ENGINEERING EXTRA

WHAT DID I JUST SAY?
Barry Blesser reminds us why we can't remember that last meeting. Page 20

RADIOWORLD

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NewBay Media

FM Host Compatibility With HD PowerBoost IBOC Transmission

System Shown to Improve Efficiency Without Side Effects on Analog Or Digital Reception

BY JOHN KEAN

The author is senior technologist at NPR Labs in Washington.

Nautel Ltd. retained NPR Labs to conduct objective (laboratory) measurements with consumer FM

WHITEPAPER

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. 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 more the critical MP3 (Extended Hybrid) mode, rather than MP1.

The testing found that in comparison

(continued on page 4)

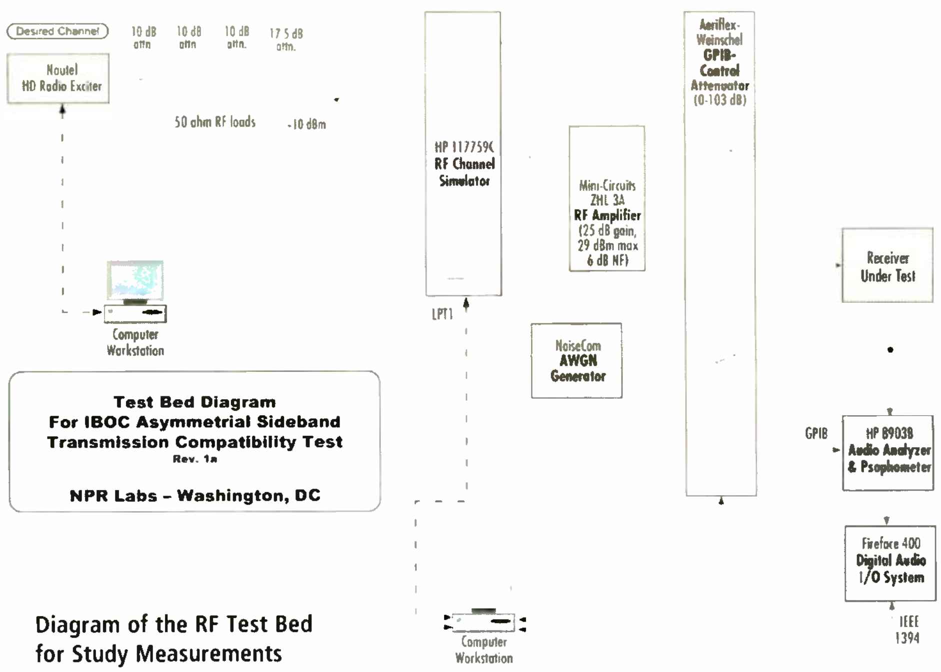

Diagram of the RF Test Bed for Study Measurements

Four Steps to Build a Test Web Server

Free Apache Software Is Easy to Install, Easy to Use

BY STEPHEN M. POOLE

While many people maintain their websites through a hosting provider, you still need to know how it works. This month, we'll use the free and open source Apache Project to build a Web server.

RADIO IT MANAGEMENT

Most people think of a Web page as eye candy arranged for viewing in a browser. But have you ever wondered what HTML actually looks like, and how it's actually sent to that browser?

"HTML" stands for HyperText Markup Language, which is the standard for Web pages. An actual ".html" or ".htm" file is plain text with embedded commands such as "add an image here" or "use this size font there." The server uses the HyperText Transfer Protocol, or HTTP, to deliver HTML pages to your browser, which then translates them into viewable content.

The original HTML 1.0 specifica-

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GPS Systems Threatened By Wireless Data Proposal

LightSquared Claims Its System Will Protect GPS, But Industry Tests Show Otherwise

BY MICHAEL LECLAIR

This is one of those odd stories that illustrate the way business and government sometimes work together to build new and powerful communications systems. The outcome could affect many consumers who own and use GPS guidance systems in their cars or for outdoor recreation. To a certain degree, it could affect radio engineers.

The story began with an FCC allocation for a satellite communication system in the spectrum 1525 to 1559 MHz — an allocation that until now has had limited commercial appeal and is not heavily used.

Along came a company with a vision to help supply wireless data services, what we used to know as the cell phone industry. Wireless data is in short supply and high demand.

The company, LightSquared, came up with an idea to make this L Band spectrum useful for terrestrial data: Use the spectrum to build a terrestrial network and connect it up with satellites. The plan had a lot to like. An underutilized segment of spectrum would be converted into a highly profitable and useful segment of the wireless data industry.

This is where the government help comes in. When this spectrum was allocated, it was for satellite communications; it was not a license to build a terrestrial network. So a petition for an exemption was filed, quietly and just before the Thanksgiving holiday, on Nov. 19, 2010. Instead of the normal 30-day comment period, the petition was "fast-tracked," which allowed only a few days for comment.

The FCC then ruled in favor of LightSquared and gave it the permit to build a new terrestrial network of high-power transmitters for high-speed data. The permit allows up to *40,000* of these repeaters to be built at effective radiated powers of up to *15,000 watts*.

THERE'S JUST ONE PROBLEM …

Although the proposal was fast-tracked at the commission, there were technical concerns. Specifically, LightSquared spectrum was perilously close to a satellite system that has been in place for many years: the network of GPS satellites used for civilian and military purposes.

Generally, it isn't a good idea to mix terrestrial and satellite uses on the same or nearby frequencies. Satellite communications require receivers to be able to detect very low signals coming from outside the earth's atmosphere. That requires a receiver that has exceptional sensitivity. Terrestrial services, on the other hand, use relatively high-power signals to convey large amounts of data over a wide geographical distance.

In this case, the GPS system requires receivers to not only detect low-power signals but simultaneously to detect a range of satellites that are spread across the visible sky. Now mix in a huge number of terrestrial amplifiers on a close frequency that require omnidirectional antenna systems and high power. Due to their proximity and power requirements, these terrestrial amplifiers likely will overwhelm the sensitive GPS receivers that are trying to pick out very weak satellite signals.

And that is just what happened, in spite of LightSquared's claims that its own extensive testing indicated little to no interference would occur.

The main L1 band of frequencies used by the GPS system is centered on 1575.42 MHz and extends down to 1559 MHz. Testing by Garmin Corp. showed that operations proposed by LightSquared would cause a typical consumer GPS receiver to fail within 3.6 miles of its terrestrial repeaters. An FAA-certified General Aviation receiver that employs GPS to help determine aircraft height began to fail within 13.8 miles of a terrestrial transmitter, according to the report, which was sent to the FCC in January. (The study can be found at *http://tinyurl.com/rwgps*.)

