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HD Radio EVOLVES

Tech Developments Make the Digital Platform More Consistent, Efficient and Profitable

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Making Digital Broadcasting **Work.**

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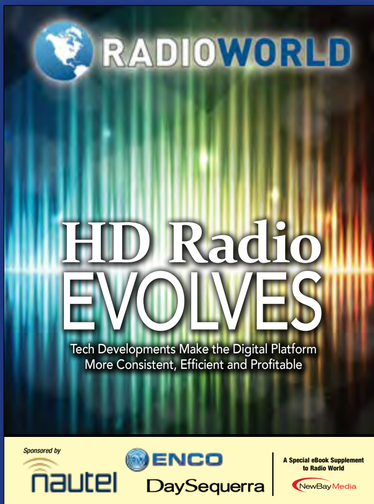


HD Radio Evolves

With HD Radio now part of the FM radio fabric in the United States, developer iBiquity Digital Corp. has focused much of its recent public work on growing the technology's automotive footprint — it's in some 200 vehicle models now — and revenue-specific efforts like helping broadcasters monetize their HD2/HD3 channels with the launch of an HD Radio Ad Network.

But the platform itself continues to evolve, and there are technical developments, too that, while less visible, are aimed at making HD Radio more consistent, efficient and profitable. Those are the subject of this special eBook.

Radio broadcasters have become more aware of the importance of diversity delay analog and digital audio synchronization; and more products are on the market to help. Alan Jurison explores this topic.

Scott Fybush gathers industry reaction to a demo at the spring show of Nautel HD Multiplex, a prototype technology that the company says would enable placement of up to 15 audio streams or stations within 600 kHz of signal bandwidth, or up to nine audio streams in 400 kHz of signal bandwidth. What might this portend?

Tom Vernon reports on the creation of a nationwide monitoring network, which iBiquity Digital Corp. says is "focused on improving the quality of HD Radio broadcast operations and the consumer HD Radio Experience."

And Nautel's Philipp Schmid explains that the latest IBOC broadcast systems architecture from iBiquity transforms the Importer, Exporter and Exgine hardware components into software-defined components that can run on any of three iBiquity-supported hardware platforms. His paper provides a history of how the architecture has evolved and the hardware platform choices now available to equipment manufacturers. His white paper was presented at the spring NAB Broadcast Engineering Conference.

— Paul McLane, Editor in Chief

Measure Diversity Delay and Correct for It Automatically

Vendors are responding to this important issue with solutions

by **Alan Jurison**

The hybrid digital and analog broadcasting solution deployed in the United States, FM and AM IBOC, more commonly known as HD Radio, allows simultaneous transmission of broadcast radio signals in both the analog and digital domain. A key component is that receivers can immediately acquire the analog signal and then transition (or blend) into the digital signal after it has acquired and buffered. The transition process is called blending.

> Imagine your station's most important client in a vehicle with HD Radio, hearing their commercial stutter.

In order to have this blend be seamless and transparent to our listeners, we broadcasters have had to employ delays on our analog AM and FM signals to match the digital. This delay is typically called "diversity delay" because the HD Radio transmission system uses a variety of techniques and buffering to add redundancy or diversity to the system for signal robustness.

This robustness and signal processing create significant delays compared to the near-instantaneous analog transmissions, typically anywhere from 6–10 seconds depending on hardware, software and data links in use. At a properly configured AM or FM station broadcasting in HD, there is a device in the analog air chain providing this delay.

In the first and second generation of HD hardware, this delay often was in the same device producing the HD signal. Over time, engineers demanded flexibility in configuration, reduction of hardware costs and fewer points of failure (the first two generations of hardware weren't particularly reliable).

The most common deployment of HD systems came in third-generation and recently introduced fourth-generation hardware, and these systems broke out the functionality of that single device into two, the Exporter and the Exciter. These components communicate over common Ethernet using a system designed by iBiquity called the Exgine platform. The connection between the two is considered the Exporter to Exciter (E2X) link.

As a station-level engineer, ever since I got my hands on an Exgine system (now in its tenth year in production hardware), I was challenged to keep the analog diversity delay perfectly aligned with the digital; and I wasn't alone. But this was the early days; the system was still being worked out, and many many of the major drifting issues were resolved over several software updates.

