

Tomorrow Radio Project Field Test Results

A Modest Step Towards an Open Architecture Approach to the iBiquity Digital HD Radio System

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ABSTRACT

The Tomorrow Radio Project sought to test the robustness of Supplemental Audio Channel (SAC) coverage when splitting the main audio program channel (MAP) into both a digital simulcast channel operating at 64 kbps (with blend-to-analog retained) as well as an SAC operating at 32 kbps (without the safety net of blend-to-analog).

BACKGROUND

In October 2002, the FCC endorsed the iBiquity Digital IBOC system for transmission by all AM and FM broadcast stations. The interim rules in the First Report and Order did not authorize nighttime AM operation, use of separate transmit antennas for digital transmissions, or use of extended hybrid signals. Significantly, the Order mandated simulcast-transmissions for FM stations. The Commission recognized each of these topics as areas of broadcaster interest and encouraged the generation of additional data to inform future regulatory action.

The main audio program (MAP) in iBiquity Digital's FM-HD Radio system transmits a 96 kbps audio stream using the HDC audio coder. The system is designed to blend-to-analog whenever digital service is lost. NPR announced the formation of the Tomorrow Radio Project with co-sponsors Harris and Kenwood at the Consumer Electronic Show in January of 2003. A project update was provided to the NRSC in April of 2003 and input gathered at that meeting resulted in the addition of New York, Washington, and San Francisco to the original single test plan for Long Beach. Harris, Kenwood and NPR conducted a series of bi-weekly conference calls throughout the spring and early summer of 2003 to finalize test station selection, equipment and test plan logistics. Station engineering staff from each of the four test stations were added to the planning sessions. Additionally, Douglas Vernier of V-Soft, technical consultant to CPB on digital radio transition, joined the planning sessions.

Management at each of the four test stations supported the activity and the FCC's Media Bureau authorized the experimental license requests in early August 2003. iBiquity Digital provided significant

support for the field tests by developing and delivering the necessary software customization to Harris and Kenwood for transmission and reception using the original PAC audio coder in late June of 2003, and an HDC audio coder version for final regression tests in early November of 2003. In October, NPR provided a progress update to the NRSC, as well as to the IEEE's Broadcast Technology Symposium.

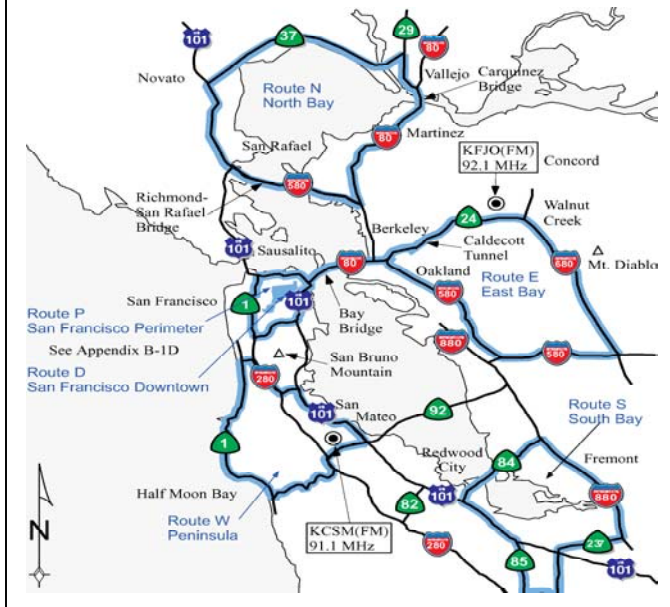
Between August and December of 2003 NPR, Harris, and Kenwood collaborated in conducting extensive SAC propagation field tests in New York, Washington, D.C., Long Beach (Los Angeles), and San Francisco under experimental licenses granted to NPR member stations WNYC-FM, WETA-FM, KKJZ-FM and KALW-FM, respectively. Hammett & Edison provided test design support, data analysis and final report preparation to the FCC. Kenwood provided production run receivers modified for Tomorrow Radio reception as well as complete data collection systems used in each market. Harris Corporation provided transmission equipment used at each test station. The Corporation for Public Broadcasting provided significant funding support and design input to NPR.