As I do the math, this comes out to approximately 1.6 million square miles of interference to consumer units and about 6.4 million square miles of interference to aviation uses. Ouch.

It makes the engineer in me just sigh. Wouldn't you think the possibility of massive interference would be obvious *before* investors and regulators wrote contracts and rules that committed billions of dollars?

This calls to mind the recent pleas from the Society of Broadcast Engineers to mandate that FCC commissioners retain at least one staff member with an engineering background. If such a rule were in place, would this proposal have received fast-track approvals from Julius "Cell Man" Genachowski?

INCONSTANT RULES

The whole affair reminds me of the history of the satellite radio industry.

It may seem like I am dredging up buried garbage. But when initially proposed and awarded, this was supposed to be a satellite service that delivered programs directly to a consumer receiver. When that failed to be possible technically, a decision to allow the service instead to become a second terrestrial radio band was made without comment, even though doing so changed the terms of the original license and altered the competitive landscape radically.

Satellite radio eventually became a competitive Frankenstein, vowing to destroy the existing terrestrial radio industry and sowing the market with devices intended to interfere with standard FM band. And when the two satellite radio companies mismanaged their way to bankruptcy with their impossible give-aways and contracts for high-priced programming, they were allowed to merge,

(continued on page 19)

> **Satellite radio eventually became a competitive Frankenstein, vowing to destroy terrestrial radio and sowing the market with devices intended to interfere with the standard FM band.**

THIS ISSUE

AUGUST 17, 2011

POWERBOOST

(continued from page 1)

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.

With optional asymmetrical operation, the audio noise level of the home receivers were reduced 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 shown on page 1. 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.

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

Table 1: Digital Sideband Power Cross-Reference Chart

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 of the calibration 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.

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). The NC1110A produces an input power level of –29 dBm in a 200 kHz bandwidth, commonly used to represent the IF filter width of FM receivers. Assuming an effective noise power bandwidth of 200 kHz, the Boltzmann constant formula ($B_i N_i$ /1.38x10^{-23}), relates a thermodynamic temperature of 30,000 degrees K to an RF noise power of 8.3 x 10^{-14} watts, or –100.8 dBm.

The RF attenuator after the noise generator was adjusted for a total loss of approximately 71.8 dB, including combiner and cable losses, to produce the desired 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 degrees 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. For example, the highest stereo audio WQPSNR at a host FM input of –60 dBm was 43 dB, due principally to the effect of AWGN being inserted into the receiver at a medium-weak RF signal power. Thus, the effects of elevated IBOC sidebands, both symmetrical and asymmetrical, would be more noticeable with either stronger desired signal power or lower RF noise environments than was simulated.

Some simplifications were made for presentation. Individual sideband powers listed in the tables are 3 dB less than indicated with levels chosen to correspond to common total injection levels, such as –10 dBc or –14 dBc. For cross-reference to the normalized values used in the report, Table 1 includes the power levels in percent 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 WITHOUT 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 on page 1, the audio analyzer collects WQPSNR measurements in accordance with International Telecommunication Union Recommendation 468-4, which is intended to measure the audibility of noise at low levels. Reference level was 1 kHz L+R, producing 100 percent peak modulation with a 9 percent 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.

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 2: Test Conditions — Analog FM Compatibility With and Without Multipath

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 conditions without HD PowerBoost and four 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 3 summarizes the test data for analog FM receivers, detailed in Table

(continued on page 6)

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POWERBOOST

(continued from page 4)

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.

RBDS COMPATIBILITY

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. RBDS injection was set to 5 percent of reference peak FM modulation, and multipath fading with 30,000 degrees K AWGN was used.

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

Table 3: Summary of Changes in Analog Noise With PowerBoost

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.

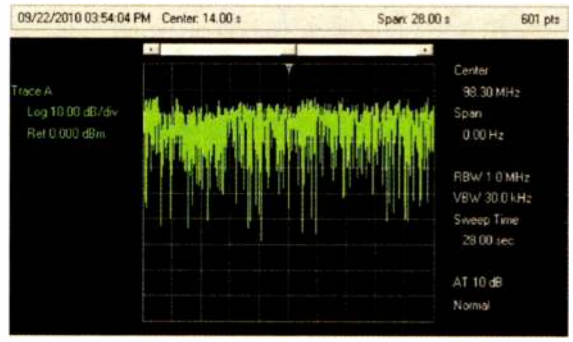

Fig. 1: Representation of HT100 Amplitude Fading Over One Profile Interval (28 Seconds)

ANALOG COMPATIBILITY 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 improves amplifier efficiency, negative peaks in the hybrid carrier envelope remain a concern for reception of the FM host. On negative peaks as the carrier envelope approaches pinch off, the FM receiver's limiter-detector system is liable to generate audible noise bursts.

In recent papers it was suggested that multipath conditions could add amplitude distortion of the signal sidebands, leading to carrier pinch-off and aggravated noise effects (see Hershberger, "Look Before You Leap," Parts I and II, Radio World Engineering Extra, Aug. 23 and Oct. 19, 2010). 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 in series with the Nautel exciter as shown in the Test Bed diagram on page 1. Multipath reception was generated with the delay profile "HT100" as defined by COST 207 (Cooperation in the field of Scientific and Technical Research — Project 207).

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POWERBOOST

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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.

Fig. 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 percent modulation (including a 9 percent stereo pilot), as specified in the Hershberger paper. Two 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 Fig. 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.

It is apparent from Fig. 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.

