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March 11, 2011

FILED/ACCEPTED

MAR 11 2011

Federal Communications Commission
Office of the Secretary

Marlene H. Dortch, Secretary
Federal Communications Commission
Washington, DC 20554

Re: Request for Extension of Experimental Authority
Executive Committee of the Board of Trustees
of American University, FRN 0002108165
WAMU(FM), Washington, DC
Facility ID No. 65399

Attention: Audio Division, Media Bureau

Dear Ms. Dortch:

On behalf of The Executive Committee of the Board of Trustees of American University, submitted herewith in duplicate is a request for a six-month extension of the Experimental Authority granted September 23, 2010, for noncommercial educational Station WAMU(FM), Washington, DC, to increase digital power up to -10 dB relative to the analog carrier power.

If there are any questions about this matter, please contact the undersigned.

Very truly yours,

Peter Tannenwald

Attachment
cc: (w/att) Ms. Caryn Mathes
Ms. Anne Healy
Mr. John Holt
(via e-mail)

AMERICAN UNIVERSITY
WASHINGTON, DC

March 11, 2011

Marlene H. Dortch, Secretary
Federal Communications Commission
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Dear Ms. Dortch:

The Executive Committee of the Board of Trustees of American University hereby requests a six-month extension of the Experimental Authority granted September 23, 2010, for noncommercial educational Station WAMU(FM), Washington, DC, to increase digital power up to -10 dB relative to the analog carrier power.

All operating parameters, interference considerations, and the contact person remain unchanged from those set forth in our initial experimental application, filed September 21, 2011.

Operation during the past six months has been successful and has improved reception of WAMU's digital signal significantly, without complaints of interference from other stations. Attached is a report of the experimental testing we have done and the results. We wish to continue our experimental efforts and research.

Anti-Drug Abuse Certification. The Applicant certifies that to its knowledge, neither Applicant nor any party to this application is subject to denial of federal benefits pursuant to Section 5301 of the Anti-Drug Abuse Act of 1988, 21 U.S.C. Section 862.

Please direct any questions about this request to John M. Holt, Director of Engineering and Operations, 202-885-1242, jholt@wamu.org, or our counsel, Peter Tannenwald, 703-812-/0404, ptannenwald@fhhlaw.com.

Respectfully submitted,

Douglas Kudravetz
Associate Vice President of Finance and Assistant Treasurer
American University

PAPR and Asymmetrical Sidebands Field Results: HD Radio™ Coverage Technologies

Hal Kneller
Nautel Ltd.
Hackett's Cove, Nova Scotia

John Kean
NPR Labs
Washington, DC

John Holt
WAMU(FM)
Washington, DC

ABSTRACT

Nautel, Ltd., NPR Labs and WAMU (Washington, DC) prepared this joint paper on the results of compatibility testing and field trial of an enhanced PAPR (Peak to Average Power Ratio Reduction) algorithm for HD Radio™ broadcasters, which can provide up to 30% more transmitter output power while simultaneously improving operating efficiency when utilizing the low-level combined mode. It also permits operation of the HD Radio sideband carriers from -20 dBc to -10 dBc, and supports asymmetrical sideband ratios. This paper discusses the final phase, whereas prior NAB papers showed proof of concept. Here, independent laboratory verification measurements and on-air transmission monitoring and measurements will provide data on actual broadcast performance.

NPR Labs performed verification testing with measurements of host compatibility, including simulated multipath conditions, in comparison to the standard iBiquity PAPR. WAMU has been operating with the HD PowerBoost™ system since 25 September, 2010 for on-air verification prior to final product release to customers and will provide solid data to demonstrate the benefits of asymmetrical sideband power when an allocation does not permit full -10 dBc IBOC levels on both sidebands.[1]

The paper will provide an overall summary of HD PowerBoost™ and NPR Labs will highlight their testing and verification, while WAMU will provide information regarding the actual on-air performance.

INTRODUCTION

Previous papers and presentations on this subject have explored the theory as well as technology demonstrations and the product is now commercially implemented. This paper presents an overall technology summary, followed by the results of NPR Labs' compatibility analysis and experiences in actual field trial on WAMU in Washington, DC.

Pursuant to an FCC Experimental Authorization, on 25 September 2010, HD PowerBoost was first placed on the air at American University's WAMU (FM) in Washington, DC following some validation testing performed by NPR Labs. Nautel commissioned NPR Labs to perform independent evaluations of several parameters of digital performance and analog compatibility, compared to the standard iBiquity system. NPR Labs was chosen because of their extensive work and measurements of the HD Radio system in the past, and Nautel desired an independent assessment of its technology. The lab results and on-air testing and field study follow a summary of the PAPR technology in HD PowerBoost.

SUMMARY OF THE TECHNOLOGY

HD PowerBoost is a technology developed by engineers at Nautel, Ltd. to enhance power amplifier performance and operating efficiency when employed in HD Radio or IBOC digital/analog hybrid operation. This permits greater power output from a given power transmitter along with a reduction in electrical operating cost due to increased amplifier efficiency. The asymmetrical sideband capability is an additional benefit since the digital carriers are regenerated at whatever amplitude is required, and differentially, if so desired.

HD PowerBoost is different from the standard iBiquity PAPR because iBiquity had been only concerned with limiting amplitude excursions on the digital carrier sets. But in hybrid operation, using vector addition and subtraction, the analog carrier and the digital carriers can coexist in a constructive or destructive way, in terms of the overall peak amplitude of the entire envelope. Nautel uses the destructive nature to its advantage, and limits when constructive addition occurs beyond a certain point (which is adjustable). For the purposes of the NPR Labs evaluation and WAMU tests, the most aggressive settings were utilized so a worst-case scenario could be tested.

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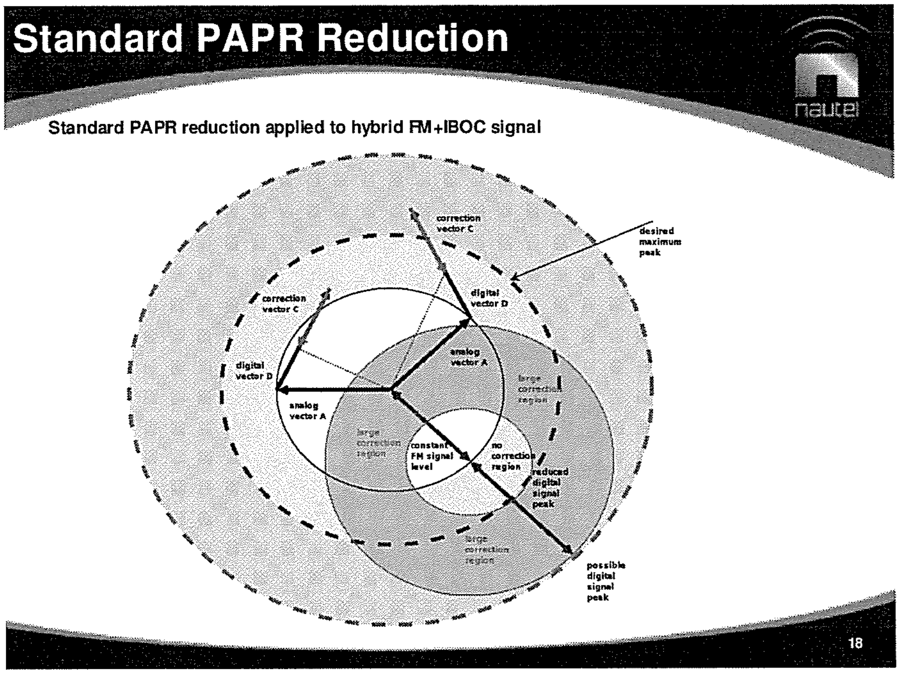
[1] HD PowerBoost is a trademark of Nautel, Ltd.

