Report to Nautel, Ltd.
On Measurements of FM Host Compatibility With "HD PowerBoost" IBOC Transmission

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npr labs

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Engineering Report for Nautel, Ltd.
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Nautel, Ltd. retained NPR Labs to conduct objective (laboratory) measurements with consumer FM receivers to determine the compatibility of FM host transmission and reception of Nautel’s “HD PowerBoost” process, an advanced peak-to-average power ratio reduction that increases hybrid-mode transmitter efficiency and enables asymmetrical IBOC sideband transmission, if desired. 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.

The testing found that in comparison with conventional IBOC operation, HD PowerBoost had little or no measureable impact on the performance of analog test receivers, even with the highest-tested asymmetrical digital sideband ratios of -10/-20 dBc. Asymmetrical operation reduced the audio noise level of the home receivers by up to 3 dB as either sideband was reduced. RBDS reception sensitivity with mobile fading was slightly affected by -10 dBc symmetrical sidebands, but showed improvements similar to analog FM reception with asymmetrical operation. Tests with mobile fading conditions found that mobile HD Radio receivers could operate well with asymmetrical transmission, exhibiting a loss in effective sensitivity of no more than 2 dB with the widest possible asymmetry, relative to total transmission power. Details on the test methodology and the results are discussed in the following sections of this report.

RF Test Bed Configuration

A diagram of the RF Test Bed is included as Figure 4. 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.[1] For the FM receiver testing, a NoiseCom NC1110A

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[1] *NRSC Noise Report*, iBiquity Digital Corporation, November 2001.

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 ($B_i N_i / 1.38\text{x}10^{-23}$), relates a thermodynamic temperature of 30,000º K to an RF noise power of 8.3×10^{-14} watts, 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.[2] Converted to electric field strength, this represents a field of 16.2 dBµV.

Although the co-channel field strength may exceed 30,000ºK (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 WPQSNR 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 4, the audio analyzer collects WQPSNR measurements in accordance with ITR Recommendation 468-4, which

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[2] For reference, 30,000º K can be converted to field strength as follows:

$$\sqrt{N_i 480\pi^2 / \left(300/f^2\right)} = 0.0065\ \text{mV/m} = 16.2\ \text{dB}\mu\text{V, where } N_i \text{ is } 8.3\text{x}10^{-14}\ \text{w and } f \text{ is } 98.3\ \text{MHz.}$$

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 5 conditions without HD PowerBoost and 4 conditions with PowerBoost, of which two used asymmetrical transmission. 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 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.)

Table 2 -Test Conditions – Analog FM compatibility with and without multipath

IBOC Mode	HD PowerBoost	Sideband Injection (dBc)*	Rcvd. Sig. Power (dBm)	Multipath Profile	Receiver Type
MP3	Off	-10 x 2	-45, -60, -75	None TU50 HT100	Auto1 (OEM analog) Auto2 (after-market analog) Home Stereo Shelf System RBDS (after-market analog)
		-12 x 2			
		-14 x 2			
		-17 x 2			
		-20 x 2			
	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 summarizes the test data for analog FM receivers, detailed in Table 6, at the end of this report, showing the change in audio SNR when PowerBoost is activated with symmetrical sidebands at -10 dBc and -14 dBc. It is apparent that for the automotive receivers, 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 Table 6, 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 3 – Summary of changes in audio WQPSNR with 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 PowerBoost and asymmetrical transmission with RBDS service are reported in Table 7, using a Kenwood model DDX7017 analog FM automobile receiver. 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 PowerBoost reduced sensitivity by approximately 2 dB, however, sensitivity was also reduced 1 dB with -20 dBc symmetrical (non-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.[3]

Previous testing by NPR Labs with 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

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.[4] In recent papers it was suggested that multipath conditions will add amplitude distortion