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 Fig. 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 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

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,

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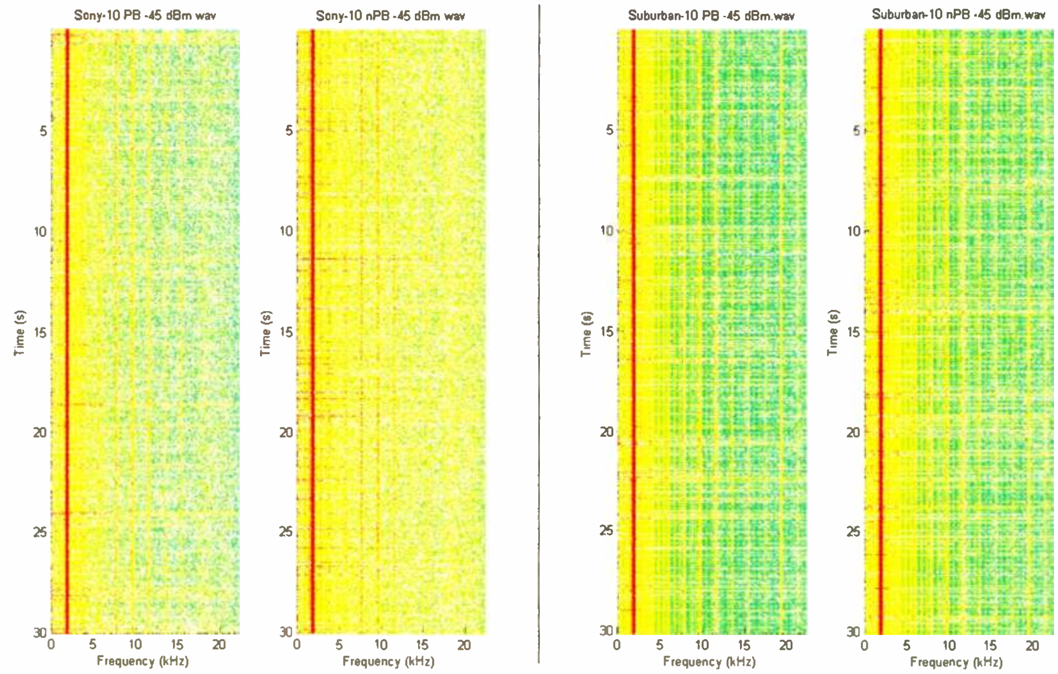

Fig. 2: Audio Spectrograms vs. Time for Sony Home Stereo and Suburban Mobile Receivers. PowerBoost is on for the left of each pair, with PowerBoost off on the right.

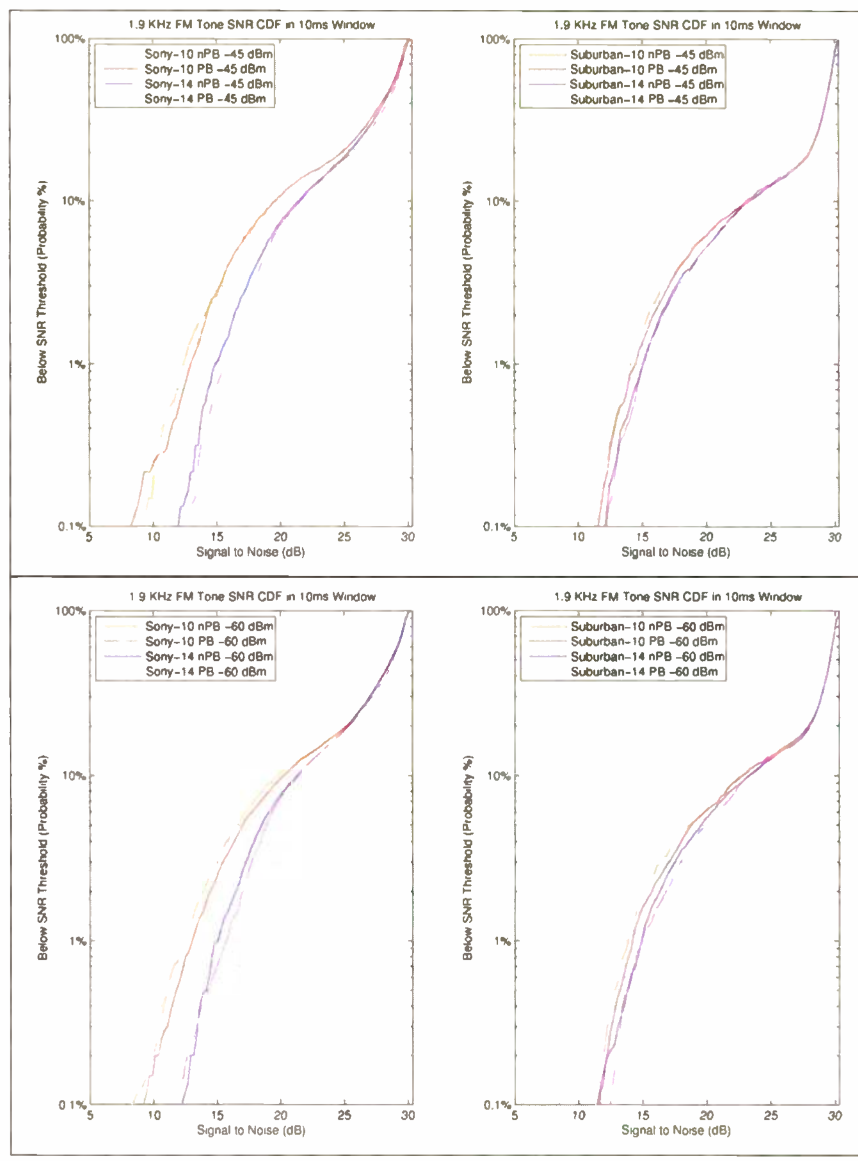

Fig. 3: Audio SNR by Percentage Occurrence for Mobile Receivers with Multipath. Received Signal Strength – 45 dBm (upper) and -60 dBm (lower). Sony Home Stereo on Left and Suburban Auto Receiver on Right

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POWERBOOST

(continued from page 8)

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 three-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 degree 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. To simplify the evaluation of changes in sensitivity, Table 5 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 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 other words, (–10, –14) dBc asymmetry "costs" approximately 0.5 to 1 dB of loss 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 dBc minus 2.6 dB) from –10 dBc symmetrical sidebands, the effect on reception with (–10, –20) asymmetry is equivalent to a symmetrical emission of approximately –15.5 dBc (–10 dBc minus 2.6 dB minus a "cost" of 1.9 dB).

However, 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" an additional 7.4 dB increase in digital power. Operation at (–14, –20) asymmetry 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. These results should provide some quantitative guidance to planners considering an increase in transmission power on one sideband to increase a station's digital coverage, while limiting emission on the other sideband.

In sum, broadcasters are best off maintaining symmetrical sideband levels, but digital coverage improvements are possible with an increase of only one sideband. PowerBoost allows the use of asymmetrical digital sidebands where desirable and improves hybrid amplifier efficiency by reducing the peak-to-average power. PowerBoost did not worsen the analog noise floor of the receivers that were tested. Similarly, the use of PowerBoost exhibited little effect on receiver sensitivity under test conditions designed to model mobile reception in the presence of multipath.