But precision tools available in the last few years have told us that there is still a long list of items that can cause diversity delay drift on a radio station: incompatible software/firmware loads, improper configuration of the hardware, poor isolation of network traffic and design of the E2X link, location of the Exporter and the Exciter and the latency or jitter on the data link it traverses, component aging and failures … and did you know that if you reboot your Exporter or Exciter, it often will come up with a slightly different delay than it had before the reboot?

A laundry list of items can cause a station's digital transmission timing to change. These, in turn, can cause diversity delay/ blend time alignment problems.

It's impossible to keep your station's diversity delay perfectly aligned through manual means. If you don't have a delay measurement device, it's also nearly impossible to know the precise amount of delay needed on your station. You should seek a way to measure the delay accurately and correct it automatically.

SPEC

We as an industry really have not been looking at diversity delay measurement with the precision it has demanded. Part of the problem was that we did not have the tools when we launched our HD stations. The initial alignment procedure was to put on a set of headphones and put a receiver in split mode with the analog on the left and the digital on the right, and get them to match. As you might imagine, it takes a "golden ear" to get it perfect. I've determined with precision devices that I'm just awful at it. Or, if I get close, I've wasted half my day trying to get it right.

And let's say you do have that "golden ear"… your UPS on the Exporter just failed, your Exporter rebooted, the delay just changed. Are you able to listen to each of your stations continuously to make that adjustment? The answer is that nobody can do this job manually and stay up on it and provide the precision required to stay in spec.

The official specification is that the analog and digital signals should be at 0 samples, plus or minus 3 samples. So the range is –3 to +3, with the center of 0 being preferred. One sample refers to 1 out of 44,100 samples per second in the 44.1 kHz bitstream.

An extreme amount of precision is required to get this perfect. One sample is 22.7 μsec. Three samples means within 68 μsec. Many broadcast monitoring products show the measurement in seconds and samples. If you've been measuring your diversity delay in seconds from any of these products and been saying things like "…the station is off –0.0001 seconds… close enough," you have been doing it wrong.

I must admit, I was doing it that way for a long time as well. At four digits beyond the decimal point, that is a resolution of 100 μsec. Any reading that is not zero essentially is out of spec. If the station is off by 3 samples, that equates to 68 μsec, rounded to the nearest 100 μsec, you would get 100 μsec or 0.0001 seconds. Four samples is 91 μsec and would round to 0.001. So, you could be in spec or out of spec with that number; there isn't enough resolution. At 2 samples, that will round to 0.000 sec.

Looking at it another way, 0.0001 sec is very close to 4 samples off, but anything between 3 and 6 samples off will round to .0001 seconds.

The best way to avoid these issues is to just focus on the number of samples and stop looking at the time. We need to be focused on samples, not seconds. And when you look at it that way, that level of precision is only available consistently if we automate the process.

WHY DOES IT MATTER?

HD Radio is here to stay and growing rapidly in the only area where volumes of radio receivers are still manufactured: factory installed radios in new automobiles. Ten years ago, the industry wondered when these digital radios would show up. They are here now; your listeners already have them. In 2014, iBiquity reported that 43 percent of new automobiles came with HD Radio, standard. In 2013, that number was 33 percent. This equates to millions of HD radios being sold and used.

Each day, more and more of your listeners have HD Radio receivers. Should trends continue for the rest of the decade, it's going to be hard to buy a vehicle without HD Radio in a few years. The digital experience of your radio station is something we should be paying attention to today. Within a few years, an HD Radio will become the primary radio your listeners will use.

If your station is not precisely aligned, all of the time, it makes that transition from analog to digital, or back from digital to analog when the HD fails, sound bad. How bad depends on how far off you are and what type of programming you have.

Stations that are lightly processed or air talk programming seem to be more susceptible to audible problems even with a small offset in samples. On loud, densely processed music stations the effects of being out of spec slightly can get buried in the program density to a point. But keep in mind, even these stations have periods of less density that are important, such as talk-intensive morning shows and commercials.

Imagine your station's most important client in a vehicle with HD Radio, hearing their commercial stutter. So every station ultimately is affected by not being "in spec."

