

IBOC DAB FIELD TEST PLATFORMS

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Abstract- In 2001, iBiquity Digital Corporation tested its AM and FM In-Band, On-Channel Digital Audio Broadcasting systems under the auspices of the National Radio Systems Committee. In preparation for this test program, iBiquity developed a new field test platform to meet the NRSC's requirements, as well as, to improve testing performance, user interfaces and post-test analysis tools. This new field testing platform is described here.

I INTRODUCTION

iBiquity Digital Corporation developed its AM and FM In-Band, On-Channel (IBOC) Digital Audio Broadcast (DAB) systems over the last several years. Both USA Digital Radio and Lucent Digital Radio, the companies that merged to form iBiquity, had created several field test platforms for the purposes of evaluating their prototype IBOC systems. These test platforms, built into full-sized passenger and cargo vans, included capabilities for capture of RF spectra, GPS information, IBOC receiver performance data and receiver audio recordings. While these platforms had provided most of the essential data to assess IBOC system field performance, iBiquity's test engineers recognized the need for improvements in performance, functionality and ease-of-use. Moreover, as the engineers were doing most of the post-test data processing manually, using spreadsheets, mapping software and a handful of custom applets, better analysis tools clearly were needed. Anticipation of the National Radio Systems Committee (NRSC) IBOC system test program provided the impetus for a ground-up redesign of the iBiquity field test platform. This redesign took place in two phases over a nine-month period.

Throughout 2001, iBiquity successfully used the newly redesigned field test platform to carry out all field testing elements of the NRSC's IBOC test program. Today, iBiquity continues to use the field test platform to support IBOC commercialization and testing of new IBOC-supported services.

II TESTING REQUIREMENTS OVERVIEW

The NRSC's Hybrid FM and Hybrid AM IBOC testing programs ^{2, 3} executed in 2001 included substantial field testing components. Under observation of NRSC representatives, iBiquity engineers collected extensive real world performance data from six FM stations and four AM stations equipped with Hybrid IBOC DAB transmission systems. These stations appear in Table 1. NRSC performance test procedures required testing of IBOC vehicular reception along four to eight radial routes extending from each test station out to the end of digital coverage.

Station	Location
WETA FM, 90.9 MHz	Washington, D.C.
WHFS FM, 99.1 MHz	Annapolis, MD
WPOC FM, 93.1 MHz	Baltimore, MD
WD2XAB FM, 93.5 MHz	Columbia, MD
WNEW FM, 102.7 MHz	New York, NY
KWNR FM, 95.5 MHz	Las Vegas, NV
KLLC FM, 97.3 MHz	San Francisco, CA
WTOP AM, 1500 kHz	Washington, DC
WWJ AM, 950 kHz	Detroit, MI
WD2XAM AM, 1660 kHz	Cincinnati, OH
KABL AM, 960 kHz	San Francisco, CA

Table 1: NRSC IBOC Field Test Stations

The specific data collection requirements in the NRSC's IBOC Field Test Procedures-FM Band² where these:

- IBOC receiver blend mode and block-error-rate (BLER) shall be recorded during the field test.
- Digital recordings of analog and IBOC digital audio indicated by these procedures

are for archival and/or subjective evaluation purposes. All such recordings will be made in the following format: uncompressed linear 16-bit digital audio sampled at 44.1 kHz, and will be suitable for transfer to CD to facilitate further analysis.

- Recordings of the test route will be made including GPS data, desired signal strength and adjacent channel signal strength.

In preparation for the first set of NRSC field tests, the iBiquity test team reviewed the functionality and performance of its legacy field test platforms. Each version of these earlier test systems provided some form of RF spectrum capture, position location, multi-track digital audio recording and digital radio data acquisition. Despite having been designed independently, the platforms were remarkably similar in principle and implementation. Each was designed to use same model spectrum analyzer, used GPS for position location, had similar control and data interfaces and was automated using National Instruments' LabVIEW. The test team concluded that a new platform incorporating several basic enhancements would improve the efficiency and utility of field testing for both the NRSC program and iBiquity's own diagnostic testing. The primary functions targeted for improvement were signal power characterization, spectral measurement flexibility, data correlation and digital audio recording. The platforms' primary users—field test engineers and technicians—contributed suggestions for a new user interface and data storage formats. Those given highest consideration in the new design were in-progress entry of test operator comments, real time test diagnostics to ensure valid data collection and the creation of an analysis toolkit for rapid review of test data.

III DESIGN & IMPLEMENTATION

iBiquity's new field test platform was designed and implemented in two major steps. The first version was released in December 2000, just prior to the beginning of NRSC Hybrid FM IBOC testing. This platform was known as *TakeATest*, after the name of the control and acquisition application at its heart. The iBiquity test team used *TakeATest* to collect field test data for the entire NRSC FM IBOC test program. The second-iteration platform, *The*

Collector, was released in July 2001 and used for the NRSC AM IBOC test program. At the present, *The Collector* is iBiquity's primary field test tool.

Design Overview

Both *TakeATest* and *The Collector* feature numerous improvements over earlier IBOC field test platform designs. Key among these are:

- A single, master antenna and distribution network for FM-band operation.
- Recording of full spectrum analyzer data
- Flexible, loop-based testing routines, supporting variable parameter spectral analysis
- Temporal correlation of recorded audio with all other test data
- CD-quality, 8-track digital audio recording using a Digital Tape Recording System (DTRS)
- In-progress entry of test operator comments into data files
- Real time indications of collected data and test instrument functional disposition
- Complementary analysis tools for post-test data review and processing

Antenna Systems— In the FM band, where multipath propagation conditions are prevalent, there may be great differences in signal reception by antennas separated by only a small spatial distance. This is due to pervasive multipath propagation and the fact that even one meter is a significant fraction of the FM signal wavelength. Consequently, using multiple, proximate antennas to supply the received signal to a field test platform's receivers and spectrum analyzer is not acceptable. Such an arrangement could not guarantee anything but a loose correlation between signals delivered to the various receivers. Distributing the received signal from a single antenna to all test platform devices is the obvious solution to this problem. However, doing this effectively over the wide dynamic signal range of a mobile environment is not trivial. Furthermore, the prevalence of high-level interferers in broadcast bands challenges the non-linear performance of the typical low-noise distribution network. The primary design objective for the master antenna and its distribution network is this: *Each receiver should perform with a master antenna system just as if connected to dedicated, 31-inch automotive whip by a standard type and length feed cable.*

The master antenna is itself a standard 31-inch automotive-style whip; therefore, it is solely the distribution network, situated between the antenna and the receivers, that determines how closely the test antenna system matches a typical automotive antenna system. The design goals for the distribution network are:

- The gain from the antenna terminals to each receiver input should be similar to that of an automotive feed cable—that is, in the range of -0.5 to -4 dB.
- The network should not significantly degrade the sensitivity of a receiver it drives. In practice, this is qualified by assuming the typical receiver has a 10 dB noise figure.
- The network should not degrade the overload or intermodulation performances of any receiver it drives.
- The distribution network shall provide up to 15 dB gain to the signal feeding the spectrum analyzer. This helps bring the sensitivity of the spectrum analyzer closer to that of the receivers.