Figure 1 - Standard PAPR (iBiquity) Reduction



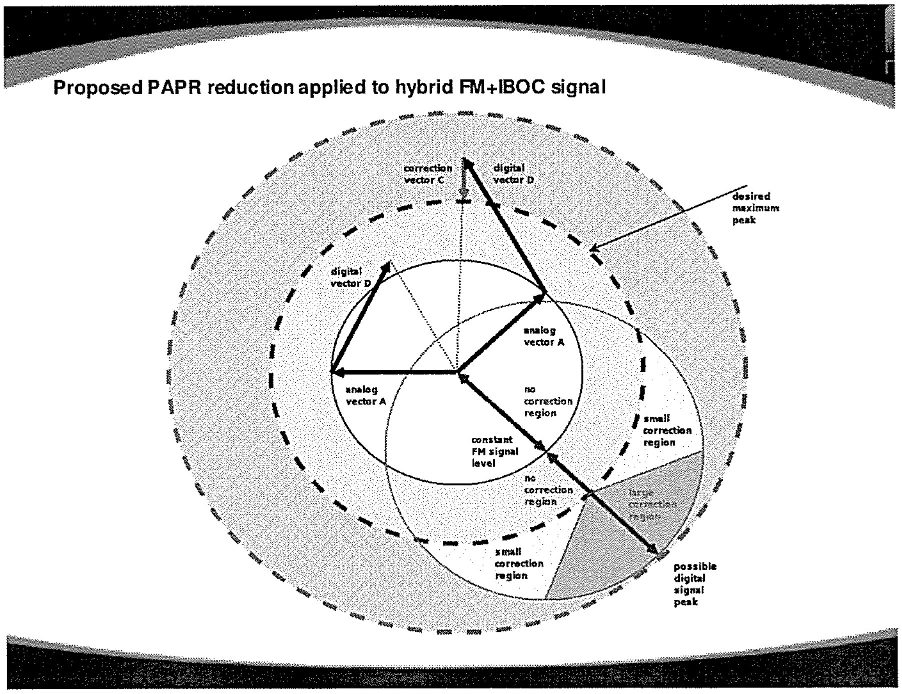
Standard PAPR Reduction

Standard PAPR reduction applied to hybrid FM+IBOC signal

In Figure 1 the analog plus digital vector sum line running from the center circle to the adjacent inner circle at about the 130 degree position, and on towards the outer circle. This worst possible case peak far exceeds available amplifier headroom because the carriers have lined up in a fully constructive manner.

Also note peaks in the left and upper regions show they are being clipped but this is not actually necessary. In the upper region, peak reduction correctly brings the resultant back within the amplifier's headroom.

Figure 2 - HD PowerBoost implemented by Nautel



Proposed PAPR reduction applied to hybrid FM+IBOC signal

Figure 2 shows regions of unnecessary peak reduction eliminated, allowing more aggressive peak reduction where it will do the most good – that is, outside the headroom limit of the amplifier. The new correction region consists of the yellow shaded area (moderate peak reduction) and pink shaded area (aggressive peak reduction).

Note in the figure the vectors towards the left and upper quadrants are adding destructively hence require little or no reduction.

HD PowerBoost is implemented in the FM exciter stage of the transmitter, outside of the iBiquity Exgine card.

LAB TEST PLAN

NPR Labs conducted laboratory measurements with consumer FM receivers to determine the compatibility of FM host transmission and reception of Nautel's "HD PowerBoost" process. The tests utilized automotive, home stereo and shelf system receivers for analog FM compatibility tests and an analog automotive receiver for RBDS performance tests. The testing also evaluated the effect of HD PowerBoost on digital reception with both symmetrical and asymmetrical sideband transmission modes. All tests were conducted with MP3 (Extended Hybrid) mode, which would be more critical than MP1 mode.

RF TEST BED CONFIGURATION

A diagram of the RF Test Bed is included as Figure 3. All RF signals were generated by an exciter supplied by Nautel for their NV Series transmitters, which was equipped with new software for HD PowerBoost. It was important to Nautel to know that the peak reduction capability of HD PowerBoost would have no side effects on the operation of analog receivers over a wide range of receiving conditions.

The exciter's DSP modulator can generate a variety of signals for transmission, including a stereo generator with convenient audio tone modulation. The tone frequencies and modulation levels proved to be very precise; consequently, most line-up tones for the test were generated by the exciter.

All tests included Additive White Gaussian Noise (AWGN), to simulate background RF noise from potential co-channel FM stations and environmental RF noise. This noise was used in the NRSC's evaluation of the IBOC DAB system for testing both analog compatibility and digital performance. A value of 30,000 degrees Kelvin was established for AWGN at the receiver input [*NRSC Noise Report*, iBiquity Digital Corporation, November 2001].

For the FM receiver testing, a NoiseCom NC1110A generator was used, having a rated output of 82 dBm/Hz (from 100 Hz to 1.5 GHz, ±2 dB), which produces in input power level of 29 dBm in a 200 kHz bandwidth, which is commonly used to represent the IF filter width of FM receivers. Assuming an effective noise power bandwidth of 200 kHz, the Boltzmann constant formula ($B_i \cdot N_i /1.38x10-23$), relates a thermodynamic temperature of 30,000° K to an RF noise power of 8×10^{-14}, or -100.8 dBm. The RF attenuator was adjusted to produce a total loss of approximately 71.8 dB, including combiner and cable losses, from the noise generator to the receiver input to produce the reference noise level. Converted to electric field strength, this represents a field of 16.2 dBμV.

Although the co-channel field strength may exceed 30,000°K (the FCC's allocation rules permit up to 40 dBμ at the protected service contour of a station, or approximately 25 dBμ at mobile receive height), this is a significant level of noise degradation that is manifested in most the test results herein. For example, the highest stereo audio WQPSNR at a host FM input of -60 dBm was 43 dB, which was due principally to the effect of AWGN being inserted into the receiver. (With the automotive receivers, the audio SNR at the -75 dBm RF test level was improved by stereo blending circuitry in the receiver.) Thus, the effects of elevated IBOC sidebands, both symmetrical and asymmetrical, would be more noticeable with lower RF noise environments.

Table 1 - Digital Sideband Power Cross-reference

Sideband Injection, *Symmetrical Equivalent* (dBc)	**Sideband Injection, *Symmetrical Equivalent* (%)**	**Sideband Injection, *Actual* (dBc)**
-10	10.0	-13, -13
-12	6.3	-15, -15
-14	4.0	-17, -17
-17	2.0	-20, -20
-20	1.0	-23, -23
-10, -14	10.0, 4.0	-13, -17
-10, -20	10.0, 1.0	-13, -23

Some simplifications were made for presentation. Individual sideband powers listed in the tables are 3 dB less than shown. For cross-reference to the normalized values used in the report, Table 1 includes the power levels in % injection and dB relative to the analog FM carrier. While all tests were performed in the MP3 mode, the power levels are specified in terms of the injection ratio for the MP1 primary sidebands.

ANALOG FM COMPATIBILITY TESTS WITH NO MULTIPATH

The analog compatibility measurements were designed to determine the weighted quasi-peak audio signal-to-noise ratio (WQPSNR) with stereo FM reception under various digital test conditions. In the RF Test Bed diagram shown in Figure 3, the audio analyzer collects WQPSNR measurements in accordance with ITR Recommendation 468-4, which is intended to measure the audibility of noise at low levels. Reference level was 1 kHz L+R, producing 100% peak modulation with a 9% stereo pilot. To correct for possible filter asymmetry in the analog receivers the asymmetrical measurements were taken with the sideband order reversed and both results averaged. Tests for analog and digital receivers were performed at 98.3 MHz, which is near the center of the FM band. To minimize extraneous RF noise effects, all receivers were tested in a shielded enclosure, providing at least 90 dB of isolation, and all external RF connections used double-shielded coaxial cable.