FIELD TEST METHODOLOGY

Mobile field test routes were developed by Hammett & Edison for each of the four test markets. In San Francisco, Washington, D.C., and New York test routes were based on routes used during the original NRSC-sponsored field tests of the iBiquity system. Long Beach/Los Angeles required the development of entirely new test routes since it was not a test market in the original NRSC testing. See Figures 1-4.

Kenwood allocated field test equipment consisting of custom receiver performance data collection, spectrum analysis, location tracking via GPS and continuous forward-view video recording. Multiple receivers were used in the original PAC runs to compare Supplemental Audio reception against Main Audio Program reception. The Supplemental Audio Channel was continuously modulated with 1 kHz audio tone as a confidence check of Digital Audio

Figure 1 - San Francisco Test Routes



Acquired flag accuracy (the status field correlating to presence or absence of service in the resulting field plots). See Initial System Block Diagram configuration in Figure 5. On two separate occasions, multiple “confidence” assessment runs were completed on test stations in New York and Washington, D.C. to determine what differences, if any, were exhibited while operating in standard HD Radio (full 96 kbps MAP simulcast mode) vs. the Tomorrow Radio (TR) mode (employing 64 kbps MAP while adding a 32 kbps Supplemental Audio Channel).

NEED FOR HDC REGRESSION FIELD TESTS

In mid August, during Long Beach/Los Angeles field testing, iBiquity unveiled their new HDC audio coder to broadly positive industry reviews during a listening demonstration held at NPR’s Studio 4A in Washington, D.C. Subsequently, iBiquity announced their commitment to the new HDC coder. The Tomorrow Radio Project, after consulting with iBiquity, concluded that additional “regression” field tests were appropriate to assess the overall performance variables of the new coder in Tomorrow Radio mode. iBiquity agreed to produce a TR version of HDC, again relying on audio multiplexing capabilities inherent in the audio coder (a feature common to both PAC and HDC).

Meanwhile, the desirability of avoiding a preamplifier and antenna distribution network were attempted in the initial San Francisco test market, but based on data analysis, directional effects were clearly evident with the three roof-mounted antennas.

Accordingly, the remaining three markets were tested with a single roof-mounted quarter wave vertical, followed by a 23 dB preamplifier and distribution network calibrated for unity gain. Certain performance variables were explored during subsequent data analysis reaching the conclusion that the overhead in the broadband preamplifier may have been exceeded in high signal strength areas. This effect was underscored in the downtown Manhattan route in New York City, especially in the vicinity of the Empire State Building. Ultimately, it was concluded that the final HDC regression test runs in New York City and Washington, D.C. would be conducted with a streamlined “straight wire” antenna-to-receiver configuration, consistent with typical consumer car radio topology.

This change resulted in a significant improvement in the Manhattan route, which now exhibited zero loss of signal locations (even with granularity of the data collection having been increased ten-fold to one sample every 100 milliseconds). Additionally, the South and Southeast signal runs in the Washington, D.C. market improved by several miles.

Figure 2 - New York City Test Routes



Presumably, the amplifier and distribution network had been affecting system performance, essentially substituting the noise and bandwidth of the preamplifier for that inherent in the KTC-HR100’s front-end. Upon investigation the unity gain calibration of the antenna preamplifier and distribution network was discovered to exhibit a net 1.2 dB loss. This, as well as other factors mentioned, affected the performance of the Kenwood receiver in earlier PAC-based testing. Additionally, the effects

Figure 3 – Los Angeles/Long Beach Test Routes



material coverage differences between the performance of 32 kbps SAC and the 96 kbps MAP.

