achieve this goal is to thoroughly test ECP-27 in an operational environment to accurately access its performance.

3. ECP-27 TESTS.

A brief description of each of the five tests conducted on ECP-27, and listed in section 1.1, is provided in the following sections.

3.1 MITRE CORPORATION TESTS.

These tests were performed during August 1988, on the Leesburg, Virginia (ZDC) to Benson, North Carolina (QRL) link, and were comprised of the following tests:

a. Field Tests
b. Signature Tests
c. Data in Voice (DIV) and Dual DIV/Data Above Voice (DAV) Modem Tests
d. Dual EF Data, Inc., DAV Modem Tests
e. Dual Fairchild DAV Modem Tests

These tests included noise loading, noise-to-power ratio (NPR), bit-error rate (BER), RF emission, and link signature. The tests did not address BER performance as a function of link fading.

3.2 OCD TESTS.

These tests were conducted in June 1990, and consisted of the following four areas of tests:

a. Preliminary testing established a benchmark for RCL system performance while carrying its standard load of 16 Supergroups (SGs). Six individual tests were conducted:

1. Transmitter Output Frequency
2. Thermal Noise and Tone Search
3. Baseband Input and Output Levels
4. Noise-to-Power Ratio (NPR)
5. Transmitter Output Spectrum
6. Noise Threshold for Protection Switching

b. RF Emission, Noise Loading, and DAV Modem testing showed that the emitted spectrum meets NTIA requirements. Testing also showed that the FDM transmission is not impaired by the DAV signals. The DAV signals are capable of providing digital transmission at Digital Signalling Level 1 (DS-1) data rates over the RCL at BERs that do not exceed $1x10^{-6}$ as the radio paths are "noised-up" until the protection switching threshold is reached.

c. Further Digital Data testing measured the BER of the system at data rates lower than DS-1 and to observe the effect of an RCL protection switch upon the data signals.

d. Voice Frequency Circuit Performance showed the interconnection of the three multiplexers (conventional Frequency Division Multiplex (FDM), Direct-to-Line (DTL) and Digital Channel Bank) into the one RCL system and observed voice frequency (VF) performance via each of them.

3.3 NASHUA TO BANGOR, MAINE, FIELD TESTS.

These tests were conducted in September 1990, and consisted of the following tests:

a. Baseline Tests: Plots were run of NPR and Thermal Noise and Tone Search on the Boston to Bangor, Maine, link to determine the quality of the link prior to activating any new equipment.

b. DAV Tests: Frequency and output levels of the DAV modems were measured.

c. Effect of DAV Modems on Baseband: Tests were performed for unfaded conditions and faded conditions.

d. DAV Modem BER Performance: Tests were made by monitoring the data performance of the DAVs during overnight periods. Data gathered should represent typical long-term performance over an RCL link.

e. Channel Bank Data Performance: Tests were conducted for the following conditions:

1. Low speed sync; 19.2 kilo bits per second (kbps); 3-hour duration
2. Low speed sync; 9.6 kbps; 3-hour duration
3. V.35; 56 kbps; 3-hour duration
4. V.35; 64 kbps; 12 hours; 3 loopbacks (27 hops)
5. 56/64 x N Unit; 1.536 million bits per second (Mbps); 2-hour duration

f. Channel Bank Voice Frequency Performance: The following three items were evaluated:

1. Order Wire Channel Unit
2. Adaptive Differential Pulse Code Modulation (ADPCM) Channel Unit
3. 4-wire E&M Channel Unit

g. Analog Voice Frequency Performance: The purpose of this test was to evaluate the effect of the DAV modems on individual VF channels of the Karkar and Granger multiplexers. The intent of the field test was not to verify the performance of the multiplexers as they are already in service in the RCL. The following four conditions were evaluated:

1. Unfaded Conditions. Testing was conducted with appropriate noise inserted into the baseband to simulate voice loading with the DAVs on. With these conditions, VF parameters were measured on various channels and compared to NAS-SS-1000 specification requirements for data quality leased lines.