Table 2 describes the test conditions for analog compatibility. The three received signal levels, in terms of analog host FM carrier power, representing strong, medium and weak signal reception were -45, -60 and -75 dBm. There were five non-HD PowerBoost modes and 4 HD PowerBoost modes, of which two were asymmetric. All the tests with asymmetrical operation were processed with HD PowerBoost, in addition to two symmetrical operating tests (-10x2 dBc and -14x2 dBc), for comparison without HD PowerBoost. (This table and following tables show the lower and upper sideband levels in dBc using the equivalent power for symmetrical operation, which may be more familiar to readers.)

Figure 3 - RF Test Bed diagram

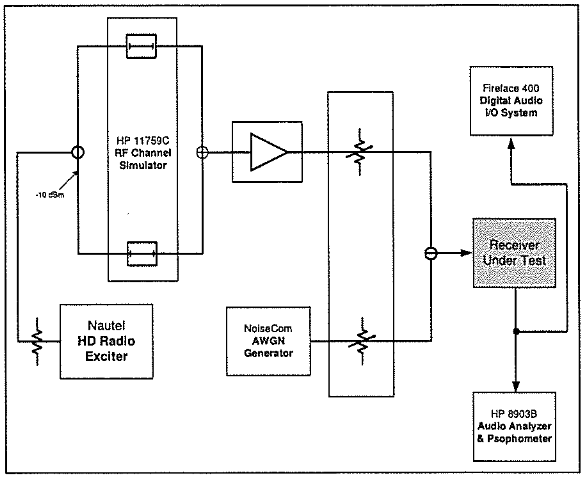


Table 3 summarizes the test data for analog FM receivers, showing the change in audio SNR when HD PowerBoost is activated with symmetrical sidebands at -10 dBc and -14 dBc. (Details of the receiver measurements are provided in Table 8 at the end of this paper.) It is apparent that for the automotive receivers, HD PowerBoost had no measurable effect on their audio SNRs. The changes in audio noise for the two indoor systems tended to drop by approximately 1 dB at the strong signal level; the changes at the weak signal level, while appearing to improve, are probably affected by internal noise in the receivers' front-end stage. Looking at the absolute audio SNRs of the automobile receivers in the Chevrolet Suburban unit was consistently higher than the JVC after-market radio because the Suburban has more aggressive stereo blending circuitry, to combat audio noise.

Table 2 -Test Conditions – Analog FM compatibility without multipath

IBOC Mode	HD PowerBoost	Sideband Injection (dBc)*	Rcvd. Sig. Power (dBm)	Multipath Profile	Receiver Type
MP3	Off	-10 x 2	-45,	None	Auto1 (OEM analog)
		-12 x 2	-60,	TU50	Auto2 (after-market analog)
		-14 x 2	-75	HT100	Home Stereo
		-17 x 2			Shelf System
		-20 x 2			RBDS (after-market analog)
	On	-10 x 2			
		-14 x 2			
		-10, -14			
		-10, -20			

*Individual sideband powers are identified relative to their equivalent MP1 dual (symmetrical) power

Table 3 – Summary of changes in audio WQPSNR with HD PowerBoost using MP3 transmission

Receiver	Sideband Injection P1 symmetrical equiv. (dBc)	Change in Audio WQPSNR at Rcvd. Sig. Powers (dBm)		
		-45	-60	-75
Auto1 Suburban	-10 x 2	0	0	0
	-14 x 2	0	0	0
Auto2 JVC KS-FX49	-10 x 2	0	0	0
	-14 x 2	0	0	0
home stereo Pioneer VSX-D814	-10 x 2	0	-1	1
	-14 x 2	-1	0	-1
Shelf System Sony CMT-NE3	-10 x 2	-1	1	1
	-14 x 2	-1	1	1

COMPATIBILITY TESTS FOR RBDS AND FM-SCA RECEPTION

Tests for compatibility of HD PowerBoost and asymmetrical transmission with RBDS service used a Kenwood model DDX7017 analog FM automobile receiver. RBDS injection was set to 5% of reference peak FM modulation, and multipath fading with 30,000°K AWGN was used. The RF signal level was varied to determine the threshold of reliable display of dynamic text. The results in the table show that compared to analog-only transmission, the -10 dBc (highest-power) symmetrical mode with HD PowerBoost reduced sensitivity by approximately 2 dB, however, sensitivity was also reduced 1 dB with -20 dBc symmetrical (non-HD PowerBoost) IBOC mode. Considering the minimal effect of elevated IBOC on RBDS sensitivity, other combinations of symmetrical and asymmetrical transmission did not appear necessary to demonstrate that the effects should be minimal. (Determining the threshold point of RBDS reception with multipath fading by observation is difficult because the data receive failures are random and infrequent, and only one receiver was tested. Hence, these measurements should not be relied upon as absolute sensitivity measurements for RBDS.)

Previous testing by NPR Labs with analog SCA receivers found general correlation to the performance of stereo FM reception. However, as the SCA results are receiver-dependent, a large number of SCA receivers are required to characterize the overall impact of asymmetrical sideband operation. Limited SCA subcarrier reception tests were conducted to confirm that the impact with asymmetrical operation was similar to the symmetrical tests previously reported, with some reduction for sideband powers, as noted for the FM stereo receivers in this study.

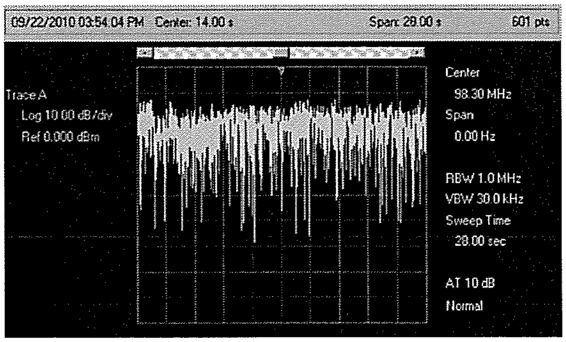
ANALOG COMPATIBILITY TESTS WITH MULTIPATH

HD PowerBoost improves transmitter efficiency by reducing the peak-to-average ratio of the hybrid (FM+IBOC) signal, which becomes increasingly important for stations that take advantage of higher digital power, recently authorized by the FCC. While control of the positive peak factor has been a goal, negative peaks in the hybrid carrier envelope remain a concern for reception of the FM host, since, as the carrier envelope approaches pinch-off, the FM receiver's limiter-detector system is liable to generate audible noise bursts. [*Look Before You Leap*, Dave Hershberger, Radio World Engineering Extra, Aug. 23 (Part 1) and Oct. 19 (Part 2), 2010.] In recent papers it was suggested that multipath conditions will add amplitude distortion of the signal sidebands, leading to carrier pinch-off and aggravated noise effects. This section of measurements was designed to determine if the peak reduction algorithm in HD PowerBoost would lead to noise or distortion of the analog FM reception, particularly under multipath conditions.

For these tests, an HP 11759C RF Channel Simulator was connected as shown in the Test Bed diagram of Figure 3. Multipath reception was generated with the delay profile "HT100" as defined by COST 207 [Commission of the European Communities, Final Report, September 1988]. The HT100 profile simulates conditions for a moving vehicle in "hilly terrain": in addition to short term echoes with low loss, there are two paths with long reflection times and higher losses. The echo delays in the paths cover a wide range and require six paths, and the echo levels are relatively high.

Figure 4 is a zero-span spectrum analyzer measurement showing the time vs. amplitude characteristic of the HT100 profile over one 28-second fading interval of the RF Channel Simulator. In accordance with the profile's Rayleigh distribution, the signal stays within a few dB of the peaks most of the time, but with sharp, brief drops of up to 45 dB below the average value. The long-term average of the signal fading profile is used in this report for the specification of RF signal power.