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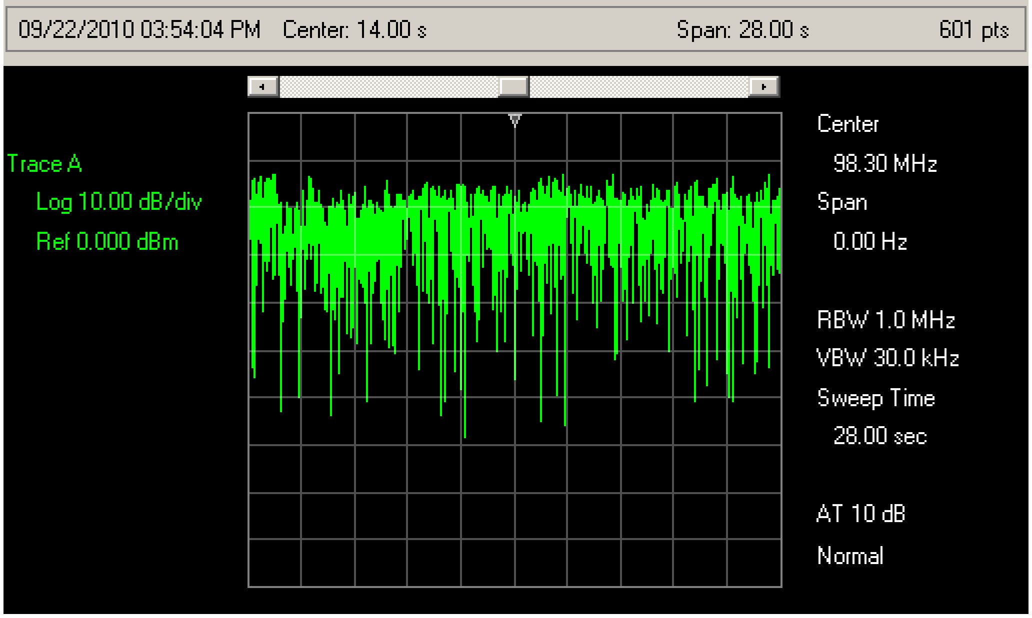
[3] Determination of the threshold point of RBDS reception with multipath fading is difficult because the displayed reception failures are random and infrequent. Because of this, and because only one receiver was tested, these measurements should not be relied upon as absolute sensitivity measurements for RBDS.

[4] Look Before You Leap, Dave Hershberger, Radio World Engineering Extra, Aug. 23 (Part 1) and Oct. 19 (Part 2), 2010.

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 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 4. Multipath reception was generated with the delay profile "HT100" as defined by COST 207.[5] 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.[6]

Figure 1 - Representation of HT100 amplitude fading over one profile interval (28 seconds)



09/22/2010 03:54:04 PM Center: 14.00 s Span: 28.00 s 601 pts

Trace A
Log 10.00 dB/div
Ref 0.000 dBm

Center
98.30 MHz
Span
0.00 Hz
RBW 1.0 MHz
VBW 30.0 kHz
Sweep Time
28.00 sec
AT 10 dB
Normal

Figure 1 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.

The two mobile receivers were tested with a 1.9 kHz sinusoidal modulation at 100% modulation (including a 9% stereo pilot), as specified in the Hershberger paper. Two