2. Faded Conditions. Testing was conducted as specified above, but with the transmitter attenuated to the baseband switch limit to simulate a fade.

3. Effect of DAV Noise. Testing was performed to determine the effect of the DAVs on the system noise level of the RCL for various fade levels.

4. Granger versus Karkar. This test was a comparison of the two multiplexers.

3.4 COASTCOM TESTS.

The purpose of the Coastcom tests was to demonstrate the capabilities of the newly revised Coastcom OCUDP Card (with secondary channel access) and the interfacing between the Coastcom Channel Bank and the Data Multiplexing Network (DMN) equipment. Twelve separate tests were performed; five with Dataphone Digital System One (64 kbps) (DDS1) channels and various clock sources, and seven with Dataphone Digital System Two (72 kbps) (DDS2) channels with various clock sources.

3.5 OT&E/INTEGRATION TEST.

A laboratory test of an ECP-27 configuration; i.e., a (Coastcom) time division multiplexer consisting of 24 DS-0 channel output to a single DS-1 channel and fed into a (Fairchild) Quadrature Amplitude Modulation (QAM) modem to a T1 line was performed at the Minneapolis Air Route Traffic Control Center (ARTCC) August 16, 1991. The specific test performed was a Signal-to-Noise Ratio (SNR) versus BER test. This test is recognized as the ultimate characterization test of any digital data system. It was only necessary to verify one of many previous similar tests in order to qualify ECP-27 in a system environment. The particular test selected was to input a 56-kbps pseudo-random data stream (from a Fireberd 6000 Communications Analyzer) into the Coastcom channel bank which would multiplex the data on to a 1.544 Mbps bipolar channel. This would then be QAM'd by the Fairchild M505M modem. This signal would be added to noise and then looped back into the Fairchild modem, demultiplexed by the Coastcom channel bank, and finally, the Fireberd 6000 would record errors due to the incorrect detection by the QAM modem after the pulses were degraded by noise.

4. TEST RESULTS.

4.1 MITRE TEST RESULTS.

Test results and related analysis have confirmed that adding two DS-1 channels above the FDM baseband is viable, meets emission bandwidth regulations, and provides acceptable transmission quality. The ability to use DAV modems, using all of the RCL's frequency spectrum resources, will increase the load capacity available to the Federal Aviation Administration (FAA), with only minor RCL retrofit required. It was also confirmed that transmission of a DS-1 signal within the FDM voice frequency channels is practical, and would allow the FAA to meet their immediate high-speed data transmission needs by using DIV modems.

The complete test report, with all test data, is available from the Program Office, ANC-140.

4.2 OCD TEST RESULTS.

Test results were derived from a review of the actual test data since no test results were provided in the test report. In general, the testing procedures and the results obtained were in conformance with standard testing methods and the results were within expected limits.

The complete test report, with all test data, is available from the Program Office, ANC-140.

4.3 FIELD TEST RESULTS.

Test results for each of the seven tests listed in section 3.3 are presented below.

a. Baseline Tests: Testing indicated satisfactory operation.

b. DAV Checks: All DAVs at Boston were within specification. At Bangor, DAV #1 was out of specification for frequency (1,599,939 hertz (Hz) versus 1,600,000 Hz +/-5 Hz), and DAV #5 was out of specification for combiner output (-31.2 decibels above 1 milliwatt (dBm) versus 31.5 dBm +/-0.25 decibel (dB)). The tolerances are those specified by the equipment manufacturer, and the out-of-specification conditions noted is considered negligible as far as operation is concerned.

c. Effect of Data-Above-Voice:

1. Unfaded Conditions. The DAV modems added up to 9 dB of noise to the baseband spectrum, however, the link still met the system requirements for NPR specified in Order 6540.5A. The DAV modems produced some spurious tones, but none of these exceeded the system requirement of -78 dBm.