Out-bound hold & in-bound acquisition – some small differences were noted in the digital system capture for out-bound vs. in-bound test runs. Since propagation models do not incorporate data granularity for buildings, overpasses and other manmade structures some, if not all, of the performance delta could be based on such real-world line-of-sight

of 2nd adjacent channel stations to somewhat restrict digital coverage were observed during both PAC and HD testing in directions toward such outlying stations. No analysis was conducted between PAC-based reception and HDC-reception performance with other factors eliminated.

RESULTS

HDC regression test runs were conducted in Washington, D.C. and New York City in November and December 2003 with permanent HD Radio systems now installed at WETA-FM and WNYC-FM.

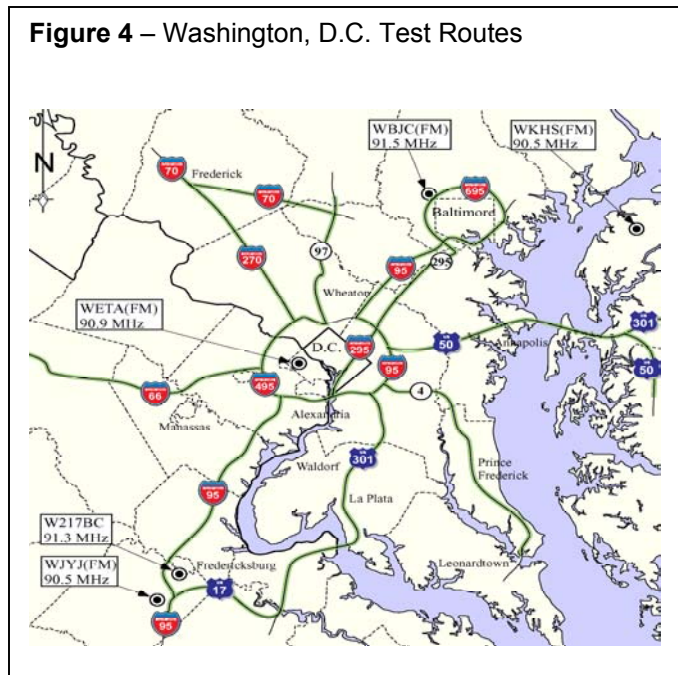
In the case of Washington, D.C., 2.1 dB improvement in “best fit” analysis was achieved and arguably even more was achieved in New York City, primarily due to the absence of front-end overload in the downtown route. See Figures 6 & 7.

Hammett and Edison used a proprietary Terrain Integrated Rough Earth Model program (TIREM) to determine a “best fit” contour that most closely matched the successfully recovered SAC signals. The coverage and population achieved in the final HDC regression runs, as well as the earlier PAC-based runs is summarized in Table 1.

TEST VARIABLES OF INTEREST

Confidence runs – field test runs were conducted in both Tomorrow Radio mode and pure hybrid (full simulcast) mode using both PAC and HDC. Interestingly, the Tomorrow Radio-based PAC runs provided noticeably better performance vs. the pure hybrid runs. No investigation for this result was conducted. HDC based confidence runs revealed no

Figure 4 – Washington, D.C. Test Routes



variables. Test van position in specific lanes during data collection could explain the observed differences. An alternate explanation could be an “acquisition hump” related to packet error correction of a captured signal near the point of failure vs. inability to correct an in-bound signal that has not been captured. SIS (station information service) packet capture is a possibly related threshold that could correlate to MAP acquisition and hold. See Mike Bergman’s paper, FM HD Radio Coverage for Specific Applications, for an illuminating look at SIS coverage area data gathered during Tomorrow Radio field testing.

Figure 5 – Test Van Block Diagram –preamplifier and antenna distribution network omitted for final HDC Regression Tests (see narrative).