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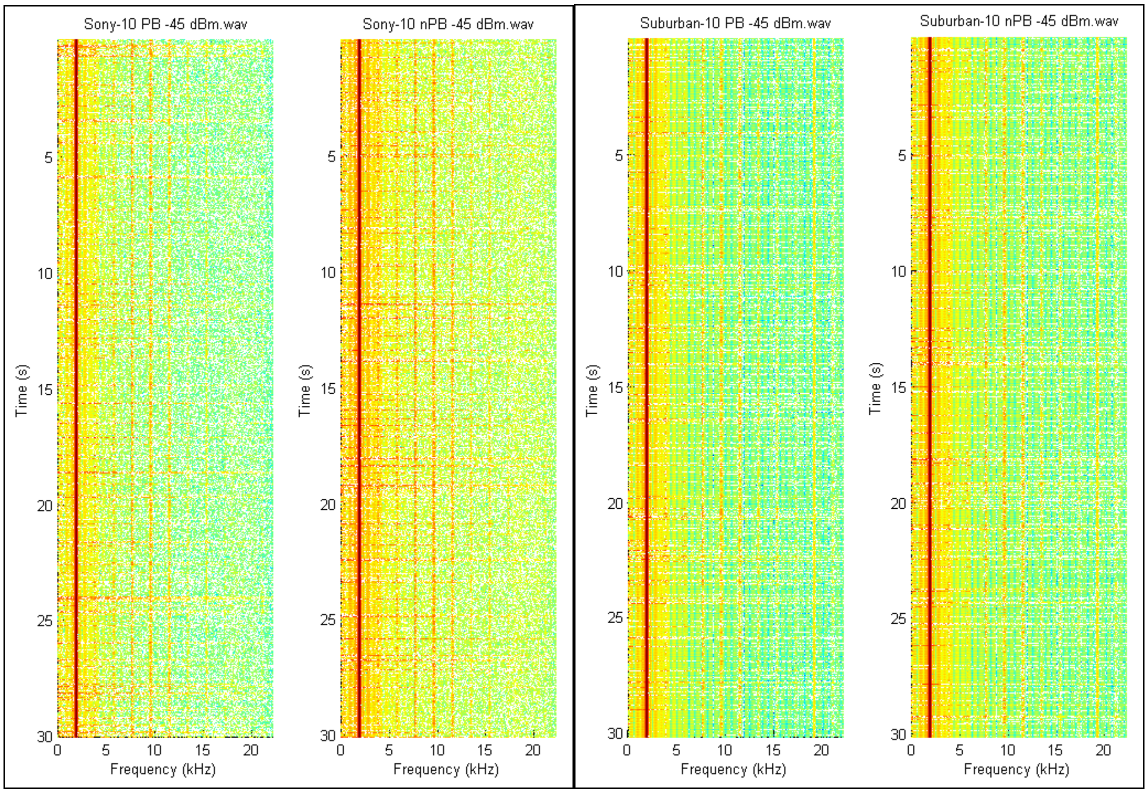
[5] "Digital Land Mobile Radio Communications - COST 207", Commission of the European Communities, Final Report, 14 March, 1984--13 September, 1988, Office for Official Publications of the European Communities (a European research organization, based in Luxembourg, which supports the wireless industry with technical procedures and standards).

[6] We also tested the "TU50" profile, which simulates a "typical urban" terrestrial wave propagation environment with a vehicle velocity of 50 km/h. In listening tests, HT100 tended to produce more consistent audible multipath fading effects, and was used for this report.

receivers from the group were employed for analysis: 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.