2. Faded Conditions. The noise generated by the DAV modems was negligible when compared to system noise under fade conditions. Performance of the system will not be degraded by DAV modems during fade.

d. DAV Modem BER Performance. Data taken shows that the DAV modem meets the requirement of NAS-SS-1000 for an E-06 BER. Performance of the DAVs on the RCL link was acceptable.

e. Channel Bank Data Performance. Data showed that the channel bank met NAS-SS-1000 requirements for an E-06 BER. Available data channels were tested with the following results:

1. Low Speed Sync; 19.2 kbps; 11-hour duration. Bangor was error free. Nashua to Bangor link suffered fades and lost sync. No BER data available at Nashua due to improper test setup.

2. The following tests ran error free:

a. Low Speed Sync; 9.6 kbps; 3-hour duration
b. V.35; 56 kbps; 3 hours
c. V.35; 64 kbps; 12 hours; 3 loopbacks (27 hops)
d. 56/64 x N Unit; 1.536 Mbps; 2 hours

3. The following results were obtained with the link faded to the switch point.

a. V.35; 56 kbps; 1 minute; Bangor to Nashua. Average BER was 1.11E-06. Percentage error-free seconds (EFS) was 96.7.

b. V.35; 56 kbps; 10 minutes; Nashua to Bangor. Average BER was 1E-07. Percentage EFS was 99.5.

c. V.35; 56 kbps: 1 hour, 20 minutes; Nashua to Bangor. Average BER was 2.6E-07. Percentage EFS was 99.3.

f. Channel Bank Voice Frequency Performance.

1. Order Wire Channel Unit. A subjective evaluation of the order wire indicated that its performance was acceptable. Unit was used throughout the test to maintain communications between Bangor and Nashua. Voice quality was good even with the link faded to the switch point. Changing between channels produced audible clicks which were not considered serious.

2. ADPCM Channel Unit. This unit uses compression techniques to provide two voice channels per 64 kbps slot, rather than one. Performance was acceptable during unfaded and faded conditions. The units are suitable for voice applications.

g. Analog Voice Frequency Performance.

1. Unfaded Conditions. No out-of-tolerance conditions were encountered.

2. Faded Conditions. Out-of-tolerance conditions were seen on almost all channels tested due to high noise levels, but this was seen with and without the DAVs on. The DAVs had no appreciable effect on the readings.

3. Effect of DAV Noise. Data taken indicates that the system noise level is unaffected by the DAVs contribution when the transmitter output is attenuated 20 to 25 dB. In other words, the DAV noise will have no effect on the existing operating fade margin.

4. Granger versus Karkar. Data taken under unfaded conditions is inconclusive due to limitations in test capabilities. Under faded conditions, data indicates the Karkar provides slightly better Signal-to-Noise ratio (S/N) than the Granger.

The complete test report, with all test data, is available from the Program Office, ANC-140.

4.4 COASTCOM TEST RESULTS.

Twelve tests were conducted during a 2-day period. The test verified the Coastcom equipment's ability to transmit and receive data on both primary and secondary channels from OCUDP card to OCUDP card and again with the Codex 3500 Channel Service Unit/Data Service Unit (CSU/DSU) placed in the system. A breakdown of the results and appropriate references are provided in table 1. Each test was performed for approximately 10 to 15 minutes, except for the DDS1 and DDS2 end-to-end configuration which was conducted for 12 hours.

The statement that a test passed means that:

1. Error-free transmission was observed.

2. At each test, errors were transmitted through the system under test, to validate the test procedure.

The test signal for the primary channel was a 56-kbps psuedo-random data signal in all cases except for Test No. 10 where the Codex 3500 "steals" some bits for the secondary channel and thus reduces the primary channel rate to 55.2 kbps. Except where noted, the secondary channel test signal was a 75 or 150 bits per second (bps) signal generated in the Codex 3500.