Figure 4 - Representation of HT100 amplitude fading over one profile interval (28 seconds)



Two receivers from the group were tested with a 1.9 kHz sinusoidal tone at 100% modulation (including 9% stereo pilot), as specified in the Hershberger paper: the Sony home stereo receiver and the Chevrolet Suburban mobile receiver. Although mobile fading is not part of fixed (home) reception, the way the path amplitudes and phases combine during one fading sequence allows an examination of the receiver behavior over a wide variety of multipath reception conditions.

WAV files were recorded from the receivers' audio output and processed with MATLAB® to generate a chart showing the percentage occurrence of audio SNR. Figure 5 shows the Cumulative Distribution Functions, with SNR on the x-axis and percentage occurrence is on y-axis. The result of each receiver test condition is drawn with a color-coded line:

Green	-10 dBc	HD PowerBoost OFF
Red	-10 dBc	HD PowerBoost ON
Blue	-14 dBc	HD PowerBoost OFF
Magenta	-14 dBc	HD PowerBoost ON

Results with the Sony home stereo and the Suburban mobile receiver are shown side-by-side. The tests were repeated at signal powers of -45 dBm (strong) and -60 dBm (moderate). The Sony receiver, at -45 dBm, in the upper left chart, shows a grouping of green and red lines, indicating that operation of HD PowerBoost at -10 dBc does not affect the audio SNR – even under conditions of higher multipath distortion. (Generally, as the level of instantaneous multipath increases, the probability decreases, and the farther down it appears on the chart.) The blue and red lines, representing -14 dBc, show a similar grouping, but curve slightly to the right, indicating that while HD PowerBoost does not affect SNR at this lower IBOC injection, the SNRs are slightly less.

The Suburban receiver shows relatively little separation between the -10 dBc and -14 dBc curves, which relates to the receiver's more aggressive stereo noise reduction during signal fades (when multipath distortion is usually worst). The results with receiver also show negligible difference in audio SNR probabilities with HD PowerBoost on or off.

DIGITAL RECEIVER SENSITIVITY TESTING

These tests were intended to determine the performance of asymmetrical transmission provided by HD PowerBoost on mobile reception, compared to standard symmetrical transmission. Since mobile reception is subject to fast (Rayleigh) fading, the RF channel simulator was used to create the effects of dynamic multipath conditions. The channel model defined in COST 207 provides two profiles for practical multipath: Typical Urban at 50 km/hr (TU50) and Hilly Terrain at 100 km/hr (HT100). As summarized in Table 4, testing with TU50 and HT100 was used for all the sideband conditions, in addition to no-multipath (fixed) signal conditions.

To meet the requirements of TU50 and HT100, the channel simulator's two 3-path channels were ganged to provide six paths. The combined output was boosted with a high performance RF amplifier before connection to the RF attenuator unit. After attenuation to desired RF test levels, the signal was combined with the fixed output of the AWGN generator. The same 30,000° K noise level for the analog testing was used, although in a 140 kHz nominal bandwidth for the HD Radio system the noise power was -102.3 dBm.

Table 4 - Test Conditions – IBOC Digital Reception

IBOC Mode	HD PowerBoost	Sideband Injection (dBc)*	Rcvd. Sig. Power (dBm)	Multipath Profile	Receiver Type
MP3	On	-10, -10	TBD	None TU50 HT100	Auto3 (after-market digital) Auto4 (after-market digital)
		-14, -14			
		-10,-14			
		-10,-20			

*Individual sideband powers are identified relative to their equivalent MP1 dual (symmetrical) power

Figure 5 - Percentage occurrence of audio SNR for receivers with mobile multipath at -45 dBm (upper) and -60 dBm (lower) for Sony home stereo (left) and Suburban auto receiver (right)

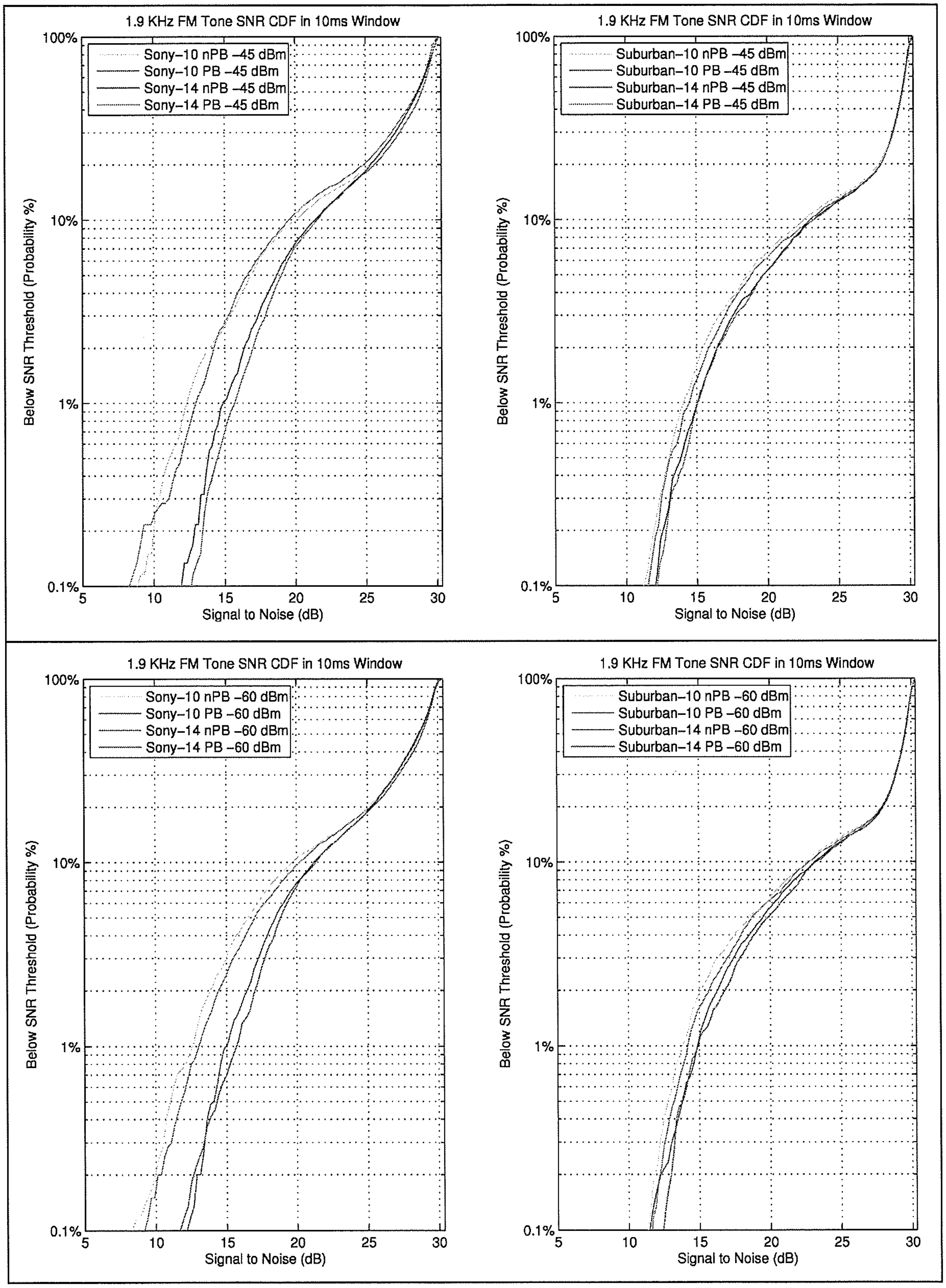


Table 5 - Summary of IBOC Digital Reception performance measurements

HD Power Boost	Sideband Levels P1 symmetrical equiv. (dBc)	Power rel. to -10 dBc	Sensitivity Change Compared to -10x2 w/o PB (dB)			Sensitivity Change Compared to -10x2 w/PB (dB, normalized to Power rel. to -10 dBc)		
Multipath mode:			None	TU50	HT100	None	TU50	HT100
On	-10 x 2	0	-0.5	-0.5	-0.5			
	-14 x 2	-4	-5	-4.5	-4.5	-0.5	0	0
	-10, -14	-1.5	-2	-3.5	-2.5	0	-1	-0.5
	-10, -20	-2.6	-4	-5.5	-5	-0.9	-1.9	-1.9
	-14, -20	-6	-7	-8	-7	-0.5	-1	-0.5
	-20 x 2	-10	-10	-10	-10	N/A	N/A	N/A