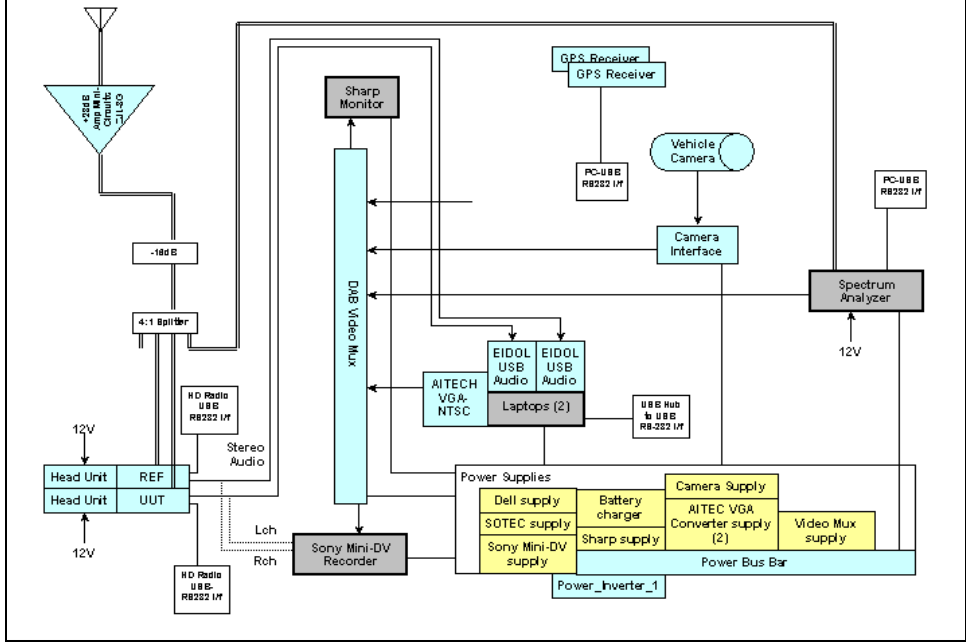


Figure 6 – Washington DC Final HDC Coverage – 4,656,986 population - ~65 dBu TIREM shaded contour – 700 watt HD signal