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

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

Table 4: Test Conditions — Digital IBOC Reception

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 6: Analog Receiver Test Data

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

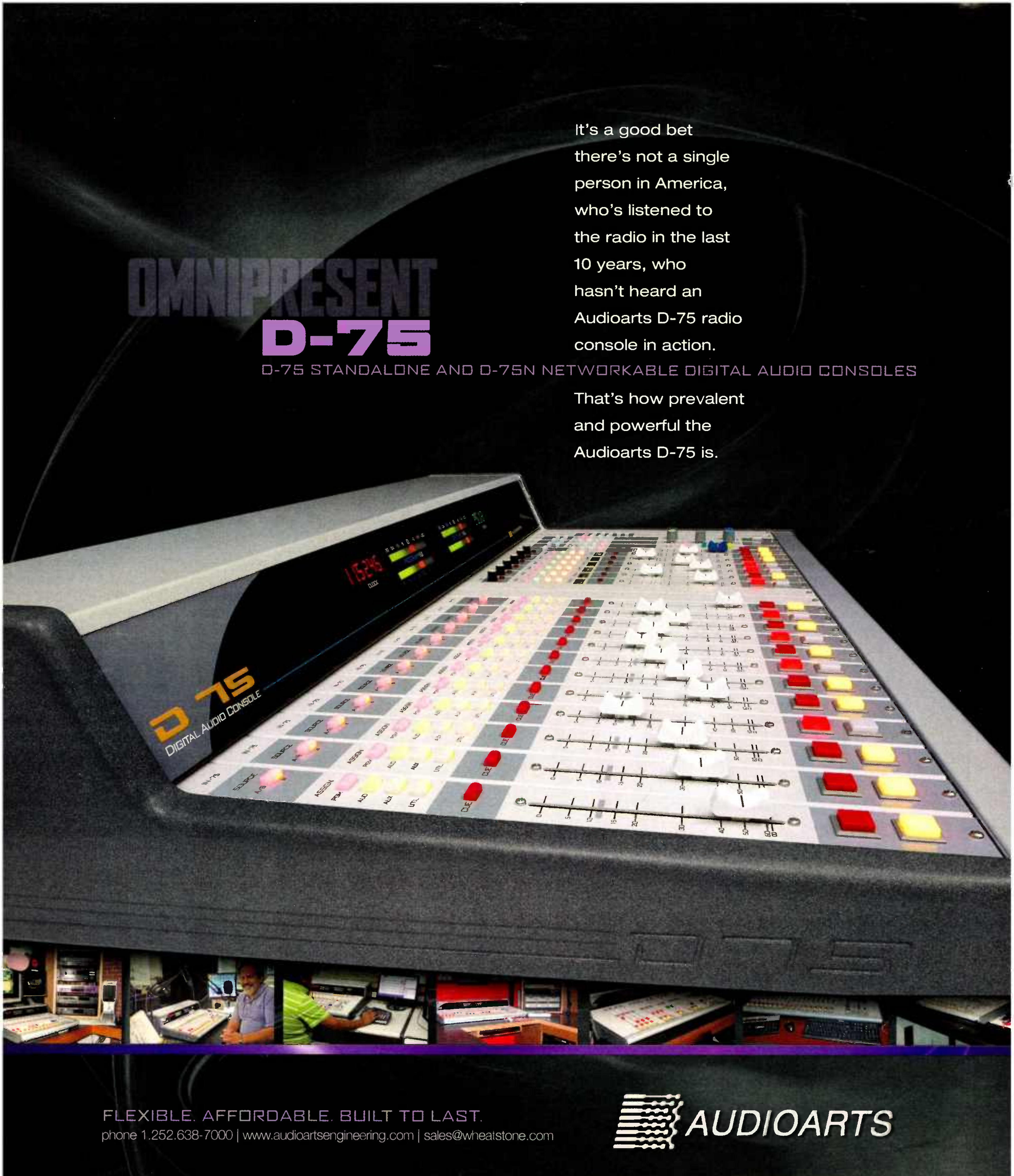
Table 5: Summary of IBOC Digital Reception Measurements

MORE ONLINE

Read the original paper in PDF format, including additional charts, at http://tinyurl.com/rweepower

ACKNOWLEDGEMENTS

The author wishes to thank Philipp Schmid and Sam Goldman for their important contributions to the study. Schmid, 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). Goldman, as a research associate at NPR Labs, carried out much of the receiver measurements and data processing.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Two Out of Four Must Go!

The Special Art of Tower Insulator Replacement

BY CRIS ALEXANDER

Hopefully you won't ever have to see riggers doing this on one of your towers. The original legs had to be sawed off in order to mount the new insulators, which used a different bolt spacing.

For the most part, tower insulators are pretty rugged. I've been in this business for more than 35 years and have never seen a base insulator fail — or even crack … until recently.

Porcelain is a rugged material that is very durable in compression; it does not crush. That makes it an excellent material for use in high weight-bearing applications (such as under a tower). The same material is used for guy wire insulators in AM applications, with the guy cable rigged through the insulators so that they compress the porcelain material and don't pull on it.

In guyed AM tower applications, a cone-shaped or cylindrical insulator is placed between the base pier and the tower base plate with the full weight of the tower compressing the material of the insulator.

Free-standing towers are a little different because they have both downward and upward moments, depending on the direction and velocity of the wind. As such, base insulators under the legs of a free-standing tower have to work in both directions, both supporting the weight of the tower and holding the tower leg to the foundation, depending on instantaneous conditions. That double duty requires a special design, usually a pair of porcelain insulators held captive in a steel or iron frame. The lower insulator supports the tower leg's weight while the upper holds the tower leg down.

A BURNING SUSPICION

In my company, we have a number of "legacy" AM signals, and some of these employ free-standing towers with this type of dual insulator design. Some of these towers and insulators date back to the mid-1930s, a testament to their toughness and durability.

Base insulators have to operate out in the elements, providing isolation between the metal members above and the ground below in all kinds of conditions — wet, dry, dirty and clean. It's almost unheard of for a properly-selected base insulator to arc over due to RF excitation or a combination of RF plus static electricity. Ball gaps are usually provided across the base insulator to provide a discharge path for static and lightning away from the porcelain material of the insulator.

There was, however, a day when it happened to our Portland AM station, KKPZ.

Our station operates with 5 kW full-time using a three-tower directional antenna. The two 310-foot and one 437-foot free-standing towers date to the early 1960s. Radio Disney operates its expanded-band KDZR with 10 kW-day/1 kW-night into tower #3 of the array, which is one of the 310-foot towers and the low-power tower of the KKPZ directional array.

