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NATIONAL RADIO SYSTEMS COMMITTEE

NRSC-R50
Digital Audio Radio IBOC Laboratory Tests
Transmission Quality Failure Characterization and Analog Compatibility of IBOC Systems
August 11, 1995

Part I - Report

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FOREWORD

NRSC-R50, Digital Audio Radio – IBOC Laboratory Tests – Transmission Quality Failure Characterization and Analog Compatibility of IBOC Systems, presents the results of digital radio system tests conducted jointly by the Electronics Industries Association (EIA, precursor to CEA) Subcommittee on Digital Audio Radio (DAR) and the NRSC Digital Audio Broadcasting (DAB) Subcommittee (now the DRB Subcommittee).

Seven different digital radio systems were involved in the joint EIA/NRSC test program—three FM in-band/on-channel (IBOC) systems, one FM in-band/adjacent channel (IBAC) system, one AM IBOC system, the Eureka-147 DAB system (operating at L-band), and a satellite system (operating at S-band). The FM and AM band systems were the only ones considered by the NRSC and consequently the L-band and S-band test results are not included in NRSC-R50. The NRSC chairman at the time of the submission of NRSC-R-50 was Charles Morgan.

The NRSC is jointly sponsored by the Consumer Electronics Association and the National Association of Broadcasters. It serves as an industry-wide standards-setting body for technical aspects of terrestrial over-the-air radio broadcasting systems in the United States.

NATIONAL RADIO SYSTEMS COMMITTEE
DIGITAL AUDIO BROADCAST SUBCOMMITTEE

Report on:

Digital Audio Radio

IBOC Laboratory Tests

Transmission Quality Failure Characterization and Analog Compatibility of IBOC Systems

August 11, 1995

Published by:
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Consumer Electronics Group

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NOTE:

The attached report was prepared for the National Radio Systems Committee, DAB Subcommittee and contains only in-band/on-channel (IBOC) related test results.

This report of laboratory test data will be supplemented at a later date with further information on the AM IBOC system (digital and compatibility results). Further, field testing of systems is expected to conclude by the end of 1995, to be documented in a subsequent report of results. Taken together, these reports will provide a comprehensive basis to evaluate overall system performance.

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1 INTRODUCTION

The Electronic Industries Association Subcommittee on Digital Audio Radio (DAR) and the National Radio Systems Committee (NRSC) Subcommittee on Digital Audio Broadcasting (DAB) are evaluating proposed digital radio systems for standardization. The Test Working Group B of the EIA DAR Subcommittee is responsible for conducting the laboratory tests for the seven proposed DAR systems. Of these, four of the DAR systems are intended to operate in the VHF (88 MHz to 108 MHz) FM band, one in the medium wave band (AM), one in the satellite S band, and one in the terrestrial broadcast L band. Of the four systems intended to operate in the FM band, one of the systems is designed to operate on adjacent channels, and the remaining three are proposed to share existing channels. The in-band/on-channel (IBOC) DAR system tests have been conducted in partnership with the National Radio Systems Committee.

The DAR tests were conducted in two laboratories, the transmission laboratory at NASA Lewis Research Center, Cleveland, Ohio (LeRC), and the expert subjective tests at the Communications Research Centre Psychoacoustics and Subjective Assessment Laboratory (CRC), Ottawa, Ontario. The tests at LeRC were conducted in two phases, digital and in-band compatibility. The digital phase evaluated quality and characterized the signal failure. Additionally, the digital tests included multipath, co-channel, and adjacent channel impairments. The in-band compatibility phase of the transmission tests were conducted at the transmission test laboratory. They included tests to measure possible interference to the existing analog program services caused by the introduction of in-band DAR. Comprehensive tests were also conducted to assess the compatibility of analog and digital subcarrier (ancillary services channels) with the in-band IBAC and IBOC signals. For the in-band compatibility tests, the committee approved the selection of five consumer receivers for the FM band and three for the AM band to assess the compatibility of each in band system. The receivers selected are representative of the existing analog receiver population.

Threshold of audibility and point of failure tests for the digital systems were conducted by the laboratory specialists in Cleveland. The results of transmission tests were digitally recorded at the transmission laboratory and sent to CRC for assessment.

In-band compatibility objective tests were conducted at the transmission laboratory. Digital audio tape recordings were made at the output of the analog compatibility receivers for subjective evaluation by industry experts.

1.1 Scope

The scope of this report is to present the data gathered on the DAR systems so as to allow direct comparison of the data from a qualitative and quantitative objective perspective.

The tests conducted on these systems are outlined in the Unified DAR Laboratory Test Procedures. Modifications to these procedures were made and approved by the EIA DAR and NRSC DAB Subcommittees. Further procedural details are contained in later sections of this report.

1.2 Acknowledgments

The Electronic Industries Association gratefully acknowledges the contributions of equipment, services and / or funding to it's Digital Audio Radio Test Laboratory from the following organizations:

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Orban
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Public Broadcasting Service
RE America, Inc.
Satellite CD Radio
Seiko Telecommunications
TDK

1.3 Working Group B

The EIA DAR Subcommittee Working Group B on testing started meeting in the summer of 1992. The working group completed a laboratory test plan, established a transmission test laboratory, selected a subjective testing laboratory, characterized the transmission multipath for the FM band (88 MHz to 108 MHz), and completed the laboratory testing process.

The seven DAR systems that were presented to the working group by the DAR Subcommittee have been divided into four subgroups. Table 1 shows the proponent, frequency band of operation, and the designated subgroup. Two of the proponent systems include a second mode of operation, Eureka 147 and AT&T/Amati resulting in a total of 9 systems to be tested.

* Systems include a second mode.			
Proponent	Band	Subgroup	Subgroup Designator
Eureka 147*	1452-1492 MHz	New Band	NB
AT&T	88-108 MHz	In-Band/Adjacent Channel	IBAC
USADR-AM	.54-1.7 MHz	In-Band/On-Channel	IBOC
AT&T/Amati*	88-108 MHz	In-Band/On-Channel	IBOC
USADR-FM #1	88-108 MHz	In-Band/On-Channel	IBOC
USADR-FM #2	88-108 MHz	In-Band/On-Channel	IBOC
VOA/JPL	2310-2360 MHz	Direct Broadcast Satellite	DBS

Table 1 System / Subgroup Designators

1.3.1 List of Test Procedures

The test procedures assembled by Working Group B call for fifteen tests. The following is a list of the test procedures:

A. Calibration: Daily, Weekly, and Monthly

B. Signal Failure Characterization
1. Noise
2. Co-Channel
3. Multipath and Noise

C. DAR Performance with Impairment

D. DAR ⇒ DAR with no other Impairments:
Co-Channel, First, and Second Adjacent

E. Test D with Multipath

F. DAR ⇒ Analog with no other Impairment:
Co-Channel, First, and Second Adjacent

G. Test F with Multipath on FM

H. Analog ⇒ DAR with no other Impairment: Co-Channel, First, and Second Adjacent

I. Test H with Multipath

J. Reacquisition

K. Transmission Quality
1. Test Materials Selection
2. Transmission Quality

L. IBOC ⇒ Host Analog

M. Host Analog ⇒ IBOC

N. Multiple Spurious
1. DAR + FM ⇒ FM

O. Subcarriers

1.4 Description of Test Procedures

The following sections detail the various tests.