Are you able to listen to each of your stations continuously to make that adjustment? The answer is that nobody can do this job manually and stay up on it and provide the precision required to stay in spec.

nautel **GVSeries** THE Choice for HD Radio® Digital AM & FM

Meet the new GV Series, the culmination of years of Nautel digital/analog transmission innovation. Nautel's field-proven, high-power FM architecture is mated with advanced RF technologies, the award-winning AUI and a new Spectrum/Efficiency Optimizer to set a new standard for digital performance, efficiency, serviceability and unmatched functionality.

Learn more about Nautel's new GV Series ›

Highest Hybrid IBOC Efficiency

With the GV Series Nautel has charted new ground for digital transmission efficiency. Traditionally, digital hybrid modes have displayed much lower efficiency compared to analog-only broadcasting. The GV addresses the need for analog/digital hybrid efficiency as well.

New HD Spectrum/Efficiency Optimizer

A new Spectrum/Efficiency Optimizer dynamically optimizes digital transmission parameters to achieve optimum spectral performance and efficiency. Digital efficiencies have improved by up to 15%. High digital efficiency can result in tens of thousands of dollars savings over the life of your transmitter.

70% at -20 dB | **60%** at -14 dB | **55%** at -10 dB

Nautel 1st to Deliver MER HD Radio Instrumentation

Nautel's award-winning AUI enables real-time measurement of MER including the ability to diagnose issues such as interference with the MP3 carriers near the analog signal due to FM analog signal over-modulation. Measurements follow the new NRSC standards and require no external equipment.

Learn more about MER Instrumentation ›

Try Nautel's Exclusive NPR HD Radio Calculator

npr labs

Calculate a proposed IBOC power increase using Nautel's exclusive Asymmetrical IBOC Sideband Elevated Power Calculator from NPR Labs®.

Try the NPR HD Radio Calculator now ›

HD PowerBoost™ GEN4

Nautel's award-winning HD PowerBoost GEN4 is a revolutionary technology that increases HD Radio power output while increasing efficiency, and addresses the FCC HD injection level increase ruling. It uses an intelligent peak to average power ratio (PAPR) technique to squeeze more hybrid power from any given transmitter and increase hybrid-mode efficiency.

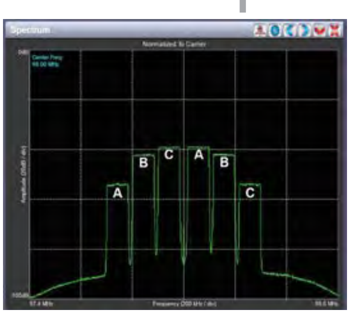
Learn more about HD PowerBoost GEN4 ›

More IBOC Power at Any Nameplate Level

Nautel's GV Series offers more IBOC power than any other transmitters available today. In a single cabinet, Nautel GV transmitters can provide up to 36 kW of analog power with a -14 dB injection level and up to 26 kW with -10 dB injection. In fact they can even make their nameplate power at -16 dB. (e.g. a GV30 can make a full 30 kW of analog power with digital carriers at -16 dB).

Pushing HD Radio Transmission Boundaries

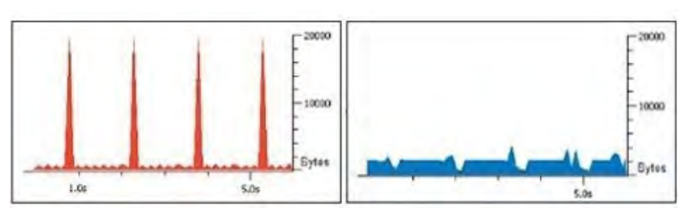
HD Multiplex



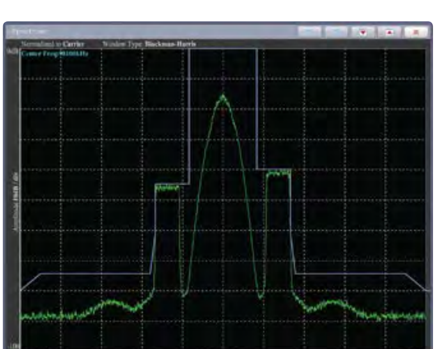
This new experimental technology is a spectrally efficient and energy efficient means to implement all-digital radio utilizing a multiplexed implementation of iBiquity's Gen4 HD Radio™ transmission technology. It enables the placement of up to 15 audio streams or stations within 600 kHz of signal bandwidth or up to 9 audio streams in 400 kHz of signal bandwidth. Learn more about HD Multiplex ›

HD Reliable Transport

This software solution helps eliminate IBOC audio drop-outs. It is applicable to every HD Radio deployment and allows various multiple exciter configurations to be implemented, such as main standby exciters, multi frequency networks, single frequency networks and satellite distribution applications.