We were wrapping up a tower painting project awhile back when at the end of a workday, our chief engineer noticed paint overspray on the porcelain surface of two of the base insulators under tower #3. He notified the tower crew and they wiped the insulators down with a wet rag.

The next morning was foggy and everything was soggy-wet. When our

(continued on page 16)

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INSULATORS

(continued from page 14)

engineer arrived at the site early that day, he was greeted by one of the tower crew asking, "Are those base insulators supposed to be steaming?" Our engineer noted that indeed there were copious amounts of steam rising from two of the insulators, and from his vantage point in the parking area he saw what appeared to be a sustained plasma arc dancing over the surface of the nearest insulator.

Cracks and discoloration are visible on the lower section of the southwest insulator.

He quickly went into the building and shut off the transmitters, which immediately extinguished the arcs. He and the tower crew examined the base insulators and found carbon tracks and cracks on the two insulators that had been contaminated with overspray and cleaned.

The insulators were thoroughly cleaned and everyone held their breath as RF excitation was applied. To our great relief, the insulators held; there was no more arcing.

The question at that point: Were the cracks simply in the glazing on the surface or did they go deeper? Was this a cosmetic or a structural issue? (See photo above.)

DON'T TIP THAT THING OVER

Replacing a base insulator is a big deal, especially on a self-supporting tower. With a guyed tower it's possible to loosen the guy wires and "pick" the tower with a crane or lift it with a jack, gaining enough clearance to rotate the old insulator out and the new one in.

Not so with a self-supporting tower. The forces on all three or four legs are in balance. You can't just use a crane or jack to lift one leg without providing some means of also holding the leg down. Once the bolts that hold the insulator assembly are out, if there is nothing holding the tower leg down, a gust of wind on that side of the tower could well topple the structure.

All that was taken into consideration as we evaluated whether to replace the insulators immediately. We decided to wait and see whether any evidence of structural problems would appear.

The insulators used on this tower have not been manufactured in many years, and new replacements would be both very expensive and totally different mechanically from the existing ones. I put the word out through the grapevine what we were looking for; within a few days I found a pair of salvaged insulators of the exact make and model. The only difference was the bolt pattern, which was different than the pattern on the tower legs.

To deal with the bolt pattern issue, I hired a structural engineer to design an adaptor section, essentially a piece of tower leg (angle iron) drilled to match the insulator hole pattern on one end and drilled with another pattern on the other end. These sections were fabricated by a local foundry, so we were ready to go.

But before we jumped into the project, I opted to wait and carefully observe the existing insulators. It was, after all, entirely possible that the cracks were only surface deep and we might be able to avoid the ordeal of replacing the insulators altogether. In that case, we would only be out a couple of thousand dollars for the surplus insulators, engineering and fabrication.

Things went along fine for about a year. The cracks did not widen or otherwise show any signs that they were more than surface deep. Eventually, however, we began to see some horizontal displacement at one of the crack lines, a sure sign that the crack was deeper than the glaze. It was time to swallow the bitter pill and change out the insulators.

The lifting bracket is visible with the insulator assembly out.

BRACED FOR ANYTHING

We hired P&R Tower, a West Coast tower maintenance company that had done some excellent work for us in the past, and they carefully devised a procedure for jacking the tower and replacing the insulators. They custom fabricated some jacking brackets that would take care of securing the tower leg in both directions during the insulator replacement. And then we waited for the perfect weather window. And waited. And waited.

It was many months after the decision was made to proceed with the insulator replacement that we finally got our window, several days of forecast calm winds and good weather. Of course the weather didn't quite adhere to the prognosticators' predictions, but we did get enough good days to get the job done.

The crew started with the southeast leg, set the lifting bracket in place, tried it, made some adjustments, tried it again and finally lifted the tower leg about 1/8-inch off the insulator, which was enough to rotate the old insulator out and the replacement in.

Next, the tower leg was sawn off above the old bolt holes and the adaptor section was bolted into place on the insulator. A magnetic drill was then affixed to the tower leg and used to drill the tower leg to the bolt pattern of the adaptor section. The bolts were installed and then the "cathedrals," the diagonal supports that attach to the insulator assemblies, were welded together.

The northwest leg was done next, and with the replacement insulators in place and all the bolts and welds made, we breathed a sigh of relief.

One of the completed insulator replacements, ready for priming and painting ... without the overspray! Note the bare metal adapter plate bolted to the tower leg.

I have replaced base insulators before, but always on guyed towers. That made me nervous. Replacing two insulators on a free-standing tower was just about terrifying. I hope I don't ever have to do it again.

Cris Alexander is director of engineering at Crawford Broadcasting and a past recipient of SBE's Broadcast Engineer of the Year award.

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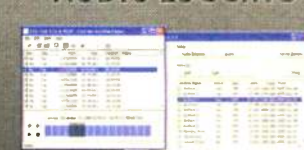

PC Software for archiving and logging all of your stations audio.

APACHE

(continued from page 1)

tion was limited and was intended for "static" Web pages: simple text with embedded images, with minimal formatting. Later HTML incarnations have allowed more control over the display of the page, and Cascading Style Sheets (CSS) are often used now to specify layout and appearance. CSS acts as a template, telling the browser how to display content; this way your site has a more consistent "look" from one page to the next. For example, CSS might be used to say, "Always put my header image at the top of the page and the table of contents here on the left."

Provided that the browser supports it (and most do), Web content creators can also embed commands, such as JavaScript, into HTML to build interactive pages.

On the server end, things like PHP can be used to generate content on demand. "PHP" originally came from "Perl Home Pages" (Perl is a popular programming language). Nowadays, the acronymn doesn't mean anything; PHP is just the name of a special language that's ideal for building Web pages.

The bleeding edge for interactive Web applications combines the two: The browser sends user input back to the server, which then creates active content on the fly. In the open source world, "AJAX" is the mantra for software requirements ("Apache, JavaScript and XML") and Microsoft offers ASP.NET for the same thing.

This article won't concentrate on content. Entire books have been written about AJAX, PHP, JavaScript, Adobe Flash and other "tricks" that a modern Web developer uses to create a professional-looking website. We're going to look at the basic Web server itself.

PLAY AND LEARN

The Apache Web server is one of the most successful of all open source projects. Like Linux itself, it's a free download and it's developed by a dedicated (fanatical) group of programmers from around the world. OpenSUSE Linux supports it fully and is ready to install it as soon as you say "Go."

I'll assume that you've installed openSUSE Linux on a PC on your office network, and that it has Internet access. Given that, Yet Another Setup Tool (good 'ol YaST) makes it easy.