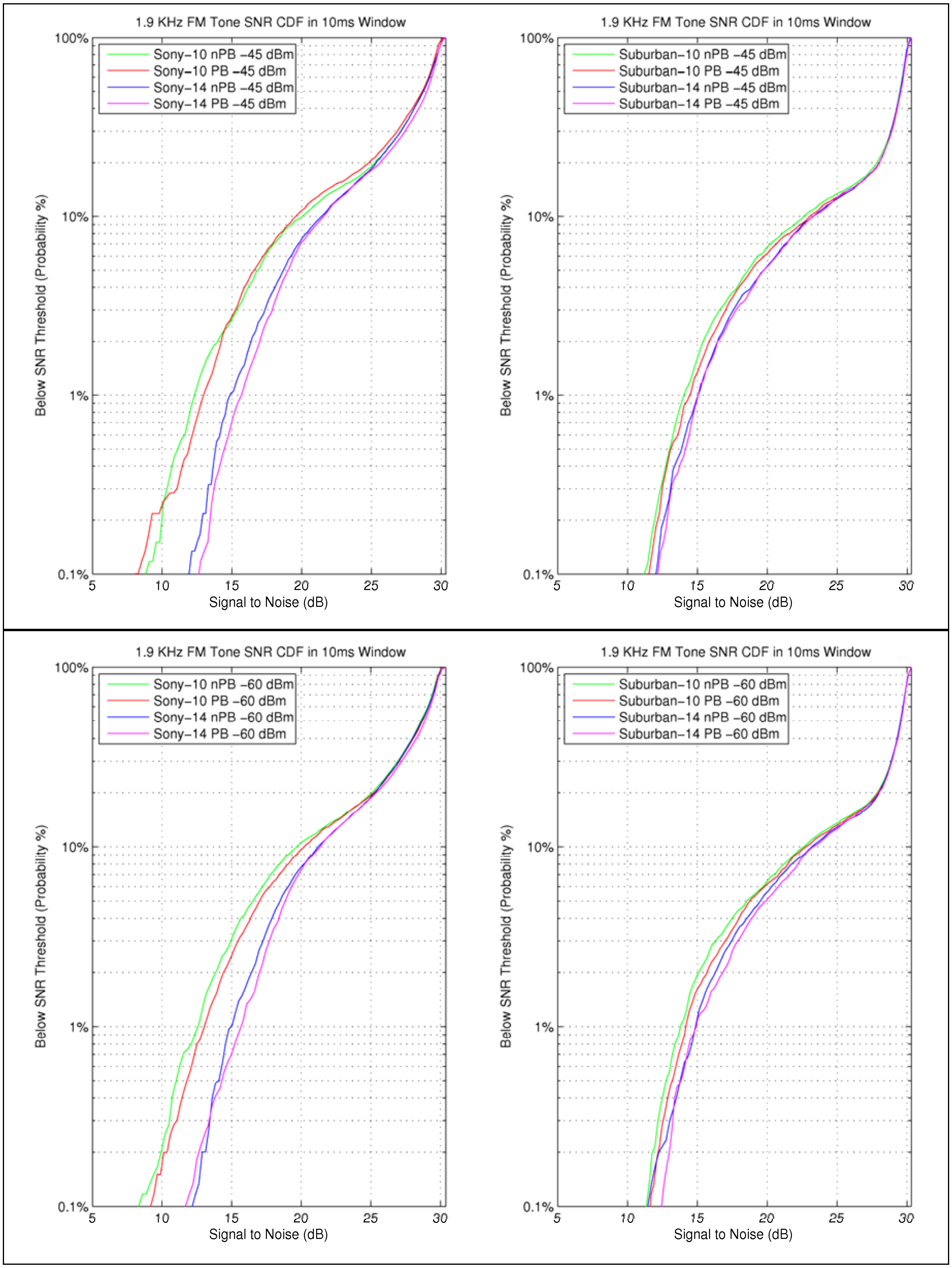
In the first analysis of multipath effects, the receiver audio was recorded over one multipath interval of the RF Channel Simulator, and the audio spectral content was drawn across a colorized graph, from top to bottom, in Figure 2. Amplitude is represented by color, varying from red (highest intensity), through yellow to green (lowest intensity). The 1.9 kHz tone fundamental is shown as the solid red bar to the left side of each chart. Harmonics of the tone (2nd, 3rd, etc.) register as fainter red bars right, which vary in intensity according to their amplitudes from moment to moment. Horizontal streaks of red indicate wide-spectrum noise bursts during instants of high intensity multipath.

Figure 2 - Audio spectrograms vs. time for Sony home stereo and Suburban mobile receivers; PowerBoost is on for the left of each pair with PowerBoost off to the right



It is apparent from Figure 2 that the Sony receiver shows lower intensity harmonics and weaker multipath noise “hits” with PowerBoost (left “PB”) than without PowerBoost (right “nPB”). Both audio spectra of the Suburban receiver are much the same as the Sony receiver with PowerBoost.