BEFORE AFTER



Asymmetrical Sidebands

If interference issues prevent the use of increased IBOC injection levels on both sidebands, broadcasters can use Nautel's award-winning asymmetrical HD Radio transmission capability to increase only one sideband while leaving the other at levels that do not cause interference with adjacent stations, and still achieve maximum coverage of their digital signal.

Learn more about Asymmetrical Sidebands ›

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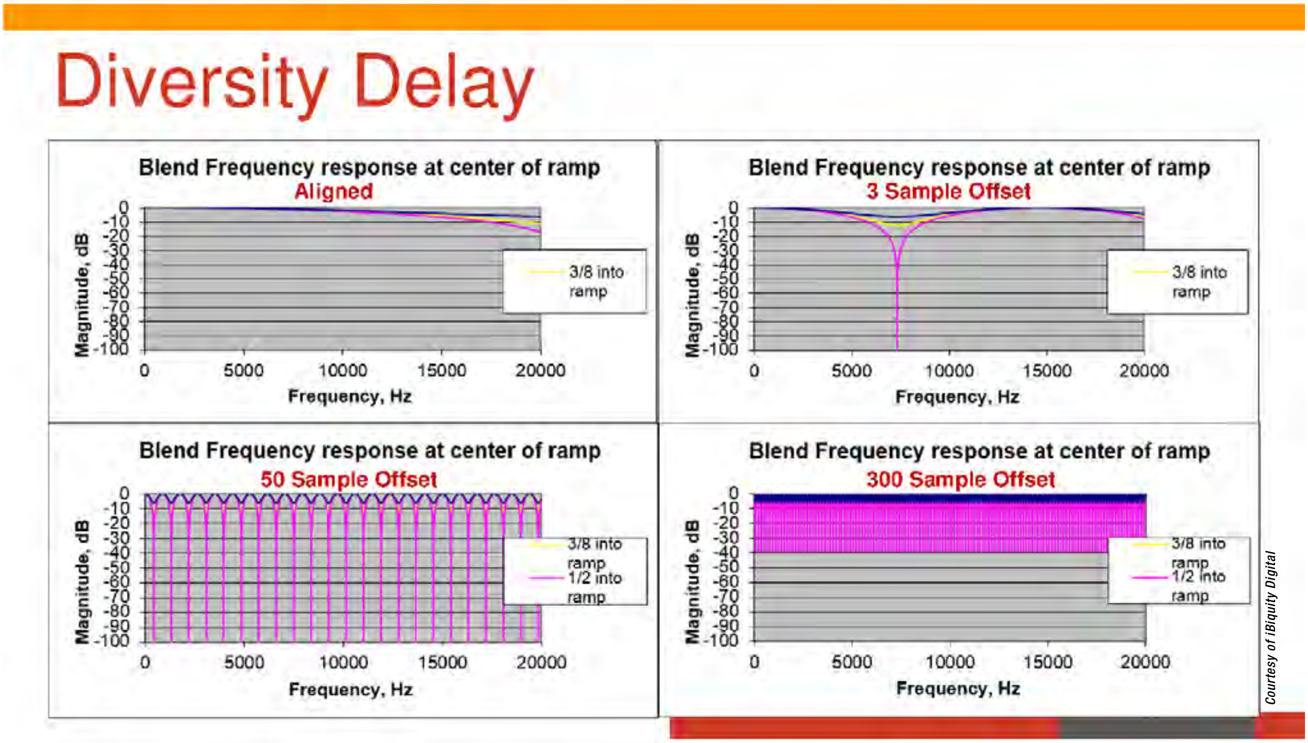

Fig. 1: Audible effects on blending at various sample offsets

IBiquity has done research, and you can get various audible blending effects depending on how many samples you are off. Fig. 1 shows the effect of different sample offsets and the impact on the audio. During a blend, any misalignment >5 ms (approx. 200–300 audio samples) will be perceptible to a listener as an echo or skipping effect. The two audio sources will sound distinct. Even small misalignments (< 200 samples) will produce a filtering effect during a blend. It will sound like one audio source, but will have a "hollow" sound due to a comb filtering effect. The effect is not noticeable if the misalignment is less than 3 samples.