Step 1: Installing Apache

Click Computer > YaST, then scroll down to the Software section. Click "Software Management." In the window that appears, enter "Apache" in the search ("find") box at the top. Everything Apache-related will appear in the lower selection screen; all we need is "Apache 2" (see Fig. 1). Click that, then "Apply." The Apache Web server will be downloaded and installed.

We'll also install the YaST Apache module, so next enter "yast" in the search box. Scroll down to find "yast2-http-server"; click that, then "Apply." Now you can close YaST, then restart it. When it comes back up, scroll down to the Network Services section. You should see an "HTTP Server" entry. Click that and, for this example, we'll configure a very basic (but quite functional) Web server.

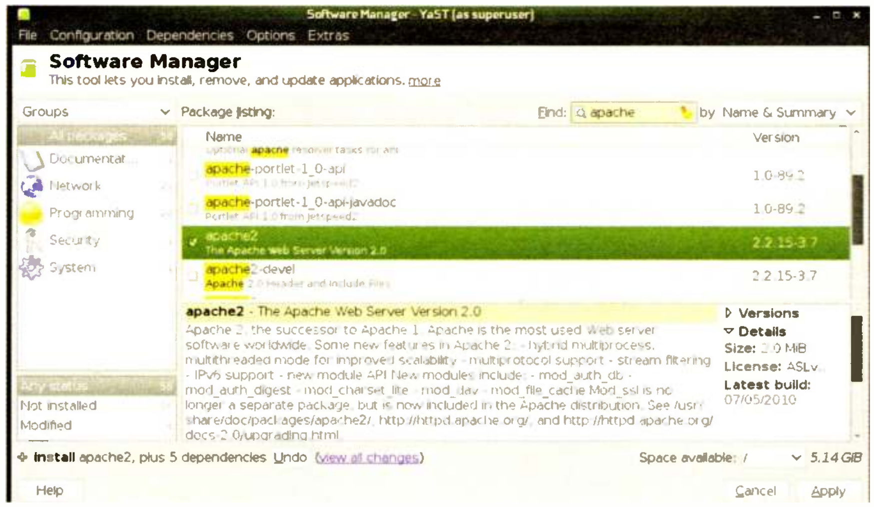

Fig. 1: Installing Apache on OpenSUSE Linux

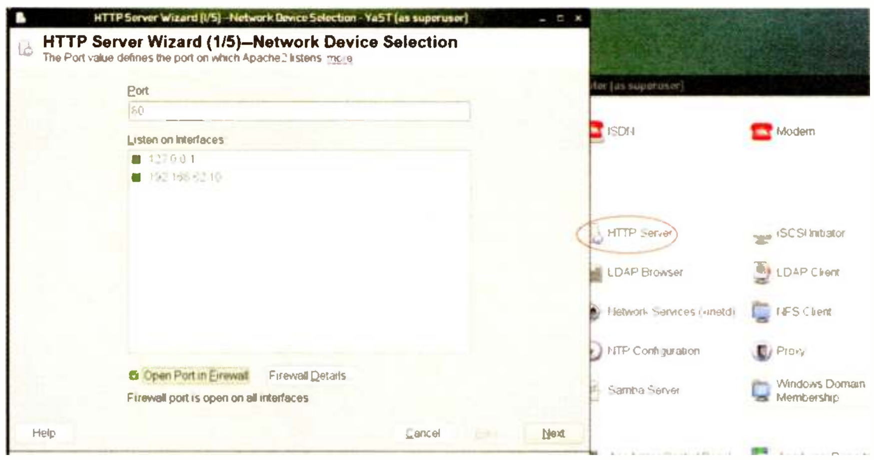

Fig. 2: Configuring the Apache Web Server — just accept the defaults here.

Step 2: Apache Configuration

Fig. 2 is the first screen of the HTTP Configuration module. This lists the available network interfaces (127.0.0.1 is the Local interface on the server itself). Just accept the default here, which is to listen on all interfaces. Be sure that the "open port in firewall" button is checked.

The next page is where you enter some server-specific information. For this test, you're just playing with the Web server on your local network, and we can accept the defaults. If you expose this server to the Internet, though, you should change the server name and the contact email address. Click on those lines and select the "Edit" button.

The next configuration page allows you to set up virtual hosts. *Don't* touch this; this is an advanced trick that we won't need here. Basically, you could create and register many different domain names with DNS — *forums.myserver.com*, *events.myserver.com* and so on — and have the Apache server use a different home directory (or even a different server) for each one. We won't need that for this example.

That final configuration page is the summary of proposed changes. If you missed anything, you can click the "Back" button to fix it. You should check the "Start Apache2 Server When Booting" button, or you'll have to manually start the Web server each time you restart the machine.

Step 3: Test Your Server

I recommend that you reboot your Web server before continuing: click Computer > Shutdown and select "Restart The Computer." When it finishes rebooting, click Computer > Firefox to open the browser and enter "127.0.0.1" in the address bar. (You could also try browsing to your server's IP address from another PC on your local network.)

Most Apache installations include a default page that says, "It Works"; for some reason, my installation of openSUSE 11.3 didn't. But an error page still proves that Apache is running (if it weren't, your Web browser would complain that it couldn't connect at all).

Note that the default base directory for HTML is /srv/www/htdocs. You'll have to log in as the root to put Web pages there. Fortunately the openSUSE build of Apache supports personal Web pages by default. Enter "127.0.0.1/~username" and you'll see a directory of that user's home "public.html" directory. This is where we'll put our HTML files.

Step 4: Create Your Web Pages

The word processor LibreOffice (the successor to OpenOffice) can create HTML. Click Computer > LibreOffice Writer. In LibreOffice, select File > New and choose "HTML Document." Enter some text, then save the file in your home directory, in the "public_html" folder, with the name "index.html." Now click Computer > Firefox to open the Web browser. Enter "127.0.0.1/~(yourusername)" and you should see your new page. If you want to see what the actual HTML looks like, right click anywhere in the page and click "View Page Source" (don't be surprised if there's a lot of stuff there just to display a few lines of text).

As I said above, Apache is quite reliable and you could, if you wanted to, expose this to the Internet as a for-real Web server. If you're on an extreme budget (or just want complete control of content), you can do this. But don't skimp on the security: Make sure the firewall is running, use very good passwords, and regularly click Computer > YaST and check for updates.