The difficulty in meeting these goals lay in achieving the intermodulation (IM) performance. Many automotive receivers achieve good IM performance through switchable or variable RF front-end attenuation. However, the distribution network cannot use this method of piecewise linearity, as it would interfere with the operation of the receivers it drives. The final distribution network design is a combination of a 1 to 2 MHz bandwidth preselector filter cascaded with a high intercept-point, low-noise amplifier, passive hybrid splitter and gain normalizing attenuators.

For AM-band operation, each receiver and the spectrum analyzer has its own, dedicated antenna. In this mediumwave frequency range, the automotive whip antennas mounted on the top of the test vehicle can simultaneously deliver very nearly the same received signal to their respective output terminals—if setup properly. There are two factors that help achieve this: (a) all antenna structures must be of an identical implementation, placed at the same elevation, oriented for the same directivity and polarization and be subject to the same parasitic capacitive loading—mainly from the vehicle body, and (b) the antennas must be close to one another in wavespace. These criteria may be met through the careful installation of several short-wavelength whip antennas on the roof of a test van. Also, since short whips are not resonant

structures, inter-antenna coupling is extremely low, providing acceptable isolation between the receivers connected to this miniature van-top “antenna farm.”

RF Channel Characterization— Spectral data provide most of the transmission channel state information during field tests. The spectrum analyzer delivers the raw information used to calculate all desired and adjacent channel signal levels, as well as indications of non-broadcast interference and anomalous transmission conditions. Given the primary use of the spectral data is in-band signal power measurement, an immediate conclusion might be that the test platform should calculate an array of channel powers for each sweep and store only those values. This approach, while efficient in terms of data storage, results in the loss of significant RF channel information. More importantly, storing only calculated signal powers reduces the possibility of post-test measurement error detection. Thus, the field test platform captures and stores every data point from each spectral plot. During test execution, the platform’s graphical user interface does display estimations of the various channel signal levels of interest. But as these are only estimates, they are not stored with the data. All “official” signal level calculations are performed during post-test data processing. Furthermore, post-test data processing routines also examine the spectral plots for measurement errors occurring where signals have exceeded the analyzer’s usable dynamic range. Additionally, VCR-like data playback tools also allow rapid review of spectra, permitting the analyzing engineer to “relive” the test. This proves extremely useful in both identification of anomalous channel conditions and confirmation of data verity.

The capability to automatically perform variable parameter spectrum analysis is another useful transmission channel characterization feature. In short, the test operator may specify several different spectrum analyzer measurement configurations and execution patterns in which these configurations will collect data. In a simplified example, the controller application might be programmed to take spectral data using these four measurement loops that are repeated in sequence over the course of a test:

- 1) Center Freq. = 90.9 MHz, Span = 5 MHz, RBW = 30 kHz, VBW = 3 kHz, ST = Auto, Loop = 4, Step = 3 sec.

- 2) Center Freq. = 98.0 MHz, Span = 20 MHz, RBW = 30 kHz, VBW = 3 kHz, ST = Auto, Loop = 1, Step = 3 sec.
- 3) Center Freq. = 90.9 MHz, Span = 5 MHz, RBW = 30 kHz, VBW = 3 kHz, ST = Auto, Loop = 4, Step = 3 sec.
- 4) Center Freq. = 90.9 MHz, Span = 500 kHz, RBW = 1 kHz, VBW = 1 kHz, ST = Auto, Loop = 1, Step = 3 sec.

This setup results in a ten-step, repeating spectral measurement routine in which an analyzer sweep is triggered and its data captured every three seconds. The first four sweeps are made in 5 MHz spans centered on 90.9 MHz, the fifth sweep captures the entire 88 to 108 MHz FM band, the sixth through ninth sweeps are again 5 MHz spans about 90.9 MHz and the last sweep is a close-in 500 kHz sweep centered around 90.9 MHz. Other spectrum analyzer parameters settable in each loop include reference level, attenuation and video averaging.

Though conceptually simple, multi-sweep programmability is one of the most powerful features of the field test platform. In a single test run, it allows the specification of different spectral sweeps, each tailored to capture accurately specific types of information, e.g., low-resolution, rapidly swept spectra for best desired-to-undesired power ratio measurement interleaved with high-resolution, slowly swept spectra to elicit spectral detail.

Audio Recording— A Digital Tape Recording System (DTRS) is recommended by the audio recording industry for reliable, high-fidelity audio recording. CD-quality—16 bit @ 44.1kS/s—audio recording requires an enormous amount of data storage capacity. Compared to a fixed-disk audio recorder, a DTRS provides virtually limitless audio recording capacity with a quick swap of media. The DTRS media is readily available Hi-8 videotape, whose maximum capacity is 8 tracks by 120 minutes. The DTRS transport is more resistant to mechanical stress than those of hard- and removable-drive recorders. This is a significant consideration in a vehicular test environment.

As for all professional audio recorders, a DTRS has the capacity for sourcing or accepting SMPTE timecode. In operation, the test platform records along with the other test data the timecode provided by the DTRS recorder's internal timecode generator. This ensures precise

correlation between recorded audio and all other test data.

Observer Comments— Test operator observations often are as enlightening as the machine-collected data. In pre-NRSC field tests, engineers and technicians were encouraged to enter their observations in a logbook for later review. In practice, this produced varied and sometimes incomprehensible results. Often, observations were not linked with certainty to automated data, casting doubt upon their value. To better capture useful operator input, the test platform design supports two methods of direct user input into the recorded data. The first is by insertion of operator comments into the data during execution. This type of entry is well suited to configuration notes, as well as, in-progress comments. However, text entry can be a cumbersome exercise in many situations. The second input method, hotkey entry, gives the operator a simpler, more rapid way to log observations. In operation, when one of a reserved set of PC keys or combinations of keys is depressed, the test automation application will enter a corresponding code into the current test record. Each code represents a significant event or condition that observers may witness during testing. Examples are *Overpass*, *Lightning*, *Tunnel*, *Large Sound Impairment* and even *Ignore Last Comment* to correct erroneous entries.