Figure 3 – Percentage occurrence of audio SNR for mobile receivers with multipath at -45 dBm (upper) and -60 dBm (lower) for Sony home stereo (left) and Suburban auto receiver (right)



While interesting to view, the audio spectrograms provide no quantitative information about the intensity of harmonics or noise, or their rate of occurrence. To provide this information, the audio recording WAV files were processed with MATLAB® to generate a chart showing the percentage occurrence of audio signal-to-noise ratio. The results are shown in Figure 3 and CDF (cumulative distribution function) graphs, where the SNR is on the x-axis and the percentage occurrence is on y-axis.

The result of each receiver test condition is drawn with a color-coded line:

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

The 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 the green and red lines, indicating that the operation of PowerBoost at -10 dBc does not affect the audio SNR – even under conditions of higher multipath distortion. (Generally, as the level of instantaneous multipath increase, 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 PowerBoost does not affect SNR at this lower IBOC injection, but also that SNRs are slightly less degraded.

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 this receiver also show negligible difference in audio SNR probabilities with PowerBoost on or off.

Digital Receiver Sensitivity Testing

These tests were intended to determine the performance of asymmetrical transmission provided by 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.

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

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.

The direct results of the IBOC receiver testing are listed in Table 8, which show the digital receiver thresholds in dBm for the analog FM host carrier.[7] 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.

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 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

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 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 PowerBoost mode with -10 dBc symmetrical transmission, the changes of 0 dB, -1 dB and -0.5 dB. In

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[7] The tests included relatively severe fast multipath fading and added noise, to represent the effects of mobile reception. Of course, interference to digital reception on one sideband or the other may cause differences from the results reported herein. It is advisable for a planner to prepare a study map that considers one-sideband digital interference effects as well as coverage benefits from asymmetrical transmission.

other words, 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 TU50 and HT100 fading profiles. Thus, while average digital power is reduced to -12.6 dBc (-10 - 2.6) from -10 dBc symmetrical sidebands, the effect on reception with -10, -20 dBc asymmetry is equivalent to a symmetrical emission of approximately -15.5 dBc (-10 - 2.6 - 1.9). 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 4.5 to 5 dB by ‘spending’ the power of a 7.4 dB digital 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 to increase transmission power on one sideband to increase a station’s digital coverage, while limiting emission on the other sideband.

Figure 4 - Diagram of the RF Test Bed for measurements of HD Radio with asymmetrical sidebands