Some people may think, "Well, the radio blends once 8 seconds after it tunes to the station, so it skips once; why does it matter that much?" Perhaps they think of the blend as an initial acquisition; then you keep digital forever. But that isn't always the case. Receivers of all types lose digital lock at some point. We could go into an exhaustive investigation of those situations, but that's a topic in itself.

The easiest way to think about this is in the car. Perhaps you think of the blend as if someone is driving out of your market. They have coverage, and at some point on the highway, they lose digital lock, it blends to analog, and eventually as you go out further and further, the signal is gone. But that's not the typical experience of your listeners. Most of your listeners do not leave the market and stations' signal coverage each day.

Think about your station's 60 dBu contour, which is where most –20 dBc stations tend to start to lose digital lock. If you live and work in that area, you can experience constant drifting in and out of digital. You can run into situations where the radio is blending quite a bit.

CAR COMPANIES CARE

Diversity delay blending issues are the number one complaint from auto manufacturers. IBiquity has told the industry that for years, their number one complaint about HD Radio is time alignment. I can independently vouch for this. I work closely with many automotive companies, and I've had emails, phone calls and idle conversations at lunch about this problem with their engineers. I have been in vehicles with these engineers where they hear stations skip and ask me to help fix it. The problem is, those stations typically belong to other companies, so it takes time to research who owns that station and to contact their engineering staff to have them make a manual adjustment.

GM temporarily removed HD in some vehicle models to help fine tune their implementation to address consumer feedback about HD Radio blending. It turns out that their customers (and our listeners) have been complaining to them about this for a long time. But instead of calling up the radio station to complain about it, the customer takes the car back to the dealer and thinks there is a problem with the radio. Listeners are not (and should not be) educated enough on this issue to think to contact the radio station about this annoyance. This customer feedback is not unique to GM vehicles.

Automotive designers are sensitive to this problem, and it is my experience that 99 percent of the problems come back to issues on the broadcast side. We need to fix this with automated monitoring and correction.

WHAT CAN YOU DO ABOUT IT?

For years, broadcast engineers have been working with iBiquity and transmitter hardware manufacturers to resolve this problem. We have made progress, and addressed some of the most common problems that cause drift. But as I transitioned from a traditional broadcast engineer to an HD Radio implementation specialist, I have discovered there are just too many variables beyond the control of all parties involved; there really needed to be a push for automated diversity delay measurement and corrective systems. I and other colleagues have been asking for products and solutions in this area, and we've seen the industry respond in the last few years. This year at April's NAB Show in Las Vegas, we saw a large collection of solutions being introduced to the marketplace.

Below, we've created a roundup of products that can help you monitor and manage diversity delay. Note that we have not personally tested each solution, and the list should not be construed as a product review or endorsement. Also, this is an evolving space. Some vendors are working on integration efforts with other products; and there may be other offerings available. Check with each vendor about pricing and delivery schedules for products or software you are considering.

TWO IMPLEMENTATION STRATEGIES TO CONSIDER

Create a two-piece system. Consider pairing a monitoring receiver that can measure the diversity delay offset and send a correction offset to a device that is active in the analog air chain (an audio processor, delay unit or exporter). If you have some of these products already, this could make a lot of sense for your station. By upgrading firmware on your devices, you can possibly put together two pieces of hardware to come up with an automated hardware solution.

Single-box solution. Some stations may choose to implement devices that measure and correct the diversity delay in a single device. This is especially handy for stations that do not have products below already in their air chain, or for companies looking for standardization of delay solutions from station to station. The devices below can be inserted into either your analog or digital air chain to make delay adjustments and have an integrated receiver to make the measurements of delay offset. You can use a simple antenna on these units, or wire off an RF sample (in FM+HD installations) with the appropriate amount of attenuation and the device. Many engineers I have spoken with are most comfortable about having these right before the HD Exporter, so that any adjustments it is making to delay are limited to just the HD broadcasts and the analog plant remains exactly the same as it does today. In that use case, you increase the existing diversity delay in your analog chain to a larger number than you need today; then these devices will make up the difference on the digital chain. The advantage of going in this direction is that the devices can then correct digital level and give you level alignment between analog FM and HD. The disadvantage to it being in the digital chain is that it would not work for any station that has to eliminate all delay for live programming and enter what is commonly referred to as "ballgame mode." Luckily, the products are easily configured to work in either chain.