Post-Test Analysis— The field test platform is capable of storing staggering amounts of data in the performance characterization of a single IBOC station. In order to deal effectively with review and processing of these data, iBiquity designed a comprehensive data analysis program known as *DataView*. This PC-based application can read and replay data files created by the *TakeATest* field test platform. *DataView* also includes numerical processing, data search and export facilities. *DataView* was renamed *iView* after its first major software revision, which coincided with the introduction of *The Collector* field test application.

Implementation: *The Collector* Field Test Platform

Distinguished by its name change from *TakeATest* to *The Collector*, the field test platform's second design iteration is not significantly different from the first in principles

of operation. However, many aspects of the controller program are enhanced. These include:

- A completely redesigned GUI
- Instrument state monitoring
- Program stability
- Data integrity monitoring and error trapping
- Speed of data acquisition

Figure 1 is a high-level block diagram of *The Collector* platform. The primary hardware components of this platform are:

- the NRSC analog test receivers
- the iBiquity IBOC DAB receiver
- an Agilent Model 8591E spectrum analyzer
- a Trimble Placer 455 GPS receiver
- the iBiquity antenna distribution network

- a PIII controller PC with a Microsoft Windows 98/2000 operating system (the *DAQ PC*)
- a Tascam DA-98, 8-Track DTRS recorder and a pair of Rane SM26B audio splitter/mixers for analog input level trimming
- a CCD camera and associated camera web server
- a 12 VDC-to-115 VAC power inverter and a regulated, 115 VAC-to-13.8 VDC power supply
- the van audio monitoring system

All of these components are assembled into a full-size, 19-inch rack-equipped passenger van, as shown in Figure 2.

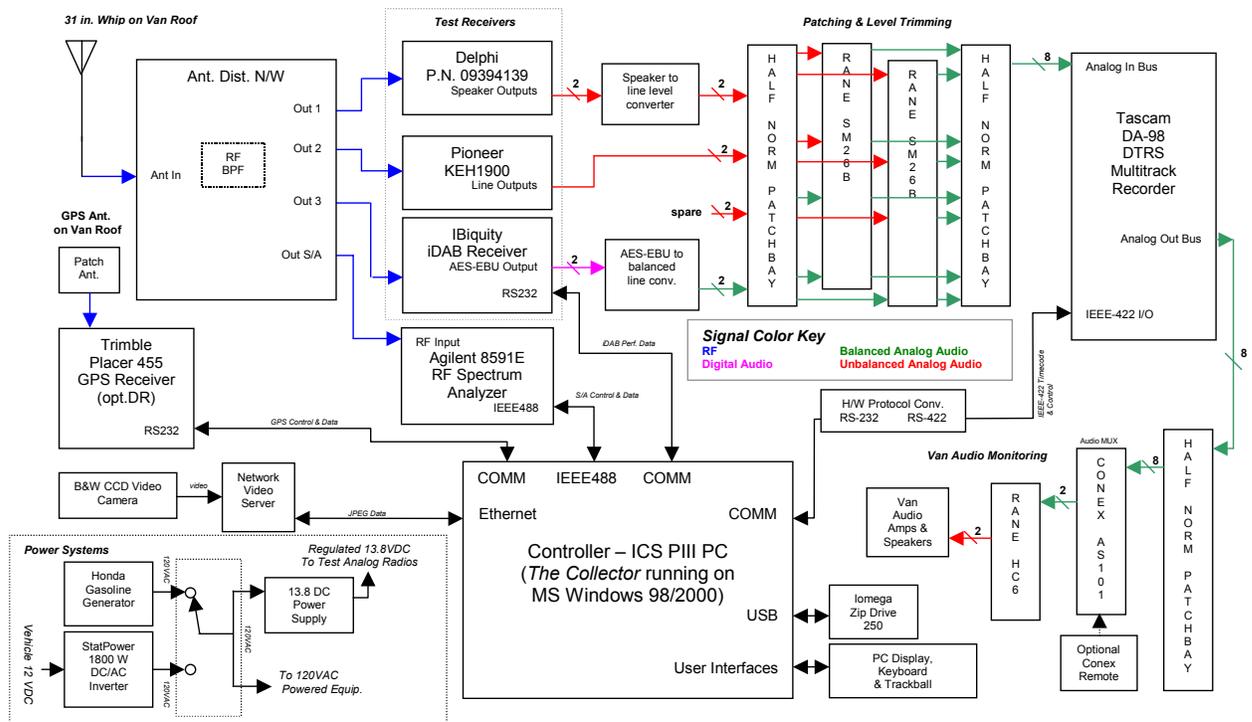


Figure 1: *The Collector*—Configured for FM-Band Testing



Figure 2: Field Test Platform Assembled in a Test Van

Test Receivers— The NRSC-specified analog test receivers are a Pioneer KEH-1900 and a Delphi OEM model 09394139. The receivers are mounted in 19-inch rack panels and powered by the platform’s regulated 13.8 VDC. The Pioneer KEH-1900 provides unbalanced, line-level audio outputs. These are connected directly to a pair of the high impedance, balanced inputs of a Rane SM-26B audio level trimmer. Since the Delphi provides no line-level audio interface, it is equipped with an off-the-shelf, speaker-to-line-level adaptor module. The output of this device drives a dedicated pair of inputs to the Rane level trimmer.

The iBiquity IBOC DAB receiver operates from the van’s 115 VAC power supply. A Lucid digital-to-analog converter converts the iDAB receiver’s AES-EBU audio output to balanced analog audio. The line-level output of the Lucid feeds a dedicated set of Rane SM-26B inputs.

For FM-band testing, receiver outputs of the antenna distribution network connect directly to the IBOC, Delphi and Pioneer receivers’ antenna ports through 50 Ω RF coaxial cables.

For AM-band testing, dedicated antennas provide signals to each receiver.

Spectrum Analyzer— The spectrum analyzer is an Agilent model 8591E. The DAQ PC controls and collects data from the spectrum analyzer by way of its IEEE-488 instrumentation interface. The FM antenna network provides an amplified signal to the spectrum analyzer input. In AM operation, the spectrum analyzer receives its signal from a dedicated whip antenna.

The spectrum analyzer is powered from the van’s 115 VAC supply.