1.4.1 TEST A CALIBRATION

This test certified that the test bed and the proponent systems were operating within specification. Daily, the system RF power, spectrum, and point of failure with noise was measured, and a digital recording was made of each system's audio quality. Weekly, the in-band proponent analog transmitters and the laboratories reference analog transmitter performance were measured. The analog AM and FM modulation monitors were checked as needed, or weekly. The test bed was re-calibrated monthly or whenever designated by the RF Test Manager. System self checking programs supplied by the proponent were run on a schedule mutually agreed by the proponents and the RF Test Manager.

1.4.2 TEST B SIGNAL FAILURE CHARACTERIZATION

Test B is designed to characterize the digital signal failure with noise, co-channel interference, and noise with multipath. The tests were conducted in the transmission laboratory (LeRC), and the results were assessed by expert listeners at the CRC. Impairment audio test material were selected and used for impairment testing. Processed audio was used for the IBOC analog audio signal.

For the signal failure with noise test, Gaussian noise was added to the signal, and the noise increased until point of failure was heard on the decoded digital audio by the laboratory specialists. Point Of Failure (POF) is the point where the signal completely fails, or the interference is very annoying. The Threshold Of Audibility (TOA) is the point where the interference is perceptible, but not annoying. To find TOA the noise was set at minimum and then increased until the laboratory specialists could hear it. To minimize the possible measurement variations caused by hysteresis, the interference was increased rather than decreased prior to recording. An attenuator with .25 dB steps was used to find the TOA. From the POF the noise was reduced in 0.5 dB steps until the noise was 1.5 dB below the TOA. From this point the noise was increased in .5 dB steps, and digital recordings were made at each step. This was repeated for each of the three impairment audio segments. The digital audio tapes produced in these tests were sent to the CRC for assessment by expert listeners. With the assessments made from these tapes, the failure characteristic was plotted for each DAR system and for each impairment. Also, the TOA found at the transmission laboratory was re-confirmed by the experts at the subjective assessment laboratory.

For the second part of test B, co-channel interference was substituted for noise, and the tapes produced were sent to the CRC for expert assessment.

Test B-3, multipath and noise, was conducted four times, each with different multipath scenarios. The multipath parameters were specified by the Channel Characterization Task Group of Working Group B. A paper describing how these scenarios were derived is part of this report. The procedure followed here was similar to the procedure used for the noise test. Digital recordings were made for subjective assessment at the CRC.

Each of the DAR systems incorporates an ancillary data channel. The BER for these channels was measured with the interference set at levels near TOA and POF for each of the three impairments in tests B-1, B-2 and B-3.

1.4.3 TEST C PERFORMANCE WITH IMPAIRMENTS

This test used the following impairments; impulse noise, CW, airplane flutter, weak signal, additional multipath scenarios not used in test B, and simulated environmental noise for the system that operates in the medium wave (AM) band. The test results are reported with Expert Observation and Commentary (EO&C) by the laboratory specialists in this document.

1.4.4 TESTS D & E DAR ⇒ DAR TESTS

These tests measured the DAR ⇒DAR interference to co-channel, first adjacent, and the second adjacent digital signals. Test E was conducted with multipath added to the parameters in test D. This is an EO&C test by the transmission laboratory specialists. The D/U at the TOA and POF is reported for each system.

1.4.5 TESTS F & G DAR ⇒ ANALOG COMPATIBILITY

This compatibility series of tests is restricted to the IBOC and IBAC systems. The analog ⇒ analog interference was used as a reference and compared to the DAR ⇒ analog interference. Co-channel, first adjacent, and second adjacent tests were conducted for tests F & G. The interference to the analog signal was measured objectively and subjectively. Digital audio tapes were recorded for further subjective assessment by industry experts. Test G is the same as test F with multipath added. Standard consumer receivers were used for this compatibility test. Five FM stereo receivers were used for the FM compatibility tests and three for the AM tests.

1.4.6 TESTS H & I ANALOG ⇒ DAR COMPATIBILITY

These tests measured possible interference from the existing analog service to the digital service. The undesired FM audio was clipped pink noise. The undesired analog signal was heavily modulated to the legal maximum with clipped pink noise and, in selected cases, with subcarriers. With the IBOC systems the FM channel was modulated with processed rock music. The desired DAB signal was modulated with the impairment test audio. This is an EO&C test with the laboratory specialists determining the D/U at the TOA and POF using the glockenspiel impairment audio test segment. Test H & I was conducted with the undesired analog signal on co-channel, first adjacent channel, and second adjacent channel.

The analog FM transmitter subcarrier to DAR compatibility test was conducted listening to the desired digital audio. With the undesired FM signal level set to produce TOA, either subcarrier group A or B was switched on and the transmission laboratory specialist noted any change in the TOA. If a change in TOA was noted when either subcarrier group was on, the undesired FM signal was reduced until a new TOA was found. Test I is similar to test H with multipath added.

1.4.7 TEST J ACQUISITION AND REACQUISITION

This test was conducted in two parts; weak signal failure acquisition time and reacquisition with simulated multipath and noise. The multipath test measured the reacquisition times with four different multipath scenarios.

1.4.8 TEST K DAR QUALITY

This test, one of the most important in the series, was conducted in two parts. The first part was the selection of audio test segments for the quality and impairment testing, and the second part was the actual quality testing.

To start the process, members of the Working Group B submitted digital audio materials on digital audio tape to be used for the selection of the test segments. Pre-processed digital audio segments were also considered. At the DAR transmission laboratory each of the proposed audio segments was transmitted through each complete DAR system. The objective of this process was to identify at least nine test segments that are suitable for digital radio system quality evaluation. Of these at least two segments were selected that are considered critical for each proponent system.

For the second part of the test K-2, the nine quality audio test segments selected in K-1 were used to assess the quality of each coding system. These tests were conducted by expert listeners at the CRC facilities in Ottawa. The procedure used for assessment is in compliance with the procedure recommended by the CCIR for testing low bit-rate audio coding systems with small impairments. The facilities at the CRC were used for both the quality test K and impairment test B assessments.

1.4.9 TEST L IBOC ⇒ HOST ANALOG and TEST M HOST ANALOG ⇒ IBOC

The IBOC to host analog tests were conducted for both the FM and AM based systems. The test compared the performance of a reference analog transmitter with the performance of the IBOC analog channel. Five selected FM stereo receivers and three AM receivers were used for these tests. Subcarrier tests using analog, 57 kHz digital, and high speed digital subcarriers were included.

1.4.10 TEST N MULTIPLE SPURIOUS

In addition to co-channel and adjacent channel minimum separations, Part 73.207 of the FCC rules specifies minimum distance separation requirements for FM stations operating at 10.6 MHz and 10.8 MHz (10.7 MHz IF) above and below the operating channel. Using the interference caused by two FM stations operating at the 10.7 MHz separation as the reference, Test N compared the two FM station's reference with the interference caused by an IBAC and FM station at the same RF power level. This is an IBAC specific test.

1.4.11 TEST O SUBCARRIER TEST

In-band DAR system compatibility with analog subcarrier tests were conducted. Table 2 shows the number, frequency and injection for the four subcarrier groups. Both objective and subjective EO&C measurements were made. For the 57 kHz RBDS and the high speed data, bit error measurements were conducted.

Subcarrier Group A	Subcarrier Group B	Subcarrier Group C	Subcarrier Group D
57 kHz RBDS 3%	57 kHz RBDS 10 % (Simulated Paging)	Analog 67 kHz 10%	
66.5 kHz 8.5% (HS Digital)	Analog 67 kHz 10%	Analog 92 kHz 10 %	
Analog 92 kHz 8.5%			92 kHz 10% (HS Digital)

Table 2 Subcarrier Group Allocation

2 PROPONENT SYSTEM DESCRIPTIONS

This report contains information regarding the performance of Digital Audio Radio Systems (DAR).