WEB HOSTING AT AN OUTSIDE COMPANY

In the good old days (just 10 years ago!), you installed the Apache HTTP Server on a decent PC and put up your own website in no time flat. Nowadays, you are more likely to use a hosting provider like Go Daddy or your own ISP. They provide the bandwidth, the hardware and the DNS (Domain Name System) work. All you have to do is create the content and upload it (or, in many cases, you can use their online content editor to create a professional-looking Web page very quickly).

Maintaining a top-quality website takes a lot of work. Unless you have staff who are really good with website design, you probably ought to consider using someone like Intertech Media (*intertechmedia.com*) to do the wizardry for you, too. It'll cost, but you may decide that it's worth it.

Nowadays, especially if your station is popular, you can expect for your website to be quite busy at times. Big active Web pages with lots of eye candy mean larger files. A simple DSL line with less than 1 megabits of upload will be inadequate for more than a few "hits" at a time. This is another reason you might consider using a hosting provider; they'll be clamped directly onto the Internet with a "big pipe" that can provide lots of bandwidth.

Finally, there's the old security issue. Apache itself is rugged and reliable, but it still requires maintenance. Unless you're willing to peruse the logs for hacker attempts and to keep the server software updated, your site will eventually be hijacked by a Bad Guy. A hosting provider takes care of these headaches for you, too.

FIND OUT WHAT IT CAN DO

In this article, as usual, we only barely scratched the surface. Books have been written about HTML, creating effective websites, and how to configure an Apache server in any of dozens of different ways. But this "test" server will work fine to learn the fundamentals.

Try creating different Web pages with LibreOffice. Save your filenames with the ".html" extension into your public_html folder, then enter "127.0.0.1/~yourname/pagename.html" to view them. Have fun!

Stephen M. Poole, CBRE-AMD, CBNT, is chief engineer of Crawford Broadcasting in Birmingham, Ala. Read past Radio IT Management columns at radioworld.com *under the Business tab.*

LIGHTSQUARED

(continued from page 18)

eliminating any inconvenient direct competition.

OK, I know this is politics and that the FCC has a mission to assist pioneering uses of the electromagnetic spectrum. But as someone who has worked in an industry that is both successful and highly regulated for my entire career, it does seem as if certain rule changes happen too easily and without a proper evaluation of the potential consequences. This doesn't seem, well, *fair*. Or even sensible at times.

Rule shifts of this kind can greatly change the value of a spectrum allocation that suddenly has newfound abilities. LightSquared is boasting that its proposed 4G data services eventually will be worth $120 billion. If the original spectrum allocation had included the right to build out a terrestrial network, it would have likely raised more bidders and a higher market value in auction. Observers are rightly uncomfortable when such sudden shifts in rules allow one company to suddenly own valuable property *after* a supposedly open auction process.

The lure of business may obscure potential harm to established users from changes that are poorly thought out and motivated by a desire to create fabulous new profits.

HOPE FOR THE BEST

GPS uses are numerous in radio. Many studios use professional clock systems that synchronize via the GPS system. Station groups with single-frequency networks rely on GPS timing to keep their signals in sync. Timing drift results in coverage being converted to interference. Consultants use them to determine tower locations and antenna elevations. GPS is used widely for measuring broadcast radials for AM and FM service.

LightSquared says it will fix the problem and is designing its systems to protect GPS with exceptional attention to minimizing out-of-band interference. Its latest proposal offers to use only the lowest 10 MHz of its frequency allocation in the initial buildout to provide protection to existing GPS systems.

Effect	Distance
Jamming is detected	13.76 miles (22137 meters)
10 dB Loss of Sensitivity	9.85 miles (15853 meters)
Loss of Fix in Open Sky	5.60 miles (9018 meters)

This table from the Garmin report describes the effect of LightSquared service on a Garmin aviation navigation device.

It also turns the blame on the GPS industry for relying on receivers that are prone to interference. Somehow this claim seems hollow given the massive change in use that has been permitted to LightSquared and the secretive way in which its license was changed.

The FCC has stated that LightSquared must prove it has resolved the GPS interference issue before it can continue its deployment. Let's hope both parties take this responsibility seriously — and that no more "Midnight Fixes" emerge from this important regulatory agency.

MEMORIES

(continued from page 22)

connections of memory fragments. You think about an upcoming vacation, that links to last year's vacation in the mountains, which links to a sudden storm, which links to the hole in your roof, which links to the fallen tree, which links to your damaged car, which links to the current price of gas, which links to the lack of an expected raise, and so on.

The brain has its own retrieval logic. The same process takes place in a serious professional conversation.

MEMORY TYPES

Neuroscience research has shown conclusively that events are decomposed into thousands of "relevant" components, each of which is linked to an array of associated experiences. When you recall an event, the brain has to reassemble these pieces into a coherent picture. Essentially, a memory is a re-creation, not a retrieval. You may not like this view of the human brain, but you were not the designer of humanity.

To make sense of memory, we have to start with a broad definition: Any experience that can influence future actions and decisions is effectively "remembered." How it influences the future is not simple. Recall is only one manifestation of memory.

There are two basic categories of memory: declarative and non-declarative. In the former category, the recall can be described in words, which is why this kind of recall often is called semantic memory. Within this category, we have factual memory and autobiographical memory. Factual memory is simply what it says, such as: Our country has 50 states. Autobiographical memory is a personal experience, such as: I had eggs for breakfast.

Facts actually arise from a personal experience. The first exposure might have been during a class when you were 6 years old. The biographic component eventually gets discarded. One can remember the "fact" but not the context and assumptions when it was learned.

Non-declarative memory is the more interesting case, because it results when experiences change the brain so that the information can be used in a high-speed non-conscious way. You may not be able to describe every turn in driving home each day, but you can do it while thinking about other things. The route is remembered experientially but not declaratively. You can drive home easily, but you may not be able to accurately describe each turn. Similar, you cannot readily describe how to ride a bicycle or give a lecture or hold a conversation or prepare a meal.

Emotional memory is central to all forms of information storage, yet it is always non-declarative. You may remember *that* you were angry but you cannot remember *feeling* angry. A remembered face cannot be put into words. Pain (or any form of social discomfort) can only be described as a metaphor, as in "his comments made me sick to my stomach." We give facial displays and tone of voice meaning, but our memory of this kind of information is far from objective.

THE WEAKNESS OF LANGUAGE

There are a large number of lectures by famous scientists on the subject of memory. Some of these are brilliant and require no background on the subject. YouTube, for example, has several lectures by Daniel Kahneman, a Nobel laureate notable for his work on the psychology of judgment and decision-making. You can also find great discussions about false memories presented by Elizabeth Loftus. (Kahneman: *www.youtube.com/watch?v=XgRlrBl-7Yg* and Loftus: *www.youtube.com/watch?v=hER-5mdloN0*).