Global Positioning System (GPS) Receiver— The GPS receiver is a Trimble Placer 455. Physically located inside the FM antenna distribution network’s enclosure, the GPS receiver takes its power from the antenna network’s internal 15 VDC supply. In the course of normal operation, the DAQ PC sends position-velocity queries over an RS-232 connection to the GPS receiver. The Placer 455 responds by returning the solution back over the serial interface. The ASCII response string contains latitude, longitude, velocity, GPS time, receiver mode and a freshness datum. This last piece of information is a simple indication of the data’s disposition and age. In post-test analysis, *iView* uses the GPS freshness datum to flag stale

location data and optionally provide interpolated position fixes.

In its original configuration, the GPS receiver operated in conjunction with a differential GPS receiver to improve its positional accuracy over that available for commercial service. However, the differential receiver is no longer necessary to realize increased accuracy, as the US government has discontinued transmission of dithered GPS signal phase.

Antenna Distribution Network— There are several methods of splitting the FM-band master antenna signal for distribution to the radios and spectrum analyzer. Depending upon the dynamic range characteristics of signals in the test area, the test team may choose either active or passive splitting of the signal received by the master antenna on the van's roof. In most test scenarios, network AAN3 (*Active Antenna Network #3*) of Figure 3 is the recommended FM antenna distribution network.

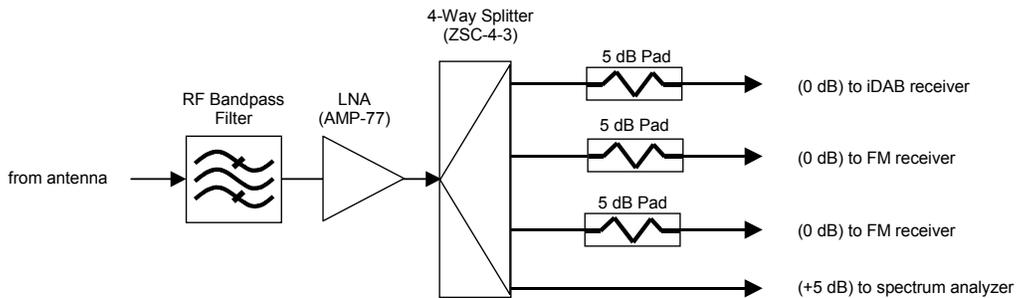


Figure 3: FM Antenna Distribution Network AAN3

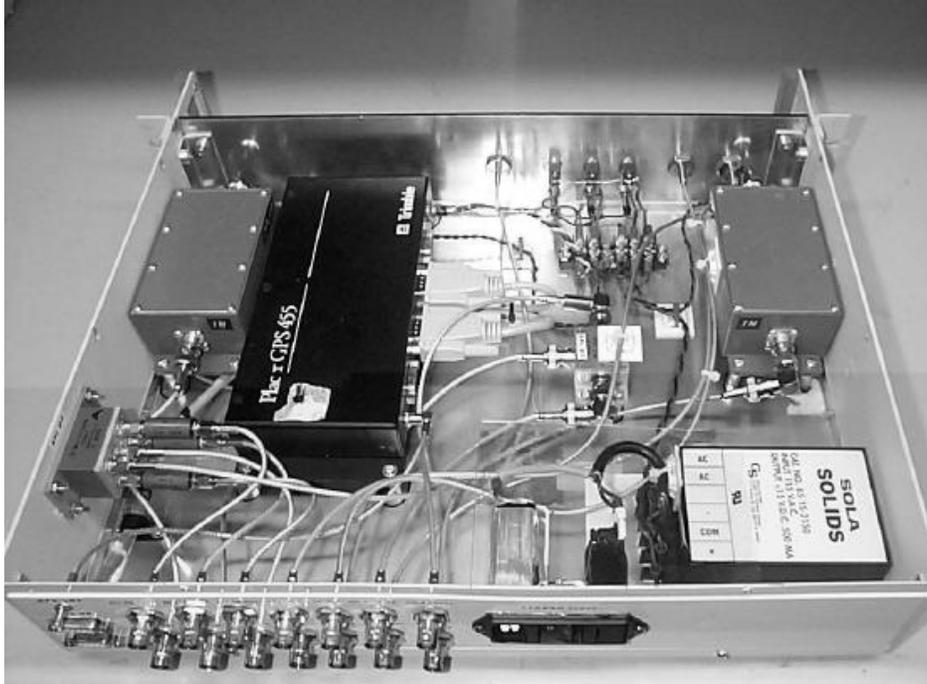


Figure 4: An implementation of the GPS Receiver and the FM-band antenna distribution network, AAN3

Network AAN3 offers the advantage of RF bandpass protection for the amplifier and test receivers against strong signals more than about five FM channels (± 1 MHz) away from the desired signal. The RF bandpass is a custom filter for each test station, usually centered on the desired IBOC signal frequency. Including feed cable loss, AAN3 has a noise figure, insertion gain and third-order input intercept point (IIP3) of 8.7 dB, -1.5 dB and 21 dBm, respectively. Thus, the insertion of AAN3 before a receiver with a noise figure of 10 dB results in an overall noise figure of 13 dB. This 3 dB increase in noise figure is about the same loss of sensitivity as inflicted by the nominal insertion loss of a vehicular antenna feed. Additionally, given its low gain and high IIP3, it is very unlikely that AAN3 will degrade the IM performance of any consumer receiver it feeds. Nevertheless, in areas where extremely high signals occur in or near the desired channel, it is recommended that appropriate attenuation be added between the master antenna and its input to AAN3.

The receiver outputs of the FM antenna distribution network connect directly to the IBOC, Delphi and Pioneer receivers' antenna ports via 50 Ω , double-shielded RF coaxial cables and adaptors. While the analog receivers' input impedances may be somewhat higher than 50 Ω in FM reception mode, they are still matched well enough to ensure good signal transfer from the antenna distribution network. Laboratory tests of AAN3 with the NRSC receivers indicate the network causes negligible differences in each receiver's sensitivity and dynamic range performances.

AAN3 boosts the signal feeding the spectrum analyzer by 5 dB. While this enhances the sensitivity of the spectrum analyzer by a mere 4 dB, this improvement is adequate for most FM IBOC coverage and performance testing.

Figure 4 is a photograph showing one implementation of AAN3. This version is designed for easy field re-configuration into a variety of active and passive splitter architectures. Along with AAN3 in the rack-mountable enclosure are a spare amplifier module, a two-branch hybrid power splitter, the Trimble Placer 455 GPS receiver and a 115 VAC-to-15 VDC regulated power supply for all active components. The RF bandpass filter (not shown) is located outside the enclosure to

facilitate its swap-out as required for various stations' tests.