The direct results of the IBOC receiver testing are listed in Table 7, which shows the digital receiver thresholds in dBm for the analog FM host carrier. To simplify the evaluation of changes in sensitivity, Table 5, below, shows the changes in sensitivity relative to symmetrical operation with -10 dBc injection, which is the highest emission level authorized by the FCC. These results are averaged from the data for the two tested mobile receivers.

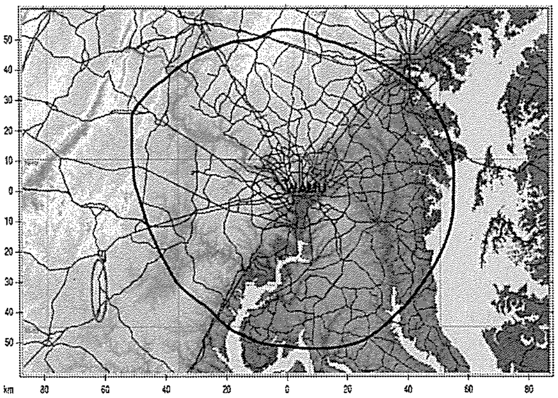
In the columns without HD PowerBoost ("w/o PB"), Table 5 shows that digital sensitivity reduces in almost exact proportion to the change in the digital sidebands ("Power rel. to -10 dBc" column). Turning on HD PowerBoost, as listed in the first row of the five "On" rows, shows an average change of -0.5 dB in sensitivity at -10 dBc. The effect at -14 dBc with symmetrical sidebands ("-14, -14") shows a shift of between -4.5 dB and -5.0 dB in received sensitivity. However, taking into account the 4 dB reduction in digital transmission power, as shown in the three "normalized" columns to the right, there was only a -0.5 dB change in sensitivity without multipath and no change with TU50 and HT100 profiles.

Looking at the "-10, -14" row, in which asymmetrical sidebands are operated, the changes in sensitivity are -2 dB, -3.5 dB and -2.5 dB for the multipath profiles; after normalization for the reduction in average digital power, relative to the HD PowerBoost mode with -10 dBc symmetrical transmission, the changes of 0 dB, -1 dB and -0.5 dB. Compared to equal sidebands, a -10,-14 dBc asymmetry 'costs' a loss of approximately 0.5 to 1 dB in potential mobile coverage under mobile fading conditions.

In the case of the widest asymmetry, shown on the "-10, -20" row, the cost on reception efficiency is the largest: the potential sensitivity was changed by -1.9 dB for both fading profiles. Thus, while average digital power is reduced -2.6 dBc compared to -10 dBc symmetrical (7.4 dB above -20 dBc), the effect on reception with -10, -20 dBc asymmetry is equivalent to a symmetrical emission of approximately -15.5 dBc (-10 dBc - 2.6 dB - 1.9 dB). Another way of looking at the data is that a station operating at -20 dBc on one sideband, and -10 dBc on the other sideband (symmetrical equivalents), could increase its effective digital coverage by at least 4.5 dB by 'spending' a 7.4 dB digital power increase.

The -14, -20 asymmetry condition provides results that are intermediate in 'cost' to potential mobile coverage: sensitivity thresholds shift by -1 dB and -0.5 dB for TU50 and HT100, respectively, relative to the savings in average power. In sum, broadcasters are best off maintaining symmetrical sideband levels, but coverage improvements are possible with an increase of only one sideband. These results should provide some quantitative guidance to planners considering increasing transmission power on one sideband to increase a station's digital coverage, while limiting emission on the other sideband.

Figure 6 - WAMU 60 dBu contour with drive-test route circled in red

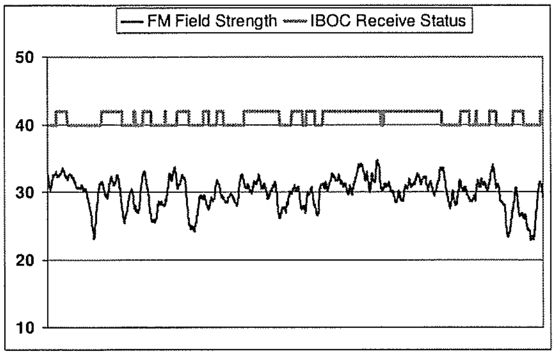


COVERAGE RESULTS

To verify the laboratory results of digital receiver performance with asymmetrical sideband transmission, a field trial was performed on

WAMU(FM), which was the first station to operate HD PowerBoost. WAMU, Channel 205B in Washington, DC, operates on 88.5 MHz with 50 kW ND ERP at 150 meters AAT. A coverage contour map of WAMU is shown in Figure 6. We chose a section of U.S. Highway 29 (circled in red) approximately 10 km in length, between Warrenton and Remington, Virginia, which is located approximately 60 km from the transmitter site.

Figure 7 - FM field strength in dBu along the South Zone, with digital receive status (magenta)



In this area of rolling hills, beyond the 60 dBu contour, the mobile IBOC digital reception is intermittent as the field strengths rise and fall around an average of 30 dBu (measured at 2 m AGL). This region is free of first-adjacent interference, so the reception is governed principally by the signal strength. (One area of the route is near WPER, Channel 210B, Culpepper, so a middle section of the route was excluded to avoid the possible effects of blanketing interference. This resulted in two subsections of the route: North Zone and South Zone.) While this short route is small in geographic size, relative to WAMU's coverage area, the data field strength data collected along with the digital reception, as illustrated in Figure 7, allows statistical analysis of reception performance that may be expanded to general coverage determinations.

Figure 8 - Digital receive availability along 2 sections of drive-test route at 5 power levels

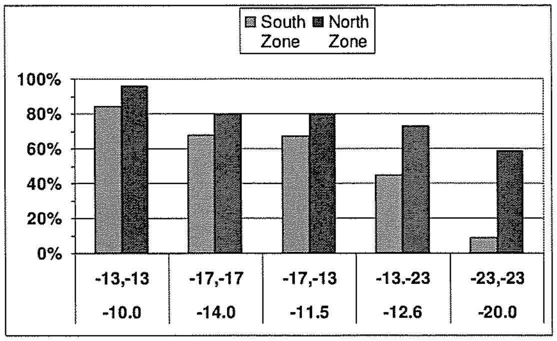


Figure 8 illustrates a composite analysis of the drive-test measurements at five sideband power levels. The power levels, listed below the chart, show the individual sideband powers, while the bottom row sums these powers. It is apparent that at -10 dBc symmetrical, on the left, the availability is highest for both zones, and drops for successively lower powers. Good reception would normally require close to 100% availability, but this level would not be useful for comparison on one route. To project performance data from each transmission condition, availability in 10-second intervals was plotted against field strength and a linear regression was used to estimate field strength requirements for 97% availability.