Local loop timing for this 56 kbps signal is provided by the Drop/Insert (D/I) Mux. The DS-1 clock was provided by the Hewlett Packard (HP) test set or by the D/I Mux as tabulated in table 1. The symbol HP/Mux means that the test was performed in two steps; in the first, the HP provided the clock, and in the second, the D/I provided the clock. For these tests, the Wire Line Simulator was set to represent various lengths of 26-gauge unloaded twisted pair as shown in the notes associated with the matrix.

The complete test report, with all test data, is available from the Program Office, ANC-140.

TABLE 1. COASTCOM TEST MATRIX

TEST NO.	FIG	TEST MODE	TEST RESULTS	NOTES	DS1 CLOCK SOURCE
1	1	DDS2	PRIMARY CHANNEL PASSED	1	HP
2	1	DDS2	SECONDARY CHANNEL PASS	1	D/I MUX
3	2	DDS2	PRIMARY CHANNEL PASSED	2	HP/MUX
4	3	DDS2	PRIMARY CHANNEL PASSED	3	HP/MUX
5	3	DDS2	LOOPBACK ACHIEVED	4	HP
6	4	DDS1	PRIMARY CHANNEL PASSED		HP
7	5	DDS1	PRIMARY CHANNEL PASSED	5	HP
8	6	DDS1	PRIMARY CHANNEL PASSED	6	HP
9	7	DDS1	PRIMARY CHANNEL PASSED	7	D/I MUX
10	8	DDS1	PRI & SEC CHANNEL PASS	8	D/I MUX
11	9	DDS2	PRIMARY CHANNEL PASSED	9	D/I MUX
12	9	DDS2	PRIMARY CHANNEL PASSED 16 HOUR TEST	9	D/I MUX

NOTES:

1. Secondary channel at 2.66 kbps per AT&T TR 62120
2. Primary channel good to 8,000-foot wire line
3. Primary channel good to 12,000-foot wire line
4. HP sent control signals to cause loopback at the OCUDP and then at the CODEX 3500
5. First CODEX failed at 4,000 feet, second CODEX passed out to 12,000 feet.
6. Primary channel good to 9,000 feet.
7. CODEX 3500 in normal mode
8. CODEX 3500 in "Bit Steal" mode
9. Secondary channel failed. It appeared that "IN CODEX 3500, String of 0's caused failure".

4.5 OT&E/INTEGRATION TEST RESULTS.

The OT&E/Integration data collected verified the expected performance of the ECP-27 configuration. The ECP-27 configuration consisted of the combination of a Time Division Multiplexer (Coastcom TDM) interfaced to a DS-1/Quadrature Phase Shift Keying (QPSK) modem (Fairchild M505M). The data indicates that a BER of 10^{-6} can be achieved with a SNR of about 15 dB, which was expected.

A summary of the data is provided below:

Carrier Level (dBm)	Noise Level (dBm)	S/N (dB)	BER
-29.5	-44.5	15.0	(Zero Errors)
-29.5	-43.4	13.9	5.5 x E-6
-29.5	-42.2	12.7	2.54 x E-5
-29.5	-41.2	11.7	8.13 x E-5
-29.5	-40.1	10.6	2.28 x E-4
-29.5	-39.0	9.5	6.91 x E-4
-29.5	-37.9	8.4	2.00 x E-3
-29.5	-36.7	7.3	(Loss of Sync)

The measurements were made in watts, therefore, the signal "S" was calculated by the following formula:

$$S = SQRT(C^2 + N^2).$$

The signal measuring device was placed in the wide-bandwidth mode when measuring the peak carrier power. The noise was measured in a 1-Hz bandwidth. It was necessary to increase that power measurement by the ratio of the Fairchild modem's receiver bandwidth (1.1 MHz) to the 1-Hz bandwidth or 60.4 dB. This data verifies previous tests at Fairchild and theoretical predictions.

The complete test report, with all test data, is available from the Program Office, ANC-140.

5. CONCLUSIONS.

Conclusions are presented separately for each of the five tests discussed in this report. It must be noted that these conclusions were derived from the test reports provided to ACN-260. ACN-260 personnel participated in the Operational Capability Demonstration (OCD), Coastcom, and Operational Test and Evaluation (OT&E)/ Integration.