As previously discussed, all receivers and the analyzer have dedicated antennas for AM-band testing. Since the analog automotive receivers are designed to work with 31-inch whips, the only additional consideration for these radios is the provision of low capacitance feed cables. The input impedances of both the IBOC receiver and the analyzer are 50 Ω , and therefore, unsuitable for direct connection to the high impedance, capacitive whip antennas. The IBOC receiver and the analyzer antennas are equipped with wideband matching networks at their bases to improve signal delivery to 50 Ω . If required, a preamplifier located between the antenna match and the spectrum analyzer's input can improve the analyzer's sensitivity. However, this must be done with due consideration to issues of non-linearity.

DAQ PC— The DAQ PC controls the operation of and collects data from all other measurement equipment except the antenna distribution network. Its chassis is a heavy-duty, industrialized design from ICS, incorporating disk drive shock mounting and extensive EMI/EMC-shielding. The main processor is an Intel Pentium II or III, running at a clock rate between 300 and 500 MHz.

All DAQ PCs use the Microsoft Windows 98 or 2000 operating system. User interfaces for the PC are the typical monitor, keyboard and mouse or trackball pointing device.

The IBOC radio, GPS receiver and DTRS recorder deliver data to the DAQ PC's RS-232 COMM ports. The spectrum analyzer operates over the IEEE-488 (GPIB) instrumentation bus. By way of its network camera server, the CCD camera delivers stop-action JPEG images to the DAQ PC via Ethernet.

Digital Audio Recording System— The digital audio recording system includes two Rane SM-26B splitter/mixers, a half-normalled, balanced 1/4 -inch TRS patchbay, a Tascam DA-98 DTRS recorder and an RS-422 to RS-232 interface converter for the SMPTE timecode signal.

As described in the test receiver section above, all receiver outputs feed dedicated channels in the Rane SM-26Bs, which are set up

as straight-through audio trimming blocks, each channel isolated from all others. The right and left channels from each radio are paired into and out of adjacent trimming sections, arranged either side-by-side or top-and-bottom. The outputs from each SM-26B section are balanced. Each drives one of the eight DA-98 balanced analog audio inputs as indicated in Figure 1. The eight, balanced outputs from the DA-98 supply the input section of the Conex AS101, which is the van's audio system multiplexer. Half-normalled patchbay sections permit breakout, splitting and substitution of audio signals immediately before the SM-26B trimmers, between the SM-26Bs and the DA-98 inputs and at the DA-98 outputs. These patch points allow straightforward access for performance verification, troubleshooting and receiver substitution.

To synchronize the digital audio recordings with other field test data, the DAQ PC captures and records the SMPTE timecode from the DA-98.

The DA-98 recorder was chosen for this mobile recording application for numerous reasons. In particular,

- It has a recording mode confidence head to allow immediate playback of the actual audio captured on tape. This allows real time verification of recorded tracks.
- It can record at both 44.1 and 48 kS/s rates.
- It has self-contained performance monitoring modes, including error rate indications, head condition monitoring and maintenance logging
- The recording medium – Hi-8 metal videotape – is widely available, durable and compact. It provides up to 2 hours of 8-track recording at CD-quality bandwidth and dynamic range.
- Interfaces are available for direct-to-PC recording (simultaneous with taping) and direct digital audio transfer.

Testing of the audio recording system demonstrates over 80 dB of A-weighted, quasi-peak dynamic range in each DTRS audio channel, virtually immeasurable channel-to-channel crosstalk and better than 0.01 % A-weighted, quasi-peak total harmonic distortion.

CCD Camera— Facing forward on its mount at the front of the van, the CCD camera captures periodic images of the field test

environment for storage with correlated field test data. The camera produces compressed JPEG image files, which it sends to its associated network camera server. The server encapsulates the image files in IP broadcast packets and “pushes” these out over its Ethernet interface to the DAQ PC.

The camera may be either color or black-and-white (B&W). Currently, only B&W cameras are used. B&W image file sizes are significantly smaller than those of color images, reducing data storage and transfer requirements.

Power Supply Systems— Each component of the field test DAQ platform has powering requirements for either 115 VAC or automotive DC, nominally 12 VDC. An 1800-watt DC-to-AC inverter provides 115 VDC. Depending upon the van configuration, the inverter receives its input power either from the vehicle's main battery over a low gauge, dedicated cable pair or via direct connection to a dedicated, deep-cycle battery that is tied into the vehicle's charging system.

All test equipment and radios except for the automobile test receivers and the audio power amplifier operate from 115 VAC. The auto receivers could operate directly from the vehicle DC supply. However, there is the possibility that the voltage fluctuations and conducted EMI typical of a vehicular electrical system could cause substandard or inconsistent performance in these radios. To avoid these potential problems, the van is equipped with a 115 VAC-to-13.8 VDC regulated supply. This provides the test radios a stable, clean power source, well isolated from the van's electrical system. The DC supply draws its power from 115 VAC inverter output.

As its operation is not critical to testing, the audio power amplifier draws its power from the vehicular 12 VDC supply.

Audio Monitoring System— The in-van audio monitoring system consists of a Conex AS101 audio multiplexer, a Rane HC-6 headphone console, a multi-channel audio power amplifier and loudspeakers. The AS101 selects the audio from one receiver at a time for routing to the HC-6. The channel 1 trimmer on the HC-6 adjusts the level of the audio fed to the audio power amplifier and van monitoring speakers.

Channels 2 through 6 are stereo headphone stations.

The audio monitoring equipment serves only to provide the test team with convenient monitoring of any receiver's audio during data collection. The audio monitor system has no official test or evaluation purpose.

Test Automation Software— *The Collector* test application is a stand-alone, executable program created by iBiquity using National Instruments' LabVIEW development system. Running under Windows 98 or Windows 2000 on the DAQ PC, *The Collector* is capable of complete control and data acquisition for performance elements of IBOC field testing. *The Collector* can query and/or control an 8591E spectrum analyzer, a GPS receiver and an iBiquity IBOC receiver. It can also sample and store push data from SMPTE or MIDI timecode sources and a network server of JPG images. As shown in Figure 5, *The Collector* GUI's main

window provides real time indications of RF channel conditions, time and position location, IBOC receiver performance, test instrument status and data acquisition status. The main screen includes virtual buttons for test execution control and manual adjustment of the spectrum analyzer reference level. The latter allows the operator to optimize the spectrum analyzer's dynamic range while testing is in progress.

A virtual button on the GUI tab bar labeled *Comments* summons a pop-up text window for entry of user comments. The window may be opened any number of times during the test; each time the operator closes it, entered comments are imbedded in the current record.