Putting a memory into language also suffers from the weakness in language. Most verbal expressions are metaphors, narratives using analogies to other shared experiences. In fact, if you describe a memory to a friend, you will notice that it is nothing but a story that is consistent and meaningful without any way to validate its accuracy.

This issue is central to our legal system. Because there have been so many cases of faulty eyewitness reports that resulted in long prison sentences, the problem of memory has been studied extensively.

When an event is described multiple times, each recall is actually the previous recall instead of the original. If I tell my spouse about my day during dinner, and tell the story again the next day, the second retelling is closer to the first retelling than to the actual event. Memories evolve and get changed. For this reason, the legal system places more credibility on a written version of events done shortly after they happened. They call this process memorializing.

Business executives use contracts as a way of stating explicitly what was agreed to without depending on memory. While a verbal agreement is legal, the courts dislike this kind of evidence. For this reason, any meeting that is worth having should also have a written summary distributed to the participants. They are more likely to recognize errors and omissions before their memories decay to the point of fantasy.

The conclusion of this discussion on memory is humility. Just as we look at a technical system as having properties, so too must we look at our brain as having a matching set of properties. In both cases, these properties arise from the way in which the system functions. We all need to become experts on the properties of the human brain, ignoring any assertion that we are what we want to be, or should be.

Barry Blesser is director of engineering for 25-Seven Systems. Contact him at www.blesser.net.

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Memories Are Imaginary Stories

Why Can't the Brain Actually Recall Anything Accurately?

BY BARRY BLESSER

When I recently discussed a meeting that had been held two weeks earlier with the attendees, I was not surprised that there was no agreement about the contents and conclusion.

Each person was convinced that the others had poor memories and that his recollection was more accurate. No doubt, each of us had a similar experience.

Some remembered the meeting as a brainstorming session to explore ideas, while others thought it concluded with an unambiguous decision. A manager might be remembered as promising a raise if a certain goal was met, while he might remember the idea only as a possibility.

Why does a shared event result in such wildly different memories of the event? This is not a trivial question.

Perhaps you remember the childhood game of "telephone," in which the first person whispers a story to the second person, who whispers the heard story to a third person and so on. Everyone gets a good laugh when the story at the end of the chain is compared to the story that started the sequence.

The starting and ending story appear to be completely unrelated. On each retelling, new errors and changes are introduced. Even over a one-minute interval, memory fails: You cannot articulate accurately what you just heard.

Recently, I have been teaching a course on cognitive science, and in preparation for the classes, I have been reviewing the most recent research on what we are as a species.

The most dramatic conclusion is that our self image of what it means to be human arises from a belief as to what we *should* be rather than what we *are*.

Even though engineers know better, we like to think of our auditory memory as a sound recorder and our visual memory as a camera. Nothing could be further from the truth.

Mechanical analogies are compelling but misleading. The brain is not a computer; the visual memory is not a camera; the auditory memory is not a recording device.

BAD WEATHER PREDICTION

Our brains were not designed to be accurate; rather, they were designed to keep our ancient ancestors alive in a hostile world.

Our ancestors had only a few goals: find food, avoid being eaten and produce the next generation of children. Logic, rationality and an accurate memory had nothing to do with survival.

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On the playground or in the office, each of us is experiencing our very own version of a story.

Overestimating our memory of danger had more survival value than overestimating safety. Hence, weather forecasters tend to predict the next big storm as massive, even if it turns out to be nothing more than a little rain. Survival is enhanced by overreacting to danger and underreacting to safety.

Over a lifetime, our eyes and ears are presented with more than 50,000 billion bits of information. Even if that information could be recorded, how would our brain find the useful information when needed? It's hard enough for me to find a document on my computer from last year. The issue of memory is more about storing it in a way so that it is available when relevant.

The brain has to break an experience into "relevant" pieces and then connect each piece in such a way that you can find the useful pieces in a fraction of a second. Something has to give; accuracy is sacrificed for retrieval efficiency.

When you daydream, you are actually watching the brain follow associated

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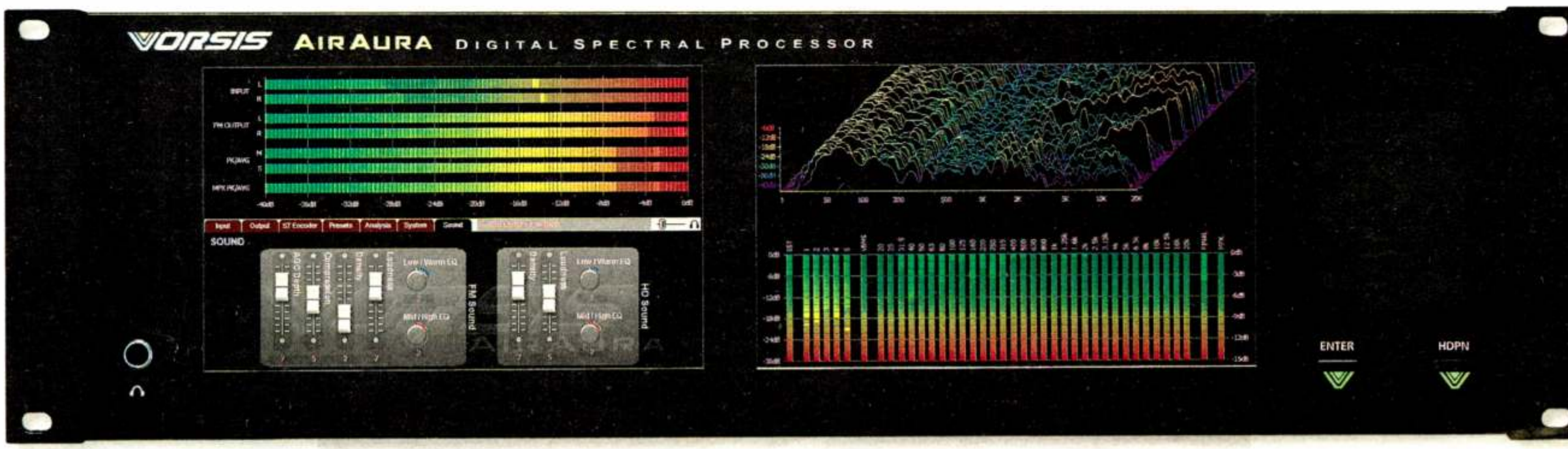

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