These systems shown below with their letter codes as used in the testing laboratories, include:

D) AT&T / Amati In Band On Channel Lower Side Band

E) AT&T / Amati In Band On Channel Dual Side Band

G) USA Digital Radio In Band On Channel FM 2

H) USA Digital Radio In Band On Channel FM 1

I) USA Digital Radio In Band On Channel AM

K) AT&T / Amati In Band On Channel Dual Side Band Revision B

L) USA Digital Radio In Band On Channel FM 1 Revision B

These systems were submitted to the Electronic Industries Association Consumer Electronics Group for testing and comparison at NASA's Lewis Research Center. Systems were delivered and set up by the designated representatives of the system proponents.

Proponents are as follow:

1) USA Digital Radio

2) AT&T / Amati Communications Corporation

A detailed description of the systems submitted for testing is included in Appendix A.

3 TEST PROCEDURES

Various issues regarding test method and procedures are included in the following sections.

3.1 Unified DAR Laboratory Test Procedures

A complete listing of the tests and procedures are in Appendix B.

3.2 Digital Subjective Test Procedures

CRC has published a report which details the Digital Subjective Tests. This report is in Appendix C.

3.3 Subcommittee Approved Test Procedure Changes

* The subcommittee approved implementing a system specific test on the Eureka 147 system.
* Approved changes for Tests, A, B & C shown in italics on July 1995 version of the test procedures.
* Added Doppler multipath to tests C-6, E, I, J and M-2.
* Reduced the number of consumer test receivers for the FM band compatibility tests to five.
* Reduced the number of consumer test receivers for the AM band compatibility tests to three.
* For test B approved the reduction of the number of intermediate measurement points to one when the TOA-to-POF spread is 1 dB or less.
* Added subcarrier test groups C and D to the procedures. Subcarrier group C has two analog subcarrier signals each with 10% injection at 67 kHz and 92 kHz. Group D is a single digital high speed subcarrier with a 10% injection.
* Modified Test H (analog-to-DAR) to use clipped pink noise (instead of processed rock program material) to modulate the interfering signal with the lab staff spot checking both to determine any correlation.
* Modified Test I (analog-to-DAR, with multipath) to use: (1) clipped pink noise; (2) two multipath scenarios (urban-fast, and urban-slow) instead of four; (3) one subcarrier mode (group A); and (4) only one desired signal level (moderate, -62 dBm) instead of moderate and weak (-77 dBm) levels, except for co-channel where both will be used.
* Approved subjective test assessment procedures and methods for Tests F-4, F-5, F-6, G-1, L-3 and L-4.
* Approved new test procedures of test N multiple spurious.
* Modified test G DAR ⇒ analog with multipath and subcarriers. (Only the test with subcarriers was eliminated.)

* The digital ancillary data channel tests (demonstrations) will be conducted using test B impairments.

3.4 Laboratory Procedures as Tested

During the course of testing the various DAR Systems, it became necessary to expand on or make deviations to the test procedures while conducting certain tests. The assumptions or deviations the laboratory staff made to or from the formal procedures are detailed in the following Digital Tests and Analog Compatibility Sections.

3.4.1 Digital Tests

The digital phase of testing focused on quality, failure characterization and performance with impairment.

3.4.1.1 Quality Test K

Quality tests were conducted at medium signal strength. The test program materials submitted for this test were transmitted through the unimpaired RF channel. The recovered digital audio, which was subjected to the encode and decode process and recorded on DAT, was sent to CRC for evaluation. Further details concerning Test K are included in Section 5 of this report.

3.4.1.2 Failure Characterization B-Series Tests

During failure characterization tests B-1, B-2 and B-3 Additive White Gaussian Noise (gaussian noise) or Co-Channel impairment was added to the desired signal in 0.25 dB steps until system threshold of audibility (TOA) was reached with three different critical materials. Then from a level 1.5 dB from TOA on the clean side of TOA, the level of impairment was increased in 0.25 or 0.5 dB steps and recorded digitally until system point of failure (POF) was reached. This was done to prevent any potential hysteresis from skewing the data. Some tests had an additional level beyond POF recorded and a clear channel recording before the POF recording to assist CRC experts in synchronizing the POF recording to the reference material. Glockenspiel, Soprano and Clarinet (tracks 35, 62 and 16 respectively from the EBU Subjective Quality Assessment Material CD) were the critical materials which CRC supplied on DAT at 48 kHz and 32 kHz sampling frequencies. These were the reference materials. CRC sample rate converted (SRC) the materials from 44.1 kHz to 48 or 32 kHz, then recorded the SRC output onto the digital audio workstation. The workstation audio was repeatedly recorded to DAT to provide the lab staff a method to have the reference materials play without rewinding the DAT for approximately 1 hour. Glockenspiel was used frequently in other digital failure tests.

The TOA to POF spread in Test B-3 was recorded only if defects in the recovered audio could not be heard while the simulation was running without added gaussian noise. If defects could be detected without gaussian noise, the recovered audio (if any) was recorded. When gaussian noise was added and a TOA to POF spread was recorded the levels recorded were determined by taking 2 levels prior to TOA in 0.5 dB steps, then TOA and TOA + 0.5 dB. Two intermediate levels, which are approximately equidistant from TOA and POF, are also recorded. In many cases the TOA to POF spread was too large to record each 0.25 or 0.5 dB step between TOA and POF.

3.4.1.3 Impairment C-Series Tests

Test C-1 Impulse response is only conducted on systems in the AM and FM bands. Reference Appendix W for further information regarding the impulse characteristics.

The CW response test C-2 was only conducted at the medium signal level; however, once the level of the interfering signal was known at POF, the manual sweep then occurred at the POF level and 2 additional undesired signal levels.

The Airplane Flutter test C-3 was conducted only at the medium signal level.

Test C-4 Weak Signal Sensitivity was conducted with an attenuator resolution of 1 dB.

The Delay Spread / Doppler Test C-5 was conducted in accordance to Multipath Stress Testing of DAR Systems by B. McLarnon (CRC) Revision 7/94. A complete listing of this document is included in Appendix D. The exact parameters used are shown in Appendix E.

Test C-7 Environmental Noise (AM Band) was only conducted at medium signal strength.

3.4.1.4 Co and Adjacent Channel D-Series Tests

The BER was not recorded for the D-Series of tests (Co-Channel, 1st and 2nd Adjacent). Also, the analog audio channel was not observed for IBOC systems in this test series. The analog audio channel was observed and recorded for later subjective assessment in the analog compatibility portion of tests (L-3).

3.4.1.5 Co and Adjacent Channel E-Series Tests with Multipath

Similarly, the analog audio channel was not observed for IBOC systems in E-Series tests (Co-Channel, 1st and 2nd Adjacent with multipath). The analog audio channel was observed and recorded for later subjective assessment in the analog compatibility portion of tests (L-4). Only the Urban Slow and Urban Fast Rayleigh simulations were included.

3.4.2 Analog Compatibility

The analog compatibility phase of testing examined the effects of digital services in the VHF frequency band and compared the effects to standard FM broadcasts. These tests also examined the effects of standard FM broadcasts on the proposed digital services.

3.4.2.1 F and G Test Series

The F and G series of tests were conducted with Subcarrier Group B on the desired and undesired analog channel.