Some solutions may be a better fit for your station than others. There are many factors to evaluate, including repurposing equipment you already have, overall system costs and your level of comfort with the devices. As mentioned, this is a rapidly developing space. If you adopt now — and I suggest that you do — you might need to provide feedback and observations to the manufacturers to refine the code and products. The industry is going to learn a lot about this issue in the next few years now that we have tools to measure and correct for this delay automatically.

Belar

The FMHD-1 broadcast monitor receiver performs a variety of HD Radio-related measurements, and it can measure diversity delay continuously. Not only is this helpful when trying to manually align a station, the correction offset can be sent to a variety of devices in this list, such as products from GatesAir, Nautel, Omnia, Orban, 25-Seven and Wheatstone below. Currently, the FMHD-1 works on a single-station basis; however a future software update is being considered to have the device scan multiple station presents and send correction codes to multiple stations devices.

Broadcast Electronics

The XPi10 esp HD Radio Exporter has a built-in diversity delay alignment feature. If you provide the Exporter with audio of the analog and digital from a receiver running in split mode through the unbalanced audio inputs, when configured, it will measure and maintain diversity delay. Note that the station must be configured to have the analog diversity delay fully provided by the exporter for this feature to be useful.

DaySequerra

The M4DDC is a single-box solution that can do the measurement and delay adjustment in a single box. It inserts in your AES stream of either the analog or digital air chain and can make the corrections necessary for time alignment, level alignment and phase reversal correction. It has a Web GUI and can alarm via GPIO, SMTP (email alarms), and also has an SNMP interface. The GUI also does data collection and can show you how the device is working overtime. This is an FM-only device; an AM version with slight hardware variations is expected later this year.

The M4.2 TimeLock broadcast monitor receiver makes a variety of HD Radio-related measurements; this product can measure diversity delay continuously, helpful for aligning stations manually. In addition, it supports automatic diversity delay correction with the GatesAir HDE-200 Exporter and the Orban processors mentioned below. Future support for Nautel, Omnia and Wheatstone products below is planned.

GatesAir

The HDE-200 Exporter can receive correction outputs from both the Belar FMHD-1 and the DaySequerra M4.2 TimeLock. Note that the station must be configured to have the analog diversity delay fully provided by the exporter for this feature to be useful.

Inovonics

The JUSTIN 808 is a solution that can do the measurement and delay adjustment in a single box. It inserts in your AES stream of either the analog or digital air chain and can make the corrections necessary for time alignment, level alignment and phase reversal correction. It has a Web GUI and can alarm via GPIO, SMTP (email alarms), and also has an SNMP interface. The GUI also does data collection and can show you how the device is working overtime. This is an FM-only device.

Nautel

The Exporter Plus can receive correction outputs from both the Belar FMHD-1 and the DaySequerra M4.2 TimeLock. Note that the station must be configured to have the analog diversity delay fully provided by the exporter for this feature to be useful.

Omnia

Omnia 7, Omnia 9 audio processors can work in conjunction with the Belar FMHD-1 to automatically adjust the analog diversity delay, with future support for the DaySequerra M4.2 TimeLock planned.

Orban

The Orban 8600, 8600S, 8500, 8500S, 5700 and 5500 audio processors can work in conjunction with both the Belar FMHD-1 and the DaySequerra M4.2. Orban notes that even the non-HD versions of these processors make diversity delay available for stations running separate analog FM and HD processors.

25-Seven

Precision Delay can be inserted in the analog air chain to achieve diversity delay and supports automatic correction adjustments from both the Belar FMHD-1 and the Worldcast/Audemat Golden Eagle HD.

Wheatstone

AirAuraX3, FM531HD, FM-55, and AM-55 audio processors can work in conjunction with the Belar FMHD-1 with future support for the DaySequerra M4.2 TimeLock expected but not available yet at time of publication.

Worldcast/Audemat

Golden Eagle HD is a broadcast monitor receiver that performs a variety of FM and HD Radio related measurements, including diversity delay. It can work with the 25-Seven Precision Delay for automatic diversity delay correction. Also, it can be configured to monitor diversity delay alignment and send alerts if alignment (or other parameters) are out of specification. All alignment measurements are available via SNMP for use by third party equipment. ■

Thanks to Harvey Chalmers and Jeff Detweiler of iBiquity for providing insights on their research.