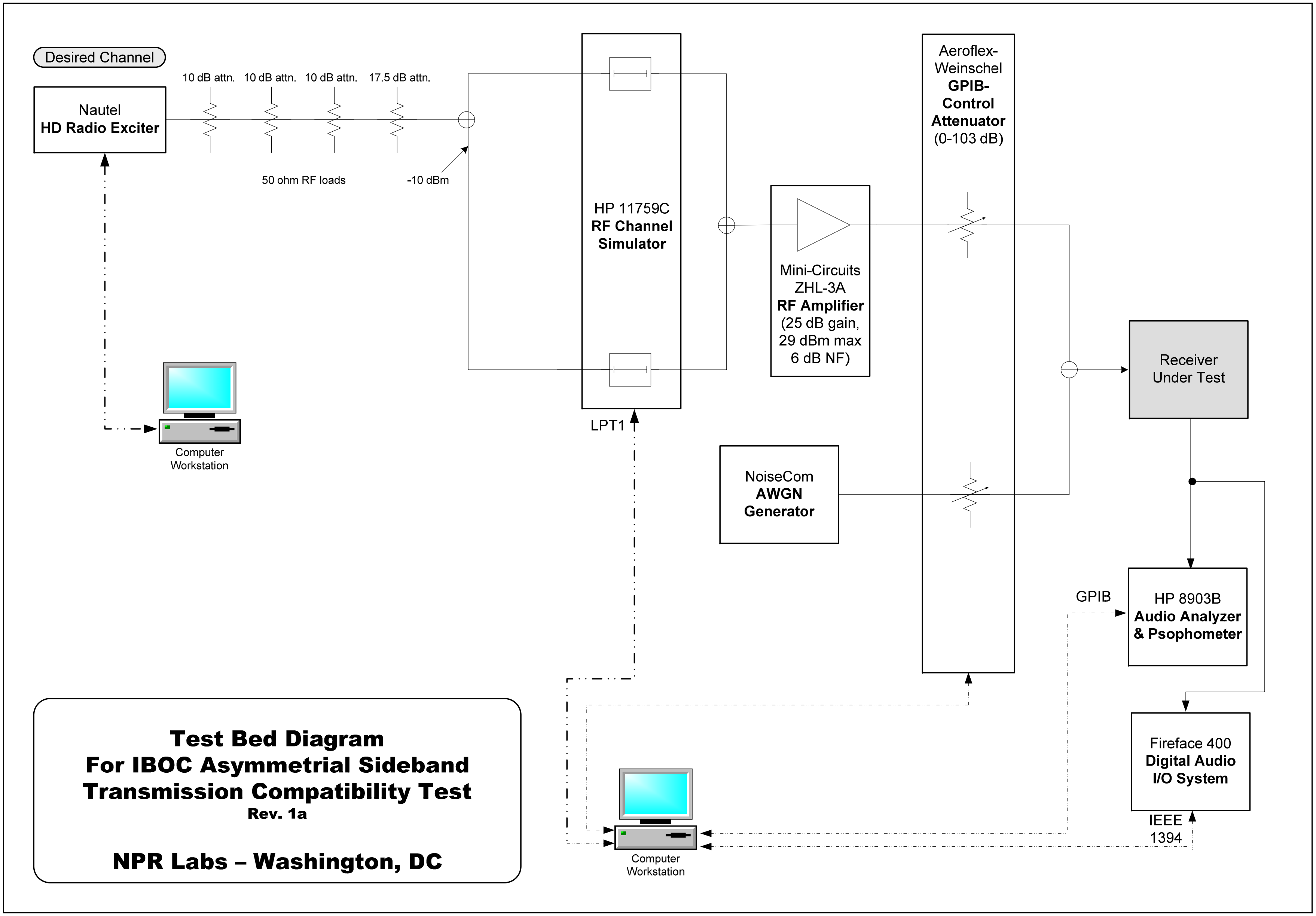

Table 6 - Analog Receiver Test Data

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

Table 7 - RBDS Receiver Test Data

Receiver	IBOC Mode	Multipath Profile	HD PowerBoost®	L, U Sidebands Injection MP1 symmetrical equiv. (dBc)	Analog Host Received Signal Power w/5% RBDS injection (dBm)
RDS Kenwood DDX7017				analog only	-82
	MP3	HT100	Off	-10x2	-
				-12x2	-
				-14x2	-
				-17x2	-
				-20x2	-
			On	-10x2	-80
				-20x2	-81

Table 8 - HD Radio Receiver Test Data

Receiver	IBOC Mode	HD PowerBoost®	L,U Sideband Injection P1 symmetrical 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

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.

John C. Kean

Senior Technologist, NPR Labs

As Senior Technologist for National Public Radio, John Kean develops and supervises technical projects at NPR Labs, which is involved in the development and evaluation of new technologies, procedures and standards on behalf of public radio. He was a Senior Engineer at NPR from 1980 to 1986, where he also supported new broadcast technology and services. From 1987 to 2000 he was with Moffet Larson & Johnson, consulting in the fields of broadband wireless networks, TV and radio facilities, FCC regulations, microwave and satellite systems. He is a member of the Institute of Electrical and Electronics Engineers and Past President of the IEEE Broadcast Symposium, contributing author to The NAB Engineering Handbook, Editions 7, 8 and 9 and presenter of numerous papers in the field of radio systems engineering to the National Association of Broadcasters' Engineering Conference. He served as a delegate to ITU Plenary meetings in Geneva on behalf of the North American Broadcasters Association, is past-president of the Audio Engineering Society (Washington DC Section), is a recent member of the Consumer Electronics Association's Audio Division Board, and has a patent pending for the prediction of coverage for In-Band On-Channel digital audio broadcasting.