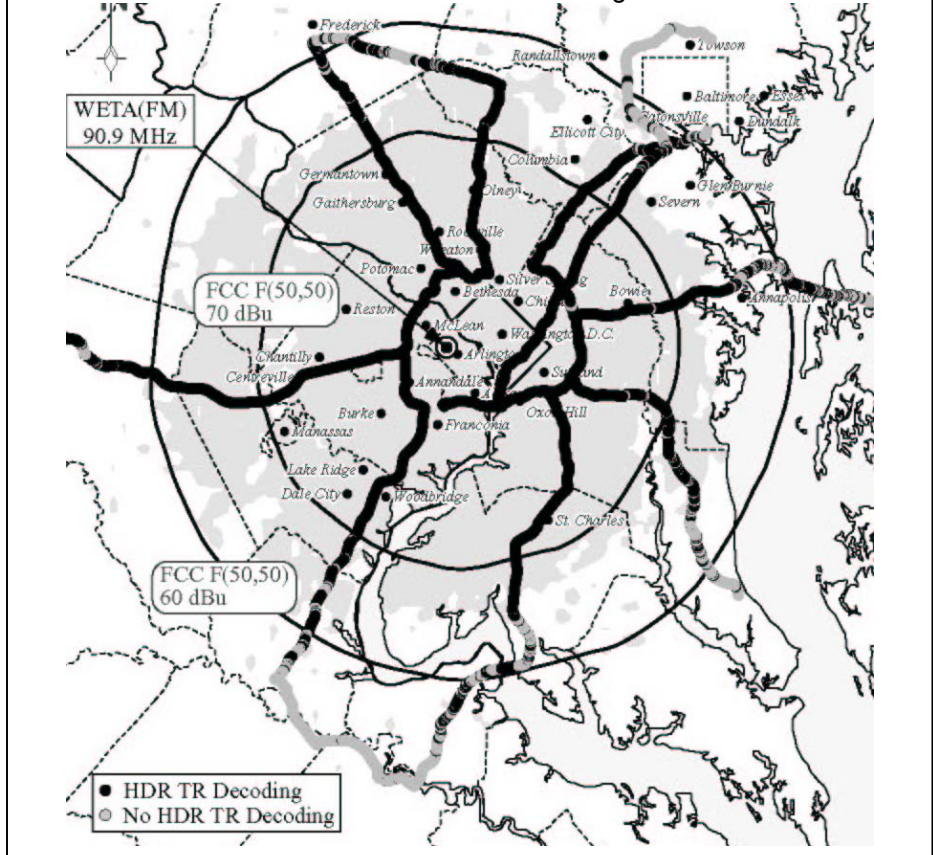
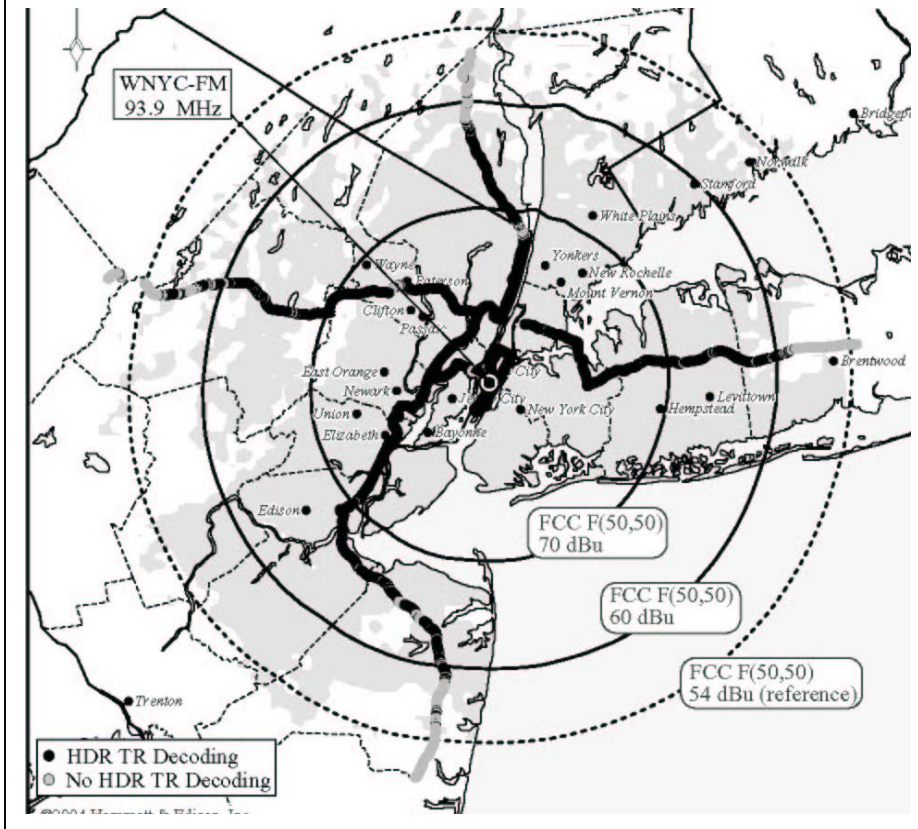


Figure 7 – New York City Final HDC Coverage - 15,747,000 population- ~61 dBu TIREM shaded contour – 57 watt HD signal



Manmade factors – during the 7,500 miles of field test runs, several electrical factors were observed in specific locations affected system operation.

- During PAC-based field runs south east of Washington, D.C. along Maryland Route 4, a spectrum shot was taken showing a first adjacent channel signal with a wide envelope characteristic of highly modulated FM signals. This signal was discovered while reviewing localized performance degradation. No licensed FM station existed that matched the signal level and location of interest.

The phantom signal was not present on other days on this same test route. Since the signal was evident on the spectrum analyzer, Receiver Induced Third Order Intermodulation Effect (RITOIE) was discounted. This phantom signal could have been an irregularly operating pirate FM station or intermittently radiated intermodulation mix. No other phantoms of this variety were noted during the field tests. No pirate operations had been reported in this area, although one had been shutdown on the opposite side of Washington D.C. earlier in 2003.