The main channel modulation source on the undesired signal was clipped pink noise at 90% (L+R) no pilot at and Subcarrier Group B at 20% for a total deviation of 82.5 kHz (110%). "The interfering signal is always operated in monophonic mode because this gives the more critical disturbing effect" (1:2).

The desired signal had a 1 kHz tone at 81% + pilot at 9% injection for the 0 dB reference signal measurement with Subcarrier Group B at 20% again for a total deviation of 82.5 kHz (110%).

The signal to noise ratios (S/N) were quasi-peak weighted measurements using a CCIR - 468 weighting filter "to provide satisfactory agreement with subjective assessments" (2:1) and a 15 kHz low pass filter (to attenuate the pilot frequency contribution). The target ratios are 45 and 35 dB. These S/N objective measurements establish the desired to undesired ratios (D/U) in subsequent subjective tests where the processed ABBA program segment was substituted for clipped pink noise on the interferers. The ABBA was injected at 81% + pilot at 9% + Group B at 20% for a total deviation of 82.5 kHz (110%). This substitution lead to a more realistic simulation. Harp, which is classically processed, was substituted on the desired transmitter at similar injection levels.

Initially, the RBDS portion of Group B was not phase locked to the pilot;. however, this problem was corrected in subsequent tests.

3.4.2.2 H and I Test Series

Clipped pink noise at 100% modulation on the main channel of the analog interferer(s) was the base line interference signal(s) in the H and I series of tests.

The IBOC Host Analog had processed ABBA at 91% modulation and pilot at 9 % injection with no subcarriers as main channel modulation.

The D/U ratios were determined at TOA and POF with interferers which included subcarrier Groups A or B, as well as the base line interferers. The interferers, which include subcarriers, were modulated with a total deviation of 82.5 kHz (110%). In these cases it was necessary to reduce the clipped pink noise modulation level to 81% + pilot at 9% so the subcarrier group could be injected at 20 % without exceeding the total modulation of 110%. The pilot was included in these cases because it was necessary to phase lock the digital subcarriers to the pilot for proper operation.

The F, G, H and I test series do not look at subcarrier compatibility from a DAR to subcarrier interference perspective; however, test L, where the focus is DAR to Host Analog Compatibility does look at this issue.

3.4.2.3 L-Series Tests

The L-Series of tests were conducted at strong and weak signal levels -47 and -77 dBm respectively, with ABBA on the analog portion of the composite wave form.

The objective S/N ratios were measured with subcarrier group A, group B or no subcarriers. The 0 dB reference was taken with a 1 kHz tone modulated at 91% (L+R) + pilot at 9% when no subcarriers were included. With subcarrier Groups A or B at 20% the 0 dB reference was taken with a 1 kHz tone modulated at 81% (L+R) + pilot at 9%.

The objective measurements were taken both quasi-peak weighted and RMS unweighted for comparison. Once the objective measurements were taken subjective recordings were made.

The subjective recordings were made with Harp, ABBA and Female speech on the analog channel. The processing was Adult Contemporary which provides "clean easy-to-listen to unprocessed audio that sounds just right on music and voice" (3:3-12). The composite stereo was modulated at 91% + pilot at 9% for the subjective recordings. The undesired signal was the digital portion of the composite IBOC wave form.

The digital portion of the IBOC wave form and how it effected subcarriers on the Host Analog were detailed in the subcarrier portion of test L. Subcarrier group A, B and D performance was examined.

The Digital subcarriers were monitored for BER or equivalent, and the S/N ratios were measured for the analog audio subcarriers in each respective subcarrier group.

The M-Series Tests examined IBOC digital performance with and without subcarrier groups A, B and D.

3.4.2.4 M-Series Tests

The undesired signal was the analog portion of the IBOC composite wave form in the M-Series of tests.

The analog channel was unmodulated (CW), modulated with clipped pink noise or modulated with clipped pink noise and subcarrier groups A, B or D and the digital TOA with gaussian noise (C_0/N_0) recorded for each case. The effect of the subcarriers on the IBOC digital performance was determined.

In the FM Analog Compatibility portion of tests, 391 segments of audio were recorded. These recordings were subjectively assessed by subcommittee approved listeners.

3.4.2.5 Subjective Assessment Procedures

The subjective assessment test report and procedures are found in Appendix V.

3.5 Multipath

A list of the parameters used for the Rayleigh and Doppler simulations necessary to accomplish the tests using multipath can be found in Appendix E. Also refer to Appendix E for documentation supporting multipath simulator operation.

3.6 Description of Multipath Scenarios

Appendix F contains a description of the multipath profiles and how they were derived.

3.7 Noise Measurements and C_0/N_0

A broad band (0 to 2.0 GHz) noise generator, the Noise/Com UFX 7112, was used as the white noise source in all noise related measurements. Band-pass filters were obtained from TTE Inc. for each of the proponent bands in the DAR test lab, namely AM, FM, L-band, and S-band. The purpose of the filters was to band-limit the noise so as not to saturate the receivers. Each filter was characterized to obtain its noise equivalent bandwidth, Bn . This procedure is described in Appendix S which also provides the Bn's obtained for each filter (see Appendix S).

The amplitude of the filtered noise was controlled by a Weinschel attenuator before it was injected into the signal path. The band-limited noise power was measured by the Boonton 4220 power meter, and then normalized to a 1 Hz bandwidth using the value of Bn appropriate to the filter in use. This noise level was referred to as N_0.

In a similar fashion the desired signal level was measured using the same Boonton 4220 power meter, and this value was normalized to a 1 Hz bandwidth using the signal bandwidth as provided by each proponent. This signal level was referred to as C_0. The desired signal was not filtered; however it was checked on the spectrum analyzer to verify that there were no spurious signals present that could adversely affect the power measurement.

Having thus obtained C_0 and N_0, the ratio C_0/N_0 can be obtained for each proponent.

3.8 System Specific

The system specific test procedures for Eureka-147, AT&T / Amati Upper Side Band and AT&T can be found in Appendix G.

3.9 Ancillary Data Channel

The Ancillary Data Channels were demonstrated by monitoring the BER with gaussian noise, co-channel and multipath impairment. Two methods were employed for monitoring BER.

The first method used an IBM PC or compatible running software written for this application. COM1 of the PC transmitted ASCII characters to the system encoder and COM2 of the PC received the recovered data from the system decoder. The software compared that which was transmitted on COM1 to that which was received on COM2 and calculated the BER accordingly. If no valid data was received on COM2 then the software just indicated no valid data was received. More details regarding the BER measurements are included in Appendix J. The first method was used on all systems except Eureka.

The Eureka system is capable of generating a pseudo random bit sequence (PRBS-20). When in this mode the Data and Clock outputs of the receiver were connected to the HP 3784A Digital Transmission Analyzer Data and Clock inputs. The clock line was attenuated to force the analyzer to trigger only on the low voltage threshold, and the analyzer was programmed to receive the PRBS-20, and in this way the BER was measured.

3.10 IBOC Re-Test

Two IBOC systems were modified after the digital phase of testing was complete. These systems are the AT&T / Amati DSB and the USA Digital Radio FM 1 systems. The changes which were made to these systems is detailed in Appendix K.

The re-tests were conducted similar to the original tests; however, the subjective assessments in tests B-1 and B-2 were limited to spot checks around TOA and POF. The B-3 tests were not subjectively assessed. All other tests were conducted similar to the Digital Phase of testing.

The Analog Compatibility Phase of testing began after the IBOC systems were modified.

4 LABORATORY

Detailed drawings of the RF, Digital and Analog Audio, Composite Stereo and Control Distributions are included in Appendix L.