A status bar along the upper left side of the main window shows the state of *The Collector's* communications with each of the key platform instruments. Status is intuitively color-coded: Green = good data, Red = no/bad data, Gray = device inactive.

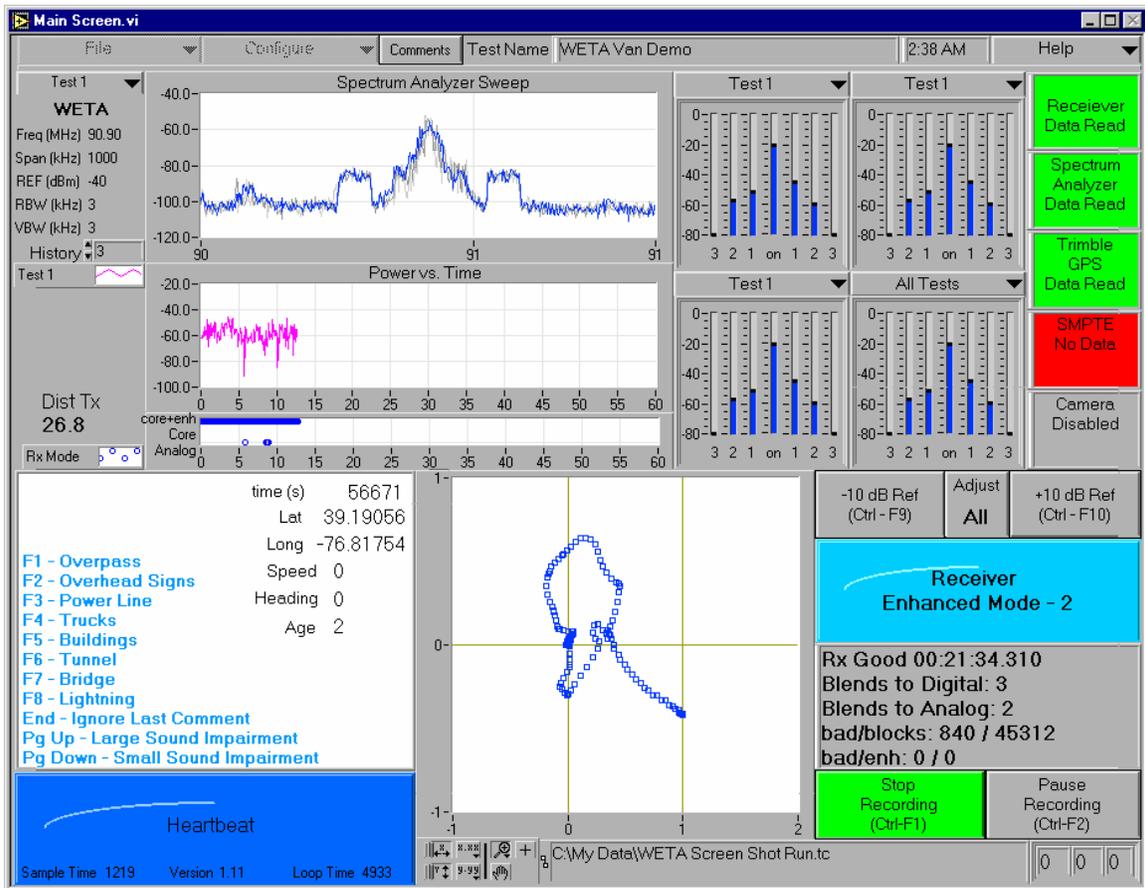


Figure 5: *The Collector's* Main GUI Screen

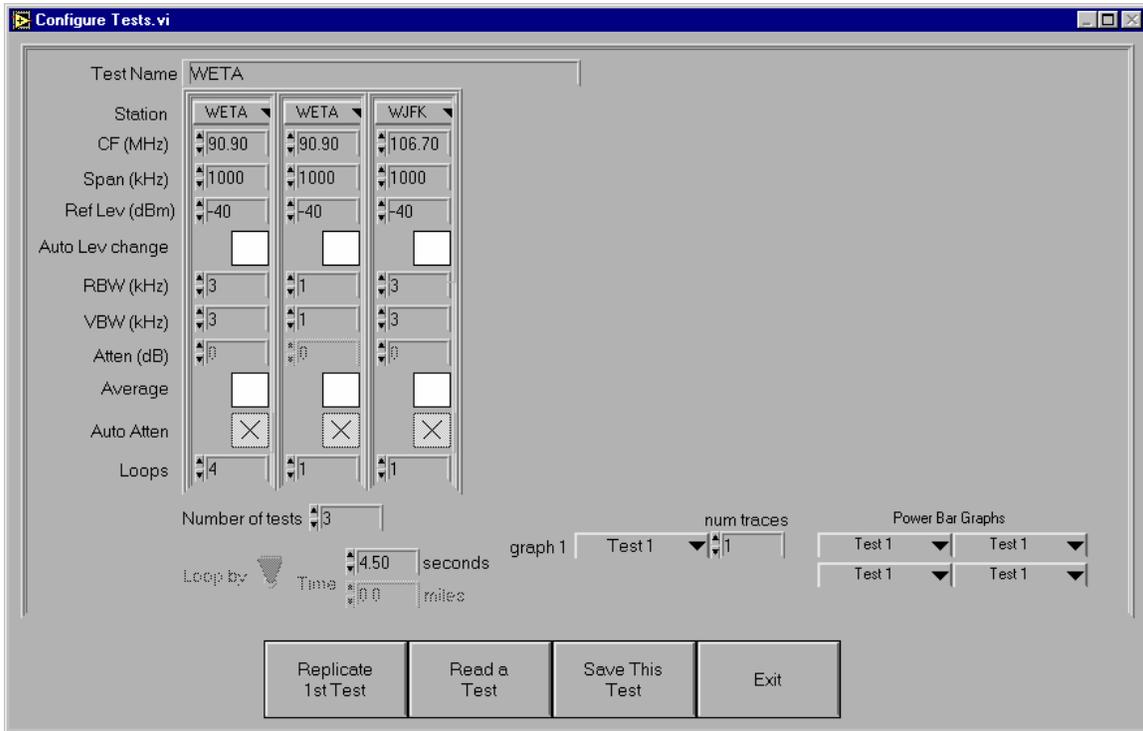


Figure 6: *The Collector's* Test Configuration Screen

IBOC radio status and performance data are indicated in the lower right quadrant. The color of the large *Receiver Mode* indicator is determined by the IBOC receiver's audio mode. Mode information also appears in histogram format near the center of the window.