TABLE 1

Test Market	Tomorrow Radio Population (Census 2000)	TIREM Best Fit Contour
Regression Markets (HDC)		
Washington, D.C.	4,656,986	64.9 dBu
New York City	15,747,274	61.0 dBu
Original Test Markets (PAC)		
Washington, D.C.	4,341,266	67.2 dBu
New York City	(not calculated due to downtown signal overload)	
Los Angeles (Long Beach)	4,181,551	70.8 dBu
San Francisco	1,603,323	66.0 dBu

- Performance investigations on this same run in late August – early September of 2003 revealed wideband hash ultimately determined to be coming from a universal cell phone charger that had been connected to the vehicle’s electrical system. The noise was readily observable on the spectrum analyzer, and based on review of spectrum shots from earlier runs was believed not to have been a factor except on the problematic test run which was promptly repeated without the cell phone charger in operation.
- One outage was noted during a November 2003 preliminary shakedown HDC run on the east side of the Washington, D.C. beltway. Both before and after this outage was observed there were no outages noticed on multiple passes anywhere along the I-495 beltway. It was concluded this brief outage was likely due to the effects of a high powered mobile transmitter passing by the test van at that location on that particular day (earlier in the same day no outage was present going past this location in the opposite direction).

AREAS FOR FURTHER STUDY

Coverage prediction refinements - Since the first broadcast coverage maps were produced in the early part of the 20th century engineers have been refining and corroborating mathematical models of “best fit” coverage predictions. HD Radio coverage is no exception and the Hammett & Edison TIREM models completed for this study show very good correlation to observed data capture. However, no coverage predictions exist with perfect accuracy and no database exists or is likely in the near future accurately incorporating manmade obstruction, translucence and refractive effects at specific frequencies and locations. Additionally, atmospheric and seasonal variations are common factors affecting day-to-day coverage in the FM band.

Moreover, although all radio reception is an interference-limited phenomena, one factor central to HD Radio performance is the effect of adjacent channel operations on HD signal recovery. Some effects were observed related to the presence of 2nd adjacent stations along particular runs during testing. Since the specific performance characteristics of the receiver under test have an obvious impact on predicted coverage, it is of no small significance that the Kenwood engineers developed and delivered first generation HD Radio receiver performance matching or exceeding those of the iBiquity reference receivers. Given the care and considerable sums spent developing the reference receivers this is an impressive accomplishment. We believe the population reach with 1/100th power as shown in Table 1 speaks for itself. The radio broadcast industry can comfortably look forward to likely

further refinements as next generation receivers are developed by Kenwood and other consumer electronics manufacturers.

Adjacent channel factors could be additional order variables in predictive “best fit” analysis using commercially available propagation modeling software. Although not matching the rigor of H&E’s “best fit” proprietary TIREM modeling, NPR has developed a first-cut, best fit projection, using commercially available V-Soft Communications’ FM Probe software. Throughout the months ahead, as new public radio stations come on line with HD Radio transmissions NPR will refine these projections through over-the-air coverage mapping. This information will be shared with the FCC, NRSC, commercial colleagues and other industry stakeholders. Because some public stations operate in the non-reserved part of the FM band (e.g., WNYC-FM on 93.9Mhz) it will be of interest whether non-short spaced HD Radio performance will generally exceed that achieved on the reserved NCE-FM channels where contour prediction allocation methods are employed.

Alternate data rates – the selection of the 64 kbps and 32 kbps data rates were convenient points of reference for investigation since audio coding results at these rates have been published for a variety of codecs and applications in recent years. Additionally, the 32 kbps rate for the Supplemental Audio Channel was believed to yield results comparable to that achieved in iBiquity Digital’s AM IBOC system which relies on a dual stream implementation (core and enhanced) using 36 kbps total. Since both the PAC and HDC coders will respond to variable audio data rates, proof of concept testing for the Tomorrow Radio Project could have been made at any number of complementary combinations. See Table 2.