4.1 Description of Test Bed

The test bed consists of four distinct sections. These sections are the RF , Audio, Composite Stereo and Remote Control Distributions. The audio distribution can be further subdivided into two sections. These sections are the Analog and AES/EBU Digital Audio Distributions. The RF portion of the test bed can be further subdivided into two sections as well. These sections are the HF/VHF and the L/S-Band sections. Details of the interconnections in each of the distributions can be found in Appendix L.

4.2 Power Measurements

The average or RMS power levels of the RF portion of the DAR were measured with a Boonton 4220 Power Meter. The sensor used with the meter is a full wave diode detector (model number 51075) with a specified frequency range of 100 kHz to 18 GHz. Power measurements were made on a daily basis before any tests were performed to ensure that the test bed was operating properly and that no significant drift had occurred in the test bed or associated equipment since the previous day. Prior to the start of any test, the proponent signal level was set at the input to the test bed by performing a power measurement on the signal and adjusting the input attenuator (if required).

4.3 Calibration

At various intervals in the testing process it was necessary to determine if the test bed was behaving as it should. To determine the operational status of the test bed, various methods were employed. The following sections detail these methods:

4.3.1 CW RF Calibration

The losses of the RF test bed from the 6 way splitter output to the three way combiner and receiver inputs were measured periodically. The losses were measured by injecting a CW signal at the frequency of interest. The power levels at the places of interest were measured on either the spectrum analyzer or the power meter. The difference in the measurements made at the various points determined the insertion loss of the test bed from point to point. The differences were always calculated with measurements made on the same instrument with the same cables and adapters. In this way losses in the measurement path factor out of the calculation automatically. The losses remain consistent, and the integrity of the RF path was verified. Data which relates to the CW calibrations is inherently embedded in the collected data sections of this report.

4.3.2 FM Bessel Null Calibration

Bessel Null Modulation Monitor Calibration was performed periodically throughout the testing process. Appendix N contains the plots which were acquired during the Bessel Null Procedure which is also included in Appendix N.

The outcome of the Calibration procedure is that the Belar Modulation Monitor is accurate ± 1 %. This applies to all modulation measurements made throughout the duration of testing.

4.4 Component Certification

The RF attenuators, pads, splitters, and combining networks which were used through out the testing process were calibrated, and the losses measured. A further check on the overall test bed was performed by measuring the end-to-end insertion loss from each proponent transmitter's output to their receiver input. This test verifies the cable losses and shows that all the FM proponents were subject to the same overall insertion loss. Appendix M contains the network analyzer plots obtained during the certification of these components, as well as the end-to-end insertion loss.

4.4.1 Test Equipment

The equipment and instrumentation used in the DAR lab is listed here in the following categories: Audio, Computer, Measurement, Signal Generation, and Support Equipment. The listings are alphabetical by manufacturer and include model numbers and serial numbers where applicable. This listing does not include the components used in the RF test bed. These components may be found in section 4.1.

4.4.1.1 Audio Equipment

Denon	Audio Amplifier (2)	Model PMA980R
Denon	Studio Monitor Speakers (8") (4)	
Denon	CD Cart Player	Model DN-970FA
Grado Labs	Dynamic Headphones	Model SR225
Nvision	Terminal Hardware Equipment	Model NV1000
Configuration:	Distribution Amplifiers (4)	
	Codec (A/D & D/A converters) (2)	
	Sync. Generator (1)	
Nvision	Sample Rate Converter	Model: NV 4448
Sony	Digital Audio Recorder (2)	Model: PCM-7010
Sony	Compact Disc Player	Model: CDP-2700
Technics	Digital Audio Tape Deck	Model: SV-DA10

4.4.1.2 Computer Equipment

Everex	386 Laptop Function: RDS Checkup monitor	Model: Tempo LX
Gateway	486 Desktop Functions: Attenuator control IEEE controller Serial RS-232 Control	Model: 2000 4DX2-66V

HP	Laserjet Printer	Model: 4P
HP	Pen Plotter	Model: 7475A
Leading Edge	486 Desktop Function: HP RF channel simulator controller	Model: Winpro 486e
Zaias	386 Tower Function: Audio Precision System One controller	
Zenith	386 Desk Top Function: Audio Booth remote controller	Model: ZUG-386-25

4.4.1.3 Measurement Equipment

RF

Boonton	Digital RF Power Meter	Model: 4220 Ser.: 32202BK
	Sensor	Model: 51075 Ser.: 26834
Boonton	Peak Power Meter	Model: 4400
HP	Power Meter	Model: 437B Ser.: 3125U10145
	Sensor	Model: 8482A Ser.: 3318A23565
HP	Peak Power Meter	Model: 8990A
HP	Spectrum Analyzer	Model: 8566B Ser.:2416A0038
HP	Frequency Counter	Model: 5316B Ser.: 2708A01401

Modulation

Belar	FM Digital Mod Analyzer	Model: FMMA-1
Belar	FM Digital RF Amplifier	Model: RFA-4
Belar	FM Stereo Monitor	Model: FMS-2
Belar	AM Digital Mod Analyzer	Model: AMMA-1
Belar	AM RF Amplifier	Model: RFA-2
Belar	SCA Monitor	Model: SCM-2
Denon	FM Tuner Modified for RDS clock & data output	Model: TU-380RD
Mainstream	Intelligent Data Receiver	
RDX	RDS Checkup Software Utility	

Seiko	Receptor Protocol Analyzer	

Audio

AP	System One Audio Analyzer	Model: SYS1-32801
	Configuration: CCIR 468 Weighting Filter	
	15 kHz Low Pass Filter	

Digital

HP	Digital Transmission Analyzer	Model: 3784A

Other

Fluke	Multimeter	Model: 8024B
Tektronix	Oscilloscope	Model: 485
Tektronix	Oscilloscope	Model: 7104
	Configuration: 7A19 Vertical Amplifier	
	7B85 Time Base	

4.4.1.4 Signal Generation Equipment

RF

Boonton	FM/AM Signal Generator	Model: 103D
Boonton	FM/AM Signal Generator	Model: 102B
Harris	FM Exciter	Model: THE ONE
HP	Signal Generator	Model: 8657B
HP	RF Channel Simulator	Model: 11759C
Noise/Com	Programmable Noise Generator	Model: UFX 7112

Function/Audio

AP	Digital Audio Generator Option Installed in System One Analyzer	
Interstate	20MHz Function Generator	Model: F71
Interstate	Pulse generator	Model: P25
Wavetek	50Mhz Function Generator	Model: 166

Stereo

Cutting Edge	Unity FM Stereo Generator/Processor	Model: 2000i
Cutting Edge	Unity AM Processor	Model: 1900
Cutting Edge	The Dividend Composite Filter	

Orban	Optimod FM stereo Generator/Processor	Model: 8200
Orban	Optimod AM Processor	Model: 9200B

Subcarrier

CRL Systems	67 kHz Analog Subcarrier Generator	Model: SCA-300B
CRL Systems	92 kHz Analog Subcarrier Generator	Model: SCA-300B
Mainstream Data	High Speed Data Transmitter	Model:
RE America	RDS Generator	Model: RE533 Prototype
Seiko Comm.	Receptor Subcarrier Generator	Model:. SKAG 1.1

4.4.1.5 Support Equipment

ADC Comm.	Analog Patch Panel	
ADC Comm.	Digital Patch Panel	
Systron-Donner	Analog Power Supply	Model: TL8-3-0V
Videotek	Audio Distribution Amplifier	Model: ADA-16
Custom	15 kHz Low Pass Filter (9 pole elliptical.) FM Stereo Measurement	
Custom	9.6KHZ Low Pass Filter (9 pole elliptical) AM Band limiting	
Custom	SCA Group/Composite Mixer	
Custom	TTL RF Switch	
Custom	High Speed RF Switch/Gate	
Custom	Automotive Radio Audio Interface/Power Supply	
Custom	Syncro-Start Remote Controller	
Custom	Receiver Test EMI/RFI Screen Box	

4.5 Custom Equipment Descriptions

The following section details the equipment designed for different aspects of testing.