Table 6 - Summary of reception field tests

Actual Digital Powers (dBc)	Total Power (dBc)	97% Threshold (dBm)	Sensitivity Change Compared to -10x2 w/PB (dB, normalized to dBc)
-13,-13	-10	-86	0
-17,-17	-14	-82	0
-17,-13	-11.5	-83	-1.4
-13,-23	-12.6	-81.5	-1.9

The results in Table 6 compare well with the laboratory test data in Table 5. Reception at -17,-17 (-14 dBc total power) shows no additional loss in receive sensitivity, when normalized to the reduction in sideband power from -10 dBc. There was approximately 1 dB more loss with -17,-13 (equivalent to symmetrical sideband powers of -10 and -14 dBc), while the maximum asymmetry of -13,-23 again matched the lab data. The -23,-23 (-20 dBc) data was judged too low in reliability to include; in theory, it should track with the two other symmetrical conditions, and produce coverage approximately 10 dB below -10 dBc. The results of laboratory and field testing indicate that effects on host FM reception and digital reception performance with HD PowerBoost are indistinguishable from the standard iBiquity transmission mode, including the supported modes of asymmetrical sideband transmission.[2]

As a comparison of coverage, we included coverage maps using NPR Labs' HD Radio Coverage Model, showing WAMU at three symmetrical power levels of -20 dBc, -14 dBc and -10 dBc, in Figure 11, Figure 12 and Figure 13, respectively. The areas in green indicate mobile reception, while the areas in red show potential mobile service lost to interference from other FM stations.

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[2] HD Radio is a trademark of iBiquity Digital Corp.

WAMU'S PARTICIPATION IN TESTING OF THE NAUTEL HD POWERBOOST EXCITER WITH ASYMMETRICAL SIDEBANDS

WAMU has been involved with digital radio since 1999 when it had experimental equipment from Lucent. WAMU Radio first broadcast with IBOC HD Radio on May 7th 2004. A day later they began broadcasting a second channel. In December 2005 WAMU began experimenting with an extended hybrid third channel; still operating today.

In 2009 WAMU replaced its high level combined system with a Nautel NV40 transmitter and in May of 2010 the station began broadcasting with symmetrical power at -14 dBc. In order to conduct the requested tests the WAMU engineering team applied for an Experimental Authority to operate at power levels above -14 dBc and with asymmetrical sidebands.

The HD PowerBoost exciter arrived in late September and took less than an hour to install. Nautel personnel in Canada logged into the WAMU transmitter through the AUI (Advanced User Interface) via IP connection and performed some final tweaking of the exciter and transmitter and installed operating pre-sets for the various sideband power levels which would be tested. The new exciter was put on the air on Saturday 25 September with asymmetrical sideband power of -13 dBc on the low side and -17 dBc on the high side (the symmetrical equivalent levels of -10,-14). This supported first-adjacent protection requirements for WAMU.

Figure 9 and Figure 10 show the AUI for WAMU operating at -10 dBc symmetrical and at -13,-23 dBc asymmetrically, respectively. A variety of digital performance characteristics are shown, including a live spectrum display, the signal constellation and Lissajous plot for the combined OFDM subcarriers, and a plot of AM-AM correction, in addition to operating powers.

An immediate observation was the increased DC to RF efficiency provided by the HD PowerBoost exciter. Initial testing at -20 dBc showed a DC-to-RF efficiency increase of 8%, from 58.5% to 66.5%. The 13,-17 operation showed DC-to-RF efficiency of 59.5%, still showing an increase over -20dBc with higher digital power output.

The asymmetrical sideband operation with -13/-17 dBc increased the total digital power close to the theoretical 493 Watts, compared to -14 dBc symmetrical operation. Station personnel noticed that the HD Radio signal extended several miles farther out than it had, and there were some spots where dropouts were filled in.

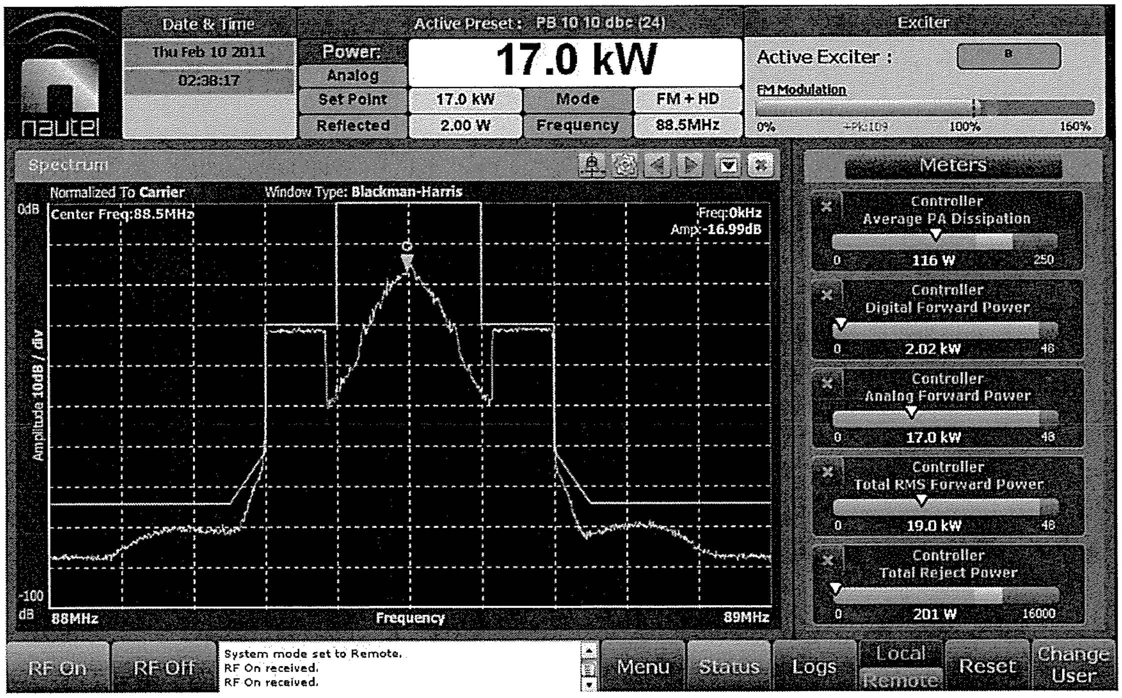
Setting up presets at various symmetrical and asymmetrical power levels was quite easy. During the test drive runs in rural Virginia, John Holt, WAMU's Director of Engineering and Operations, logged into the transmitter's AUI and switched between various presets in the car from his EV-DO equipped laptop, and logged in to the transmitter's AUI.

In summary, WAMU did not notice any deleterious effects to its analog signal with the HD PowerBoost operation at any of the sideband levels tested with asymmetrical operation, nor was there any apparent affect at -14 dBc with HD PowerBoost on or off.

ACKNOWLEDGEMENTS

The authors wish to thank Philipp Schmidt and Sam Goldman for their important contributions to the study. Philipp, as Research Engineer for Nautel Ltd., developed the PAPR software for transmission, described in "A New Approach to Peak-to-Average-Power Reduction for Hybrid FM+IBOC Transmission" (NAB Engineering Conference, April 2008). Sam, as a Research Associate at NPR Labs, carried out much of the receiver measurements and data processing. We are grateful for their time and interest in the study.