Current GPS data appear in the lower left window along with codes for the PC hotkey assignments. A plot of the covered drive route appears in the lower center of the main window.

RF channel state indicators occupy most of the main screen's upper half. These include a display of current and recent spectral data, a desired channel signal level versus time histogram and four bar charts showing desired plus upper and lower adjacent channel received power levels. Figure 6 is the test configuration screen. Using this, the operator may create custom tests comprised of up to ten measurement sub-loops. Each sub-loop can support a different spectrum analyzer configuration and may be programmed for repetitions before proceeding to the next sub-loop. Measurement cycles may be

based on time or distance traveled, as determined by GPS. From the test configuration menu, the operator may link each of the main window's power bar graphs to a particular sub-loop data acquisition cycle. Test configurations may be saved and recalled.

The Collector has several other windows giving access to functions such as configuration of communications/instrumentation interfaces, entry into and editing of the local transmitter database and viewing of the debug log file.

Acquisition Performance— *The Collector* can acquire data at a rate of up to 2 samples/second. For some test configurations, the sweep time of the spectrum analyzer limits the speed of data acquisition. Fortunately, the most accurate received signal power measurements are made using combinations of frequency span, resolution bandwidth and video bandwidth that also permit the fastest sweep times—usually on the order of 50 ms per measurement. This provides the best “snapshot”

performance possible using swept frequency analysis.

Data Analysis Tools— *iView* is designed to review and search data files that have been created by *The Collector*. All acquired data can be viewed using *iView*. In the case of segmented test drives, *iView* allows concatenation of multiple data files for continuous analysis. Designed to mimic VCR operation, *iView* provides the data analyst with a virtual transport control, effecting real time, accelerated, slow-motion, or stepped playback of field test data. Most data appear directly in the main window, with detailed views available for all plots in secondary windows. Figure 7 shows *iView*'s main window, whose primary graphical displays comprise RF spectrum, an IBOC-mode coded drive route plot and a signal-strength versus distance plot for desired and adjacent channels. Dedicated data boxes also display GPS data, IBOC receiver data, operator comments and

hotkey entries and data error diagnostics. All data displays may be printed or stored.

iView's search features can identify data records containing operator comments, hotkey entries, IBOC receive-mode changes and user-specified spectral criteria. Its export utilities can create ASCII versions of processed data, produce information layer files for use with third party mapping programs and load user-specified data into iBiquity's field test database. Figure 8 is an IBOC drive test performance plot for NRSC AM test station WTOP. Exporting IBOC receiver mode data to a mapping application creates this plot.

Figure 9 is a detailed route plot from WTOP's drive test. It shows desired and adjacent channel signal powers along with IBOC receiver mode data collected on the 45-degree (northeast) radial. *iView* exports processed test data to a Microsoft Excel template to produce this.