4.5.1 Subcarrier Group/Composite Mixer

Because of the many combinations of subcarriers, a subcarrier mixer/switcher was designed and built to make switching and calibrating subcarrier levels easy and reliable. Calibration was performed as a one time operation with periodic inspections for accuracy. The mixer has the ability of adding any combination of subcarrier groups to a stereo baseband signal.

The mixer has inputs on the rear panel for up to four subcarrier signals and one composite stereo signal. The front panel has two outputs, one for the selected subcarrier group and the other for a composite stereo signal with the selected subcarrier group added . The front panel has one rotary switch for selecting the desired subcarrier group (or no subcarriers) and a main potentiometer, "Subcarrier Level", for adjusting the group injection level from 0% to maximum group injection level. A trimmer potentiometer is located above the main subcarrier level control to allow for fine calibration of the group level.

The individual subcarriers were combined into groups of up to three subcarrier signals. The choice of individual subcarrier frequencies within a group is a function of hardwiring each subcarrier to the appropriate group summing network. The relative and absolute levels of each of the subcarriers were then calibrated for each group. Each individual subcarrier was calibrated with the subcarrier level control at Maximum and the trimmer at its midpoint position. The final subcarrier group output with the subcarrier level control at maximum was then fine tuned with the front panel trimmer. The Mixer also added the selected subcarrier group to the composite baseband signal. The input/output gain of the stereo path is unity (0 dB).

The circuit design insures that there is no cross talk from one subcarrier group to another by grounding the output of each subcarrier summing network with a high quality reed relay. When a subcarrier group is selected, its relay is open allowing the output of the group summation point to pass through the subcarrier level control and into the subcarrier group amplifiers. This design provides a constant impedance for the summing networks. The amplifiers make up for the losses in the summing networks and brings the subcarrier group amplitude up to the proper levels for addition to the composite stereo signal or to the group output on the front panel. The mixer is powered by an external bi-polar 24V power supply to eliminate hum and noise. Internal DC regulators provide +/- 15 volts to the circuitry.

Reference Appendix I for additional information.

4.5.2 Low Pass Filters

A 15 kHz low pass filter was used when making FM stereo audio measurements on all of the FM receivers to eliminate the pilot and any higher order frequency components from influencing measurement results. This filter is a 9 pole elliptical design, utilizing gyrators as FDNR (frequency dependent negative resistor) as the active elements, giving it a very steep slope with a corner or cut off frequency of 15.5 kHz. The stop band frequency is 18.6 kHz where the attenuation of the filter is -65 dB. The filter has internal +/- 15 Vdc regulators and is powered by an external bi-polar 24V power supply to simplify the construction and reduce the chance that hum and noise can be introduced to the filter.

A 9.6 kHz low pass filter was constructed for band limiting pink noise when used in an interfering AM application. This filter is the same design as the 15.5 kHz FM filter with different FDNR components to give the proper characteristics. The corner frequency in this application is 9.6 kHz. At 10 kHz the attenuation is -20 dB, and the stop band frequency is 11.52 kHz with -65 dB attenuation.

Reference Appendix R for additional information.

4.5.3 Automotive Radio Audio Interface/Power Supply

The auto radio interface (ARI) is a support instrument that has a number of key features required to run automotive radios in a test set up. The ARI provides 50 watt load resistors for the radio amplifiers to work into an audio bus, an audio multiplexer for multiple radios or audio sources, a buffer amplifier for converting the differential audio output of the typical auto radio to a single ended audio for measurement with an oscilloscope, and finally, a 12 volt 4 amp power supply for powering the radios. Also available are +/- 15V and +5V for powering auxiliary equipment.

The rear panel has XLR connectors for differential audio output, BNC connectors for the single ended audio output, and a 5 pin Lemo connector for the auxiliary DC power. The interface may be controlled remotely with TTL logic from the DB25 connector on the rear panel or locally from the front panel controls.

All switching functions are controlled with static TTL logic for low noise purposes resulting in an audio noise floor of better than -100 dB below 1 volt.

4.5.4 High Speed RF Switch/Gate

The High Speed RF Switch is basically a PIN diode switch with very fast response time characteristics. It is capable of switching times of better than 5 micro-seconds and will typically perform at 4 micro-seconds when viewing the rise and fall times of a signal on a high speed oscilloscope. Frequencies from 500 kHz to 108 MHz may be switched or gated on or off with a conventional TTL logic signal. A +5V control level turns the switch on, and 0V turns the switch off. Insertion loss is on the order of 24 dB for the AM band and 23.5 dB for the FM band.

The RF circuit is made up of two PIN diode switches ganged, or cascaded together for maximum isolation when switched off. The switches are controlled by changing the DC bias condition across the diodes. The input and output impedance is 50 ohms.

The High Speed RF Switch is housed in an RF tight metal enclosure and is constructed on a solid copper ground plane for good RF characteristics. BNC connectors are used for the RF input and output, while an SMA connector serves as the control input.

Reference Appendix R for additional information.

4.5.5 TTL RF Switch

This switch utilizes a conventional 12 volt relay to switch RF on or off and includes, in a separate enclosure, a TTL signal level controller. The RF switch is asymmetrical in nature, since both of the RF ports are terminated with 50 ohms to ground when the switch is off.

The relay is a Teledyne TO-5 style intended for RF applications and is mounted on a solid copper ground plane housed in an RF tight enclosure for use with frequencies into the UHF spectrum.

Applications for the switch include DC, audio, and RF (50Ω terminations must be removed for DC and Audio applications).

Reference Appendix R for additional information.

4.5.6 Syncro Start Remote Controller

The controller synchronizes the starting of the multipath simulator with the program material and was later modified to give a number of start commands to multiple devices.

When running a multipath scenario in a test where a relatively short musical or vocal segment is used repeatedly, it is important to have the audio program material begin at the same time the multipath simulator is started, in order to have the multipath events coincide with the audio events (notes). When the test is run many times on many systems, it is important that any skew or slip in time between the two be ruled out as a factor.

Reference Appendix R for additional information.

4.5.7 EMI/RFI Screen Box

Because outside lab noise would corrupt test results, a steel screen box was constructed to house the receivers under test. Automobile radios were immune to outside noise, not requiring further shielding .

The screen box has an overlapping steel lid that makes metal to metal contact for proper grounding and shielding. All inputs and outputs, which effectively represent antennas to pick up interference, are filtered for noise rejection. The AC power input is passed through an EMI/RFI filter module, and the audio output lines are passed through bulkhead type LC RF Pi filters. There are two RF inputs on the box where conventional BNC bulkhead connectors are used. This provided approximately 50 dB of radiated isolation in the FM band.

4.6 AM and FM Receivers

Five FM receivers and three AM receivers were used in various analog compatibility tests. Complete receiver characteristics are included in Appendix H. These receivers represent a large cross section of receivers currently being used by consumers.