	MAP	SAC1	SAC2
Mode A	96	0	0
Mode B	64	32	0
Mode C	80	16	0
Mode D	72	24	0
Mode E	60	36	0
Mode F	48	48	0
Mode AA	48	24	24
Mode BB	32	48	16
Mode CC	32	32	32

Further Audio Enhancements
iBiquity Digital, in response to NRSC requests, has been conducting HDC audio quality tests at 96 kbps,

64 kbps, and 36 kbps. This data should provide additional insights into baseline performance achieved by the new HDC coder. However, further work is needed at these rates when aided by low bit rate audio processors that are being specifically deployed and developed for such purposes. One recent publication from an Australian Study Group noted that near CD quality is being achieved at rates as low as 48 kbps. Obviously, careful scrutiny of such reports is warranted since this could have considerable significance to service providers in an open architecture, discretionary bit rate structure.

Extended Hybrid Services

While the Tomorrow Radio field testing exploited the flexibility inherent in the audio coder within the MAP bandwidth, significant opportunities to expand and offer new public services may reside in the extended hybrid partitions where up to 50 kbps lie fallow awaiting testing of compatibility and robustness. Analog compatibility tests with combinations of individual extended hybrid partitions are an important next step in furthering HD Radio services.

Public radio is especially interested in the possible marriage of the iBiquity digital delivery system for mainstreaming Radio Reading Services for the print handicapped. We believe that in as little as a single partition (12.5 kbps) it may be possible to provide a substantial technical enhancement over existing FM analog SCA-based radio reading services.

Presumably, copyright exemptions could be maintained far more effectively and efficiently by utilizing selective addressing technologies to enable consumer access to such audio services via electronic serial number (ESN) activations. Such techniques are common attributes of the subscription-based satellite radio and satellite TV services. By contrast, over the past 30 years, individual analog SCA radios have been physically delivered to each print handicapped user on a one-to-one basis.

Additionally, the Consumer Electronic Show witnessed the first real-time traffic mapping system through over-the-air demonstrations on Delphi, Visteon and Panasonic receivers. This is an exciting, low bit rate application (approximately 2 kbps) that has obvious consumer appeal. Moreover, the deployment of "Tivo-like" personal radio service and Blue-Tooth enabled back-channel interactivity are promising additional areas of interest for industry and consumers in the years ahead.

CONCLUSION

The Tomorrow Radio Project demonstrated several "firsts". This was the first field testing using production class receivers; the first field testing with HDC; the first field testing of SAC coverage; and the

first field testing done outside of iBiquity's direct influence and control. However, the Tomorrow Radio Project could not have been completed without iBiquity's support. Key iBiquity staff made themselves available throughout the testing to assist the Project team with software needs, designing test plan objectives and in data assessment.

In the Report and Order on MM Docket No. 99-325 the Commission highlighted flexibility and extensibility as important factors in assessing digital radio options for the United States.

The Tomorrow Radio Project's successful field testing represents a modest, open architecture approach to delivering value added services in the FM HD Radio system.

ACKNOWLEDGEMENTS

HD Radio is a trademark of iBiquity Digital Corporation, Columbia, Maryland.

Tomorrow Radio is a service mark of National Public Radio, Washington, D.C.

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SOURCES

Tomorrow Radio Field Testing in the Washington, D.C., New York City, Los Angeles (Long Beach) and San Francisco Radio Markets, Hammett & Edison, National Public Radio, Kenwood, and Harris Corporation, January 6, 2004. Available at www.npr.org/euonline.

FM HD Radio Coverage for Specific Applications, Michael Bergman, [NAB2004 Proceedings of the Broadcast Engineering Conference](#).

NOTE: This paper is also being presented at the NAB04 BEC.