Figure 9 – Advance User Interface showing WAMU at -10 dBc symmetrical (-13,-13)



Date & Time: Thu Feb 10 2011 02:38:17

Active Preset: PB 10 10 dbc (24)

Power: 17.0 kW

Analog

Set Point: 17.0 kW

Mode: FM + HD

Reflected: 2.00 W

Frequency: 88.5MHz

Active Exciter: B

FM Modulation: 0% +Pk:109 100% 160%

Normalized To Carrier

Window Type: Blackman-Harris

Center Freq:88.5MHz

Freq:0kHz

Amp:-16.99dB

Controller Average PA Dissipation: 0 116 W 250

Controller Digital Forward Power: 0 2.02 kW 48

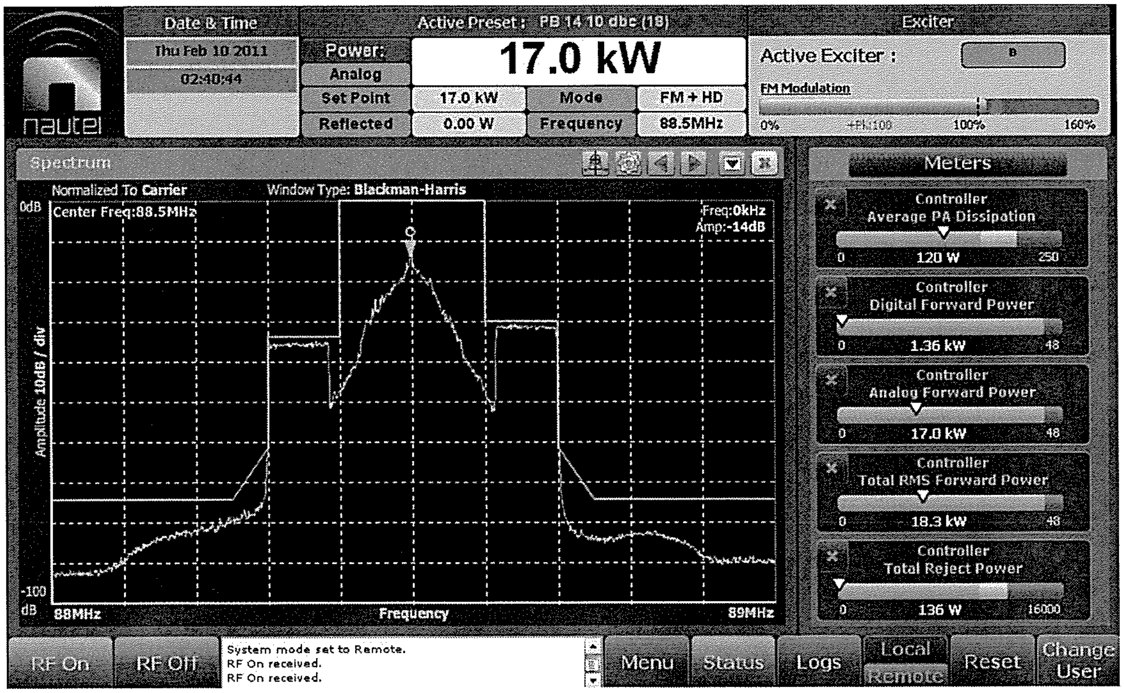
Controller Analog Forward Power: 0 17.0 kW 48

Controller Total RMS Forward Power: 0 19.0 kW 48

Controller Total Reject Power: 0 201 W 16000

System mode set to Remote.
RF On received.
RF On received.

Figure 10 - Advance User Interface showing WAMU at -17,-13 dBc asymmetrical



Date & Time: Thu Feb 10 2011 02:40:44

Active Preset: PB 14 10 dbc (18)

Power: 17.0 kW

Analog

Set Point: 17.0 kW

Mode: FM + HD

Reflected: 0.00 W

Frequency: 88.5MHz

Active Exciter: B

FM Modulation: 0% +Pk:108 100% 160%

Normalized To Carrier

Window Type: Blackman-Harris

Center Freq:88.5MHz

Freq:0kHz

Amp:-14dB

Controller Average PA Dissipation: 0 120 W 250

Controller Digital Forward Power: 0 1.36 kW 48

Controller Analog Forward Power: 0 17.0 kW 48

Controller Total RMS Forward Power: 0 18.3 kW 48

Controller Total Reject Power: 0 136 W 16000

System mode set to Remote.
RF On received.
RF On received.

Figure 11 - IBOC mobile signal coverage of WAMU at -23,-23 dBc (-20 dBc symmetrical)

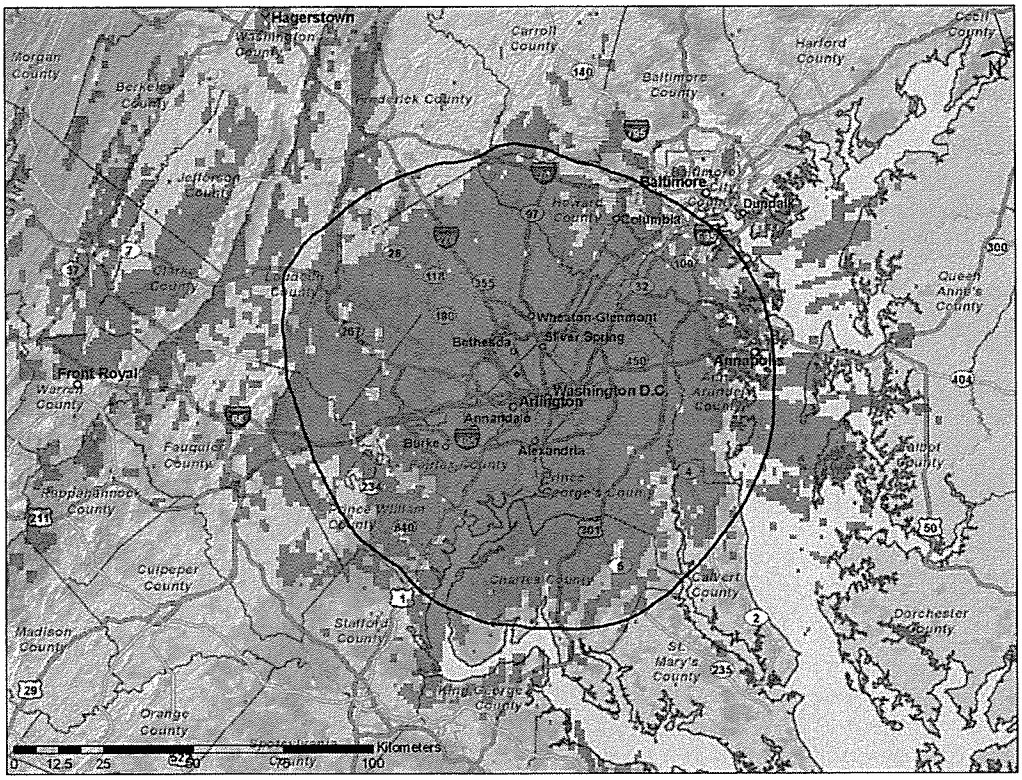


Figure 12 - IBOC mobile signal coverage of WAMU at -17,-17 dBc (-14 dBc symmetrical)