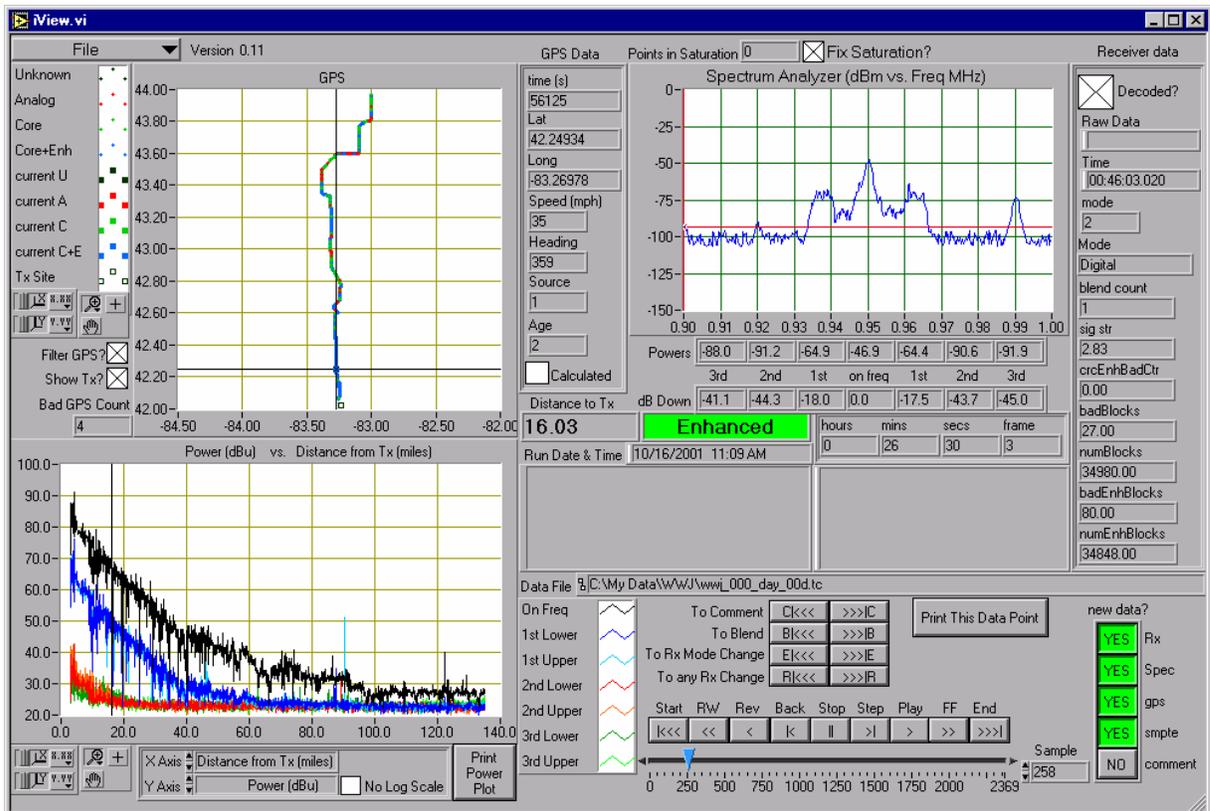


Figure 7: *iView* Analysis Tool's Main Window

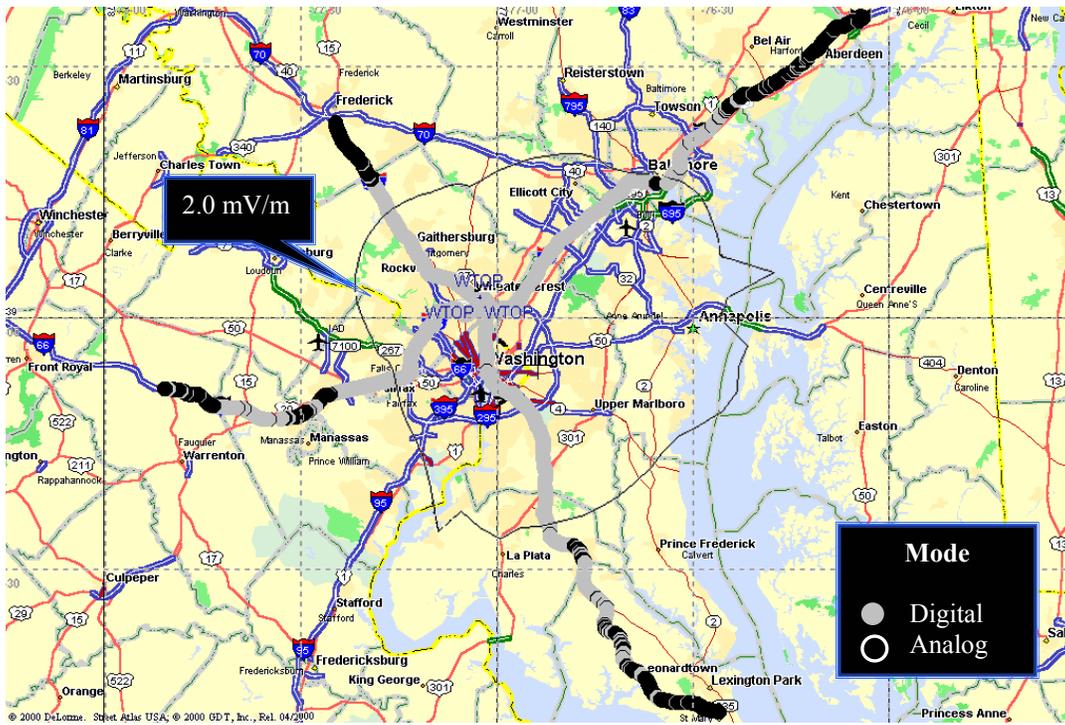


Figure 8: Hybrid AM IBOC Performance Map for WTOP

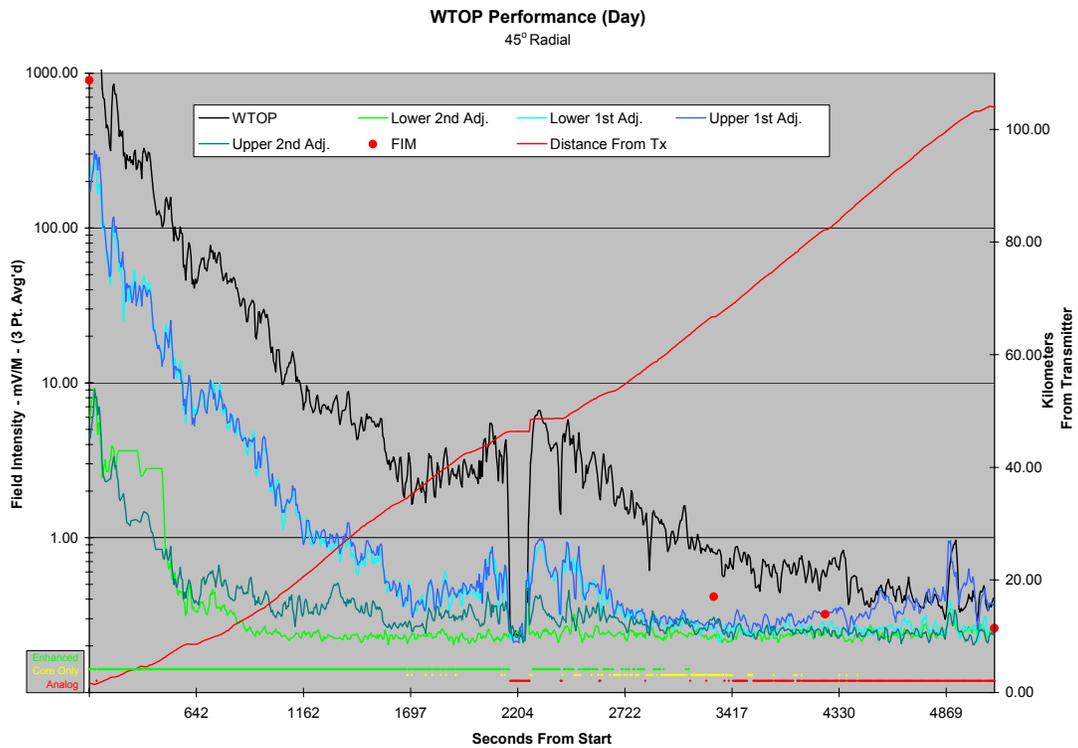


Figure 9: WTOP Radial Plot with IBOC Performance Data

Another class of data easily processed with the help of *iView* is the recorded audio. When significant conditions or performance criteria are identified within the test data, it is straightforward to locate the corresponding recorded audio using the logged SMPTE timecode. Test engineers use this method extensively to isolate audio samples appropriate for subjective evaluations.

Engineers perform more advanced analyses once test data are loaded into the iBiquity field test database. This relational database contains processed data from all IBOC field tests. As would be expected, conditional queries operating on any identification and data fields are possible. Particularly valuable is the ability to query the database for test records with complex combinations of IBOC mode, desired signal level and adjacent channel interference conditions. This query has been used for processing significant portions of the NRSC field test data.

IV CONCLUSION

iBiquity's field test platform, *The Collector*, and its companion application *iView* are capable of fast and accurate measurement and analyses of IBOC DAB field performances. Objective performance results can be processed into detailed coverage maps and RF channel characterization plots within hours of field test completion. Pertinent samples for subjective audio evaluations are easily identified through good correlation of recorded audio and other test data.

Using *The Collector* and its analysis tools, iBiquity has successfully field tested its AM and FM IBOC DAB systems to NRSC requirements. Moreover, iBiquity continues to use this platform as a key test and validation tool in IBOC commercialization and deployment.

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VI REFERENCES

- [1] R-3 (Audio Systems) Committee DAR Subcommittee, *Technical Evaluations of Digital Audio Radio Systems, Final Report December 1997*
- [2] National Radio Systems Committee, Digital Audio Broadcast Subcommittee, *IBOC Field Test Procedures—FM Band*, December 2000
- [3] National Radio Systems Committee, Digital Audio Broadcast Subcommittee, *IBOC Field Test Procedures—AM Band*, May 2001