4.7 Subcarrier Receivers and Subcarriers

Various subcarrier receivers and subcarriers are used throughout the testing process. The following sections detail these items.

4.7.1 Subcarrier Receivers

There are 5 subcarrier receivers used in the subcarrier compatibility phase of tests. These receivers include:

1) Denon TU-380RD modified to provide clock and data signals to the parallel port of a computer (IBM PC or Compatible) running the RDS Checkup Software Utility
2) Seiko Receptor Protocol Analyzer Receiver and Software Utilities
3) Compol 67 kHz Subcarrier 94.1 MHz Receiver
4) Compol 92 kHz Subcarrier 94.1 MHz Receiver
5) Mainstream Data Intelligent Data Receiver

A number of different subcarriers were used for both the FM Analog Reference system and the IBOC Analog FM Host in an effort to obtain a practical cross section of what is in use by broadcasters . These subcarriers are both analog and digital and cover the Subcarrier frequency band from 57 kHz to 92 kHz.

4.7.2 Subcarrier Groups

The subcarriers are organized into four groups as follow:

Group A	57 kHz	Digital - RDS	3% injection level
	66.5 kHz	Digital - Data/Paging	8.5% injection level
	92 kHz	Analog	8.5% injection level
Group B	57 kHz	Digital - RDS/Paging	10% injection level
	67 kHz	Analog	10% injection level
Group C	67 kHz	Analog	10% injection level
	92 kHz	Analog	10% injection level
Group D	92 kHz	Digital - Data	10% injection level

The RBDS signal at 10% injection level provides a good emulation of a 57 kHz paging application.

4.7.2.1 Subcarrier Calibration

Many tools were used to verify and cross check the injection levels of an individual subcarrier. Using an audio generator as a substitute subcarrier, source injection levels at 57, 67, and 92 kHz were measured with the two Belar modulation analyzers. These measurements were then confirmed with the composite baseband plot on the HP spectrum analyzer. Next, the spectrum analyzer utility in the Seiko Receptor Protocol Analyzer (RPA) was compared to the HP and verified in the same manner. At this point with four instruments that very closely agreed with each other, calibration was assured. Though out the process of using subcarrier signals, this method of cross checking the injection levels was used with at least 2 or 3 of the above instruments.

The injection level measurement and adjustment of the analog and RBDS subcarriers is easy and straight forward. No modulation was used on the analog generators when setting the level.

The RBDS signal was set using the modulation monitors and confirmed on the spectrum analyzers by observing the side band levels. The signal was phase locked to the 19 kHz pilot and adjusted according to the EBU procedure.

The Seiko digital subcarrier, also phase locked to the pilot, was adjusted for both level and phase according to the procedure specified in the Seiko manual. Levels, both unmodulated and modulated, were measured on the RPA spectrum analyzer utility and the modulation monitors.

The Mainstream Data subcarrier was set up to 10% injection using the modulation monitors and the RPA spectrum analyzer; however, there is no way to measure this signal unmodulated to cross check our measurement. Therefore, we had Mainstream Data come in and certify that the injection level was correct.

For additional information on this subject, please to Appendix I.

5 QUALITY TEST K

5.1 Selection of Critical Material

The selection of critical materials conducted at CRC by expert listeners is detailed in Appendix T.

5.2 Quality Test Report

This report is included in Appendix U.

5.3 System "J" Description

For the subjective quality assessments System J (USA Digital Radio AM) used a 48 kHz sampling frequency as the reference, where as System I was evaluated with a reference sampled at 32 kHz..

5.4 Selection of Critical Materials for Transmission Impairment Tests

The DAR laboratory test procedures call for the selection of three audio segments for impairment testing. Starting the process Jody Daub and Douglas McKinnie, two of the three expert panelists that selected the quality audio segments at the CRC, recommended seven of the segments they had auditioned for the quality tests for use as transmission test materials. The segments they selected were all from the EBU SQAM disc which was part of the materials used for the nine quality segment selection. The criteria for selection was a pure sound that would not mask the effects of impaired transmission. The following segments were recommended by the panel:

Track	Index	Contents	Length (seconds)
10	2	Violoncello	37
23	2	Horn	31
32	1	Triangle	21
35	1&2	Glockenspiel	29
39	4	Grand piano	27
55	1	Trumpet concerto	32
62	1	Soprano, spiritual	31

For the implementation of the selection process, each of the above segments was played at the DAR laboratory on a CD machine and rate converted to the appropriate sample frequency. Noise was added to the signal to find the TOA and POF for each of the above audio segments as they were transmitted through each system. The segments were selected for sensitivity to impairment at both the TOA and POF. For each system a minimum of two segments was selected. Three systems had the same most sensitive rating for three audio segments. A total of eight tests representing six systems were included with two systems operating in a second mode. Because of an equipment problem, the VOA/JPL system was not included in the test. The tally for each audio segment is as follows:

Track	Content	Tally
10	Violoncello	1
23	Horn	0
32	Triangle	5
35	Glockenspiel	8
39	Grand piano	1
55	Trumpet concerto	2
62	Soprano, spiritual	3

Glockenspiel was the most critical of the seven selections with triangle and Soprano spiritual second and third. To give a wider range of sound test audio, and because the triangle is similar to glockenspiel, it was replaced with clarinet (EBU SQUAM CD Track 16).

Only limited multipath tests were accomplished because the multipath scenarios for VHF band were not completed at the time of the tests. The limited tests used the multipath scenarios supplied by each proponent. These tests did not show any significant change in critical material from the noise tests.

The test segments were reduced in length by the direction of Working Group B to 30 seconds. This was to accommodate the subjective evaluation tests at the CRC.

5.5 Selection of Audio Test Material for Tests F, G and L

Through the process of expert evaluation the following segments from the EBU SQUAM CD were selected to use in tests F, G and L where appropriate:

1) Harp (Track 25)

2) ABBA (Track 69)

3) Spoken Voice (Track 49).

6 A-SERIES TESTS

The vital signs for the system under test were taken on an as needed basis to verify proper operation of the DAR system.

6.1 Power Measurements

Various types of power measurements were taken on the systems. The following sections detail these measurements.

6.1.1 Peak to Average Ratio

The peak to average power ratios of the DAR transmissions were measured on the Boonton 4400 Peak Power Meter. Appendix O contains the record of these measurements. The meter was set up in a peak hold manner, and the transmissions were monitored for a period of 5 minutes before the results were recorded. In some cases the HP 8990A Peak Power Meter was also used to make these measurements. A summary of these measurements is included on the cover page of the collected data sections of this report.

These measurements do not indicate what the instantaneous peak to average power ratios are or what percentage of the time the peaks are above the average power. Further investigation of these issues may be necessary to fully address transmitter implementation.

6.1.2 IBOC Composite to Digital Ratio

The ratios of composite signal power to digital signal power are detailed in the B-1, B-2 and B-3 sections of the collected data sections of this report.

6.1.3 Power Meter Calibration Error

The measurements made with the Boonton 4220 power meter were corrected when measurements were sufficiently out of the square law region of the Boonton power sensor. Correction to these measurements only occurred once during the testing at LeRC. This occurred in the D-Series tests for the Eureka - 147 systems. Appendix P details the correction factor applied to the undesired signal measurement for the E-147 D-Series tests.

6.2 Spectrum Plots

The spectrum or wave form of the DAR was recorded for various reasons. These reasons include compliance to FCC regulations and indication of system stability. The following sections detail the spectrum analyzer measurements made in the laboratory.