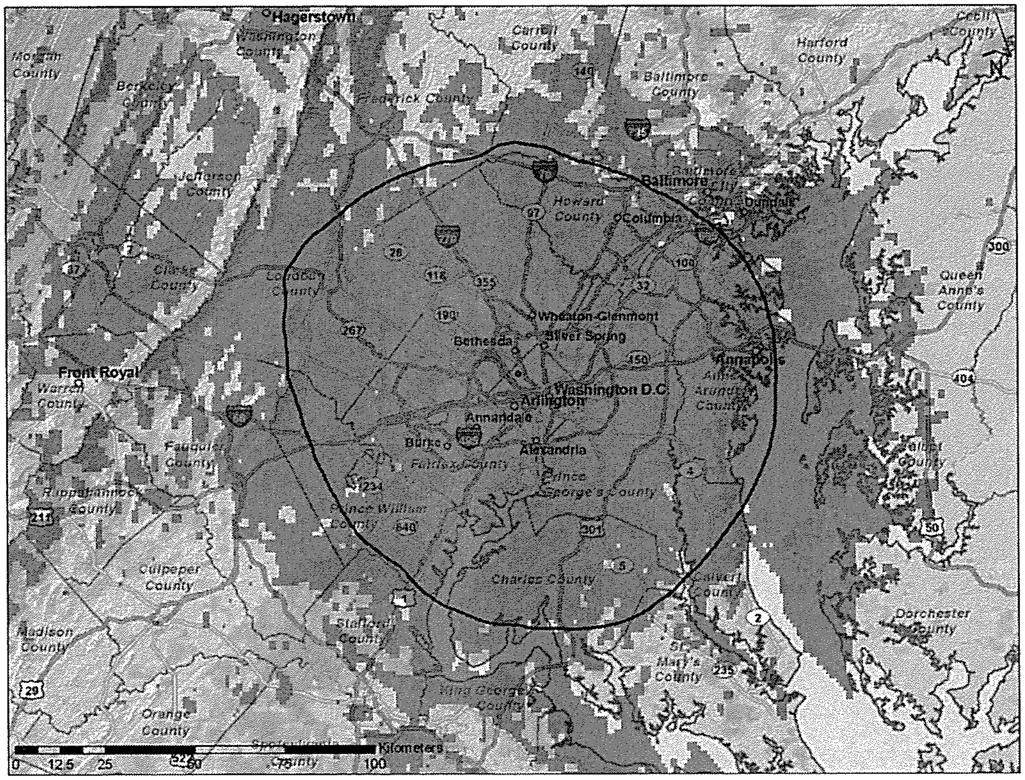


Figure 13 - IBOC mobile signal coverage of WAMU at -13,-13 dBc (-10 dBc symmetrical)

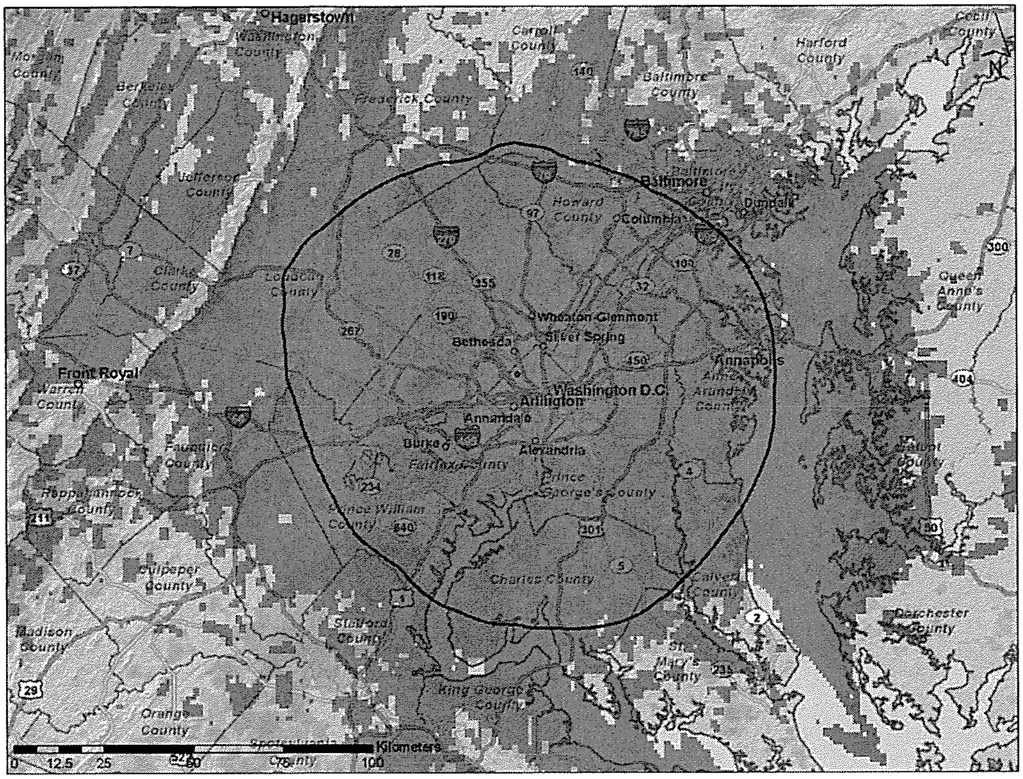


Table 7 - HD Radio Receiver Test Data

Receiver	IBOC Mode	HD PowerBoost®	L,U Sideband Injection P1 symm. equiv. (dBc)	Received Signal Power for Analog Host (dBm)		
Multipath Profiles:				none	TU-50	HT100
Kenwood KTC-HR100	MP3	Off	-10x2	-86	-86	-85
			-12x2	-84	-84	-83
			-14x2	-82	-	-81
			-17x2	-79	-78	-78
			-20x2	-76	-76	-75
		On	-10x2	-85	-85	-84
			-14x2	-81	-81	-80
			-10, 14	-84	-83	-82
			-14, -10	-84	-83	-82
			-10, -20	-82	-80	-79
			-20, -10	-82	-79	-79
			-14, -20	-79	-78	-78
			-20, -14	-79	-78	-78
JVC KD-HDR1	MP3	Off	-10x2	-86	-86	-85
			-12x2	-84	-84	-83
			-14x2	-82	-82	-81
			-17x2	-79	-79	-78
			-20x2	-76	-76	-75
		On	-10x2	-86	-85	-85
			-14x2	-81	-81	-81
			-10, 14	-84	-82	-82
			-14, -10	-84	-83	-83
			-10, -20	-82	-81	-80
			-20, -10	-82	-80	-80
			-14, -20	-79	-78	-78
			-20, -14	-79	-78	-78

Table 8 - Analog Receiver Test Data

Receiver	IBOC Mode	Multipath Profile	HD PowerBoost®	L, U Sideband Injection MP1 symmetrical equiv. (dBc)	Audio WQPSNR at Rcvd. Sig. Power (dBm)		
					-45	-60	-75
Auto1 Chevrolet Suburban	MP3	None	Off	-10x2	55	43	41
				-12x2	55	43	41
				-14x2	55	43	41
				-17x2	54	42	41
				-20x2	55	43	41
			On	-10x2	55	43	41
				-14x2	-	-	-
				-10, 14	55	43	41
				-14, -10	-	-	-
				-10, -20	-	-	-
				-20, -10	55	43	41
				-14, -20	-	-	-
				-20, -14	-	-	-
Auto2 JVC KS-FX490	MP3	None	Off	-10x2	55	43	32
				-12x2	55	43	32
				-14x2	55	43	32
				-17x2	54	42	32
				-20x2	55	43	32
			On	-10x2	55	43	32
				-14x2	-	-	-
				-10, 14	55	43	32
				-14, -10	-	-	-
				-10, -20	-	-	-
				-20, -10	55	43	32
				-14, -20	-	-	-
				-20, -14	-	-	-
home stereo Pioneer VSX-D814	MP3	None	Off	-10x2	29	29	24
				-12x2	31	31	26
				-14x2	33	32	27
				-17x2	36	34	25
				-20x2	39	37	26
			On	-10x2	29	28	25
				-14x2	32	32	26
				-10, 14	30	30	26
				-14, -10	30	29	25
				-10, -20	32	32	26
				-20, -10	31	30	25
				-14, -20	35	35	27
				-20, -14	34	33	27
Shelf System Sony CMT-NE3	MP3	None	Off	-10x2	43	41	27
				-12x2	46	42	27
				-14x2	49	43	28
				-17x2	51	41	26
				-20x2	53	42	27
			On	-10x2	42	42	28
				-14x2	48	44	29
				-10, 14	45	42	28
				-14, -10	46	42	27
				-10, -20	48	41	25
				-20, -10	49	42	27
				-14, -20	50	43	28
				-20, -14	52	43	28