5.1 MITRE TEST CONCLUSIONS.

Test results and related analysis have confirmed that adding two DS-1 channels above the Frequency Division Multiplex (FDM) baseband is viable, and also meets and provides acceptable transmission quality. The ability to use Data Above Voice (DAV) modems, thereby using all of the Radio Communications Link's (RCL) frequency spectrum resources, will increase the load capacity available to the Federal Aviation Administration (FAA), with only minor RCL retrofit required. It was also confirmed that transmission of a DS-1 signal within the FDM voice frequency channels is practical, and would allow the FAA to meet their immediate high-speed data transmission needs by using Data-in-Voice (DIV) modems.

5.2 OCD TEST CONCLUSIONS.

All tests conducted at Coastcom were successfully completed and met operational requirements.

5.3 FIELD TEST CONCLUSIONS.

The initial short-term testing of ECP-27 was successfully completed. Some of the objectives of the long-term testing could not be attained due to the lack of familiarity with the Fireberd test sets and the inability to input operational traffic on the test link. However, the data does provide valuable information on the reliability of the equipment, stability of the modems, and performance of the modems over the RCL.

5.4 COASTCOM TEST CONCLUSIONS.

All 12 tests conducted at Coastcom were successfully completed and met operating requirements.

5.5 OT&E/INTEGRATION TEST CONCLUSIONS.

The OT&E/Integration data collected verified the expected performance of the ECP-27 configuration. It is recommended that ECP-27 be incorporated into the analog RCL in order to upgrade its data handling capabilities to multiple DS-1 FDM channels with each DS-1 consisting of up to 24 Digital Signalling Level 0 (DS-0) Time Division Multiplex (TDM) channels. However, it should be recognized that when unacceptable error rates occur over a specified time interval, it is the responsibility of the end users to provide for error detection and/or correction in order to achieve a bit-error rate (BER) performance that will meet or exceed the safe air traffic control (ATC) performance of the National Airspace System (NAS).

6. RECOMMENDATIONS.

Based on the test results presented in this report, ACN-260 recommends that ECP-27 be approved for deployment into the Radio Communications Link (RCL).

7. ACRONYMS AND ABBREVIATIONS.

ADPCM	Adaptive Differential Pulse Code Modulation
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
BER	bit-error rate
bps	bits per second
CSU/DSU	Channel Service Unit/Data Service Unit
dB	decibel
dBm	decibels (above 1 milliwatt)
DAV	Data Above Voice
DDS1	Dataphone Digital System One (64 kbps)
DDS2	Dataphone Digital System Two (72 kbps)
D/I	Drop/Insert
DIV	Data-in-Voice
DMN	Data Multiplexing Network
DS-1	Digital Signalling Level 1
DS-0	Digital Signalling Level 0
DTL	Direct-to-Line
ECP-27	Engineering Change Proposal No. 27
EFS	error-free seconds
FAA	Federal Aviation Administration
FDM	Frequency Division Multiplex
GHz	gigahertz
HP	Hewlett Packard Co.
Hz	hertz
kbps	kilo bits per second
KHz	kilohertz
LDRCL	Low Density Radio Communications Link
Mbps	million bits per second
MHz	megahertz
NAS	National Airspace System
NPR	Noise-to-power ratio
NTIA	National Telecommunications and Information Administration
OCD	Operational Capability Demonstration
OCUDP	Office Channel Unit Data Port
OT&E	Operational Test and Evaluation
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QRL	ARTCC Benson, North Carolina
RCL	Radio Communication Link
RCR	RCL Circuit Restoral
RF	radio frequency
RML	Radio Microwave Link
SG	Super Group
S/N	Signal-to-Noise
SNR	Signal-to-Noise Ratio
TDM	Time Division Multiplex
VF	voice frequency
ZDC	ARTCC Leesburg, VA (Washington, DC)