6.2.1 Analyzer Settings

The spectrum analyzer was set up in a different configuration for each system, or group of systems, in the same band. The settings are detailed in the following sections:

6.2.1.1 AM

Center Frequency	1.66 MHz
Resolution Band Width	300 Hz

Video Band Width	NA
Span	NA

6.2.1.2 FM

Center Frequency	94.1 MHz
Resolution Band Width	1 kHz
Video Band Width	30 Hz
Span	500 kHz

6.2.1.3 L-Band

Center Frequency	1.47 GHz
Resolution Band Width	30 kHz
Video Band Width	10 kHz
Span	5 MHz

6.2.1.4 S-Band

Center Frequency	2.03 GHz
Resolution Band Width	3 kHz
Video Band Width	100 Hz
Span	1 MHz

6.2.2 System Measurements

The spectrum measurements were made at the 6 way splitter output, the 3 way combiner input or the receiver input.

6.3 Weak Signal and Gaussian Noise Performance

The TOA and POF for the systems was determined by lowering the signal level to the weak signal sensitivity and by artificially increasing the noise floor.

6.3.1 Additive White Gaussian Noise TOA and POF System Performance

By increasing the level of gaussian noise in quarter dB steps, the performance values were determined.

6.3.2 Weak Signal Sensitivity TOA and POF System Performance

By lowering the signal level at the receiver in 1 dB steps, the weak signal performance of the systems was determined.

6.4 Pre-Test Quality Digital Audio Recording

At medium signal strength the system recovered audio with glockenspiel program material was recorded on DAT for the record.

6.5 IBOC Analog Channel Proof

The frequency response and total harmonic distortion + noise were plotted for the IBOC FM Host Analog Channel.

6.5.1 Test Limitations

The Belar Stereo monitor was used for these proofs. This demodulator is wide band and does not filter out any effects of the digital signals. This test was therefore conducted with the digital portion of the IBOC composite wave form turned off, if it is possible to turn the digital off externally to the proponent system. This was done to gauge the performance and ensure proper operation of the FM analog channel.

6.5.2 Summary of IBOC System Data

Appendix Q contains the Audio Precision Plots of the Analog Channel Proofs.

6.6 Reference Transmitter Proof

During the Analog Compatibility Phase of testing, the Reference Transmitter performance was gauged, similar to the IBOC Host Analog Channels. Appendix Q contains the Audio Precision Plots of the Reference Transmitter proofs.

6.7 AM and FM Modulation Monitors

It was necessary to determine proper operation of the modulation monitors. The following sections detail calibration of the monitors:

6.7.1 AM

The AM modulation monitor has a built in calibration tone. Periodically throughout the testing process, the tone was turned on, and the modulation observed to be ± 100 %.

6.7.2 FM

The Bessel Null Procedure was used to verify proper operation of the FM modulation monitor. The procedure and results of the procedure are contained in Appendix N (see Appendix N).

6.8 Proponent Self Test

Two systems in the laboratory have the ability to monitor their operational status. These systems are the AT&T IBAC and the USA Digital Radio AM systems.

6.8.1 Descriptions

The self test algorithms were executed with few requirements from the lab staff. Patching and switching test signals and attenuation when prompted by the self test computer was the extent of the staff involvement during the self tests.

6.9 Test Bed Calibration

The calibration of various portions of the test bed can be found in Section 4 of this report (see Section 4).

7 DIGITAL TESTS DATA

7.1 Eureka - 147 224 Kb/s

The digital results are found in Appendix AA.

7.2 Eureka - 147 192 Kb/s

The digital results are found in Appendix AB.

7.3 AT&T IBAC

The digital results are found in Appendix AC.

7.4 AT&T / Amati IBOC Lower Side Band

The digital results are found in Appendix AD.

7.5 AT&T / Amati IBOC Dual Side Band

The digital results are found in Appendix AE.

7.6 JPL / VOA Direct Broadcast Satellite

The digital results are found in Appendix AF.

7.7 USA Digital Radio IBOC FM 2

The digital results are found in Appendix AG.

7.8 USA Digital Radio IBOC FM 1

The digital results are found in Appendix AH.

7.9 USA Digital Radio IBOC AM

The digital results are found in Appendix AI.

7.10 AT&T / Amati IBOC Dual Side Band Revision B

The digital results are found in Appendix AK.

7.11 USA Digital Radio IBOC FM 1 Revision B

The digital results are found in Appendix AL.

8 ANALOG IN-BAND COMPATIBILITY DATA

The results of Analog In-Band Compatibility are found in the following Appendices. These include results of test series F and G which detail DAR to Analog Interference and H and I which detail Analog to DAR Interference.

8.1 Tests F-1, F-4 and G-1 (Co-Channel)

These compatibility results are found in Appendix AM.

8.2 Tests F-2, F-5 and G-2 (First Adjacent)

These compatibility results are found in Appendix AN.

8.3 Tests F-3, F-6 and G-3 (Second Adjacent)

These compatibility results are found in Appendix AO.

8.4 Tests H and I

These compatibility results are found in Appendix AP.

9 IBOC COMPATIBILITY DATA

The following Appendices contain the collected data for the Land M series of tests. These tests investigated the effect of the digital portion of the IBOC wave form to the host analog channel (L) and the effect of the host analog channel to the digital portion of the IBOC signal (M).

9.1 Test L

The collected data is found in Appendix AQ.

9.2 Test M

The collected data is found in Appendix AR.

Description Appendix

System Descriptions .... A
Unified DAR Laboratory Test Procedures .... B
CRC Digital Subjective Test Report and Procedures C
Delay Spread / Doppler Procedures .... D
HP 11759C Multipath Simulator .... E
Description of Multipath Profiles .... F
System Specific Tests and Procedures .... G
Receiver Characterizations .... H
Subcarrier Calibration I
Ancillary Data Channel .... J
IBOC System Modifications .... K
Laboratory RF, Audio and Composite Stereo Distributions L
RF Component Calibration .... M
Bessel Null Modulation Monitor Calibration Procedures and Spectrum Plots .... N
Peak-to-Average Power .... O
Power Meter Calibration .... P
FM Analog Transmitter Proofs .... Q
Custom Equipment .... R
Equivalent Noise Bandwidth of Noise Filters .... S
Selection of Critical Material .... T
Quality Test Report .... U
Subjective Assessment Report and Procedures V
Impulse Documentation .... W
.... X
Digital Test Results AT&T / Amati IBOC LSB .... AD
Digital Test Results AT&T / Amati IBOC DSB .... AE
Digital Test Results USA Digital Radio FM 2 .... AG
Digital Test Results USA Digital Radio FM 1 .... AH
Digital Test Results USA Digital Radio AM .... AI
....
Digital Test Results AT&T / Amati IBOC DSB Revision B .... AK
Digital Test Results USA Digital Radio FM 1 Revision B .... AL
....
Tests F-1, F-4 and G-1 Co-Channel DAR to Analog .... AM
Tests F-2, F-5 and G-2 First Adjacent DAR to Analog .... AN
Tests F-3, F-6 and G-3 Second Adjacent DAR to Analog .... AO
Tests H and I Analog to DAR .... AP
Test L .... AQ
Test M .... AR

1: CCIR Report 796 MOD F 1978
2: CCIR Recommendation 468-2 MOD F 1970 - 1974 - 1978
3: Optimod FM 8200 Owners Manual

NRSC Document Improvement Proposal

If in the review or use of this document a potential change appears needed for safety, health or technical reasons, please fill in the appropriate information below and email, mail or fax to:

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