Alan Jurison is a senior operations engineer for iHeartMedia's Engineering and Systems Integration Group. He also chairs the NRSC RDS Usage Working Group (RUWG). He holds several SBE certifications including CPBE, CBNE, AMD and DRB. His opinions are not necessarily those of iHeartMedia, the NRSC or Radio World.

Automate Your HD Channels with DAD

Push daily audio content to transmitter sites via ENCO Push Radio™ Interface

Transmitter(s)

Looking for a powerful radio automation system that gives you flexibility and scalability to grow with you in the future?
DAD by ENCO may be your answer. Not only is DAD considered the most reliable automation system available today, it was built with scalability in mind. Adding HD channels with DAD is easy. In fact, a single instance of DAD (Digital Audio Delivery) can run 16 independent playlists simultaneously. DAD gives you the flexibility to share content, run different commercial breaks for different feeds, and even push daily playlists directly to transmitters to stay on the air during STL outages.
Broadcasters are always looking for ways to get more for their money and a scalable radio automation package like DAD will prove well worth the investment.

Key Benefits

USER FRIENDLY:
Award winning Presenter interface for live assist Playout. Fast paced changes easily made on the fly. Customizable module based architecture.

CENTRALIZED CONTENT:
Share content across multiple stations. Easily break away for local commercials, liners and jingles and rejoin seamlessly.

EASY INTEGRATION:
Seamlessly integrate into any environment. DAD interfaces with all kinds of broadcast hardware and software.

AUTOMATIC CONTENT INGESTION:
Download content on demand or schedule and convert on the fly.

AUTOMATIC PLAYLIST CREATION:
Automatically create playlists out of music and commercial logs. Re-export traffic and without having to re-merge the logs.

CONTENT DISTRIBUTION:
Rule based content distribution to push or pull content between sites, studios, and devices.

FLEXIBLE COMMANDS:
Integral programming language allows for construction of commands and macros to operate the system more efficiently.

REAL-TIME LOG:
Real time log changes in any studio at any time.
No need to reload the current hour or current day's log.

WORLD CLASS SERVICE:
ENCO's responsive client support is second to none and available 24x7x365.

DAD Flexes To Your Needs

No two DAD installations are alike. In fact, many sites use DAD in completely different ways. That's just one of the major benefits of using DAD; it's incredibly flexible to meet the ongoing demands of today's broadcasters. No longer will you be constrained by the automation system sitting at the core of your operation. Let DAD free you up to create radio how you want with the resources you have on hand.

REMOTE VOICE TRACKING:
Voicetrack into your playlists from anywhere in the world via Web Browser, iPad, or Windows PC. No VPN required.

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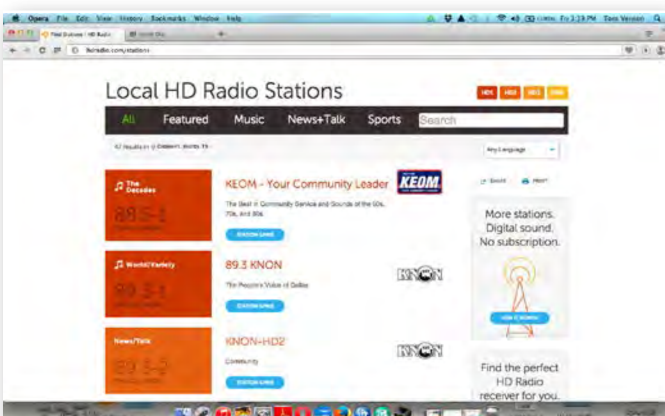
Creating the HD Radio Monitoring Network

It's intended to provide more technical insight and enhance the experience for listeners

by **Tom Vernon**

At the NAB Show in April, iBiquity Digital announced the development of a monitoring network for HD Radio stations. The project has been completed in the top 10 radio markets, as well as Detroit (market 12) and Las Vegas (32). Plans are underway to have the network operational in the top 50 markets by the end of the year. DaySequerra and MediaMonitors collaborated with iBiquity on the project.



Listeners can get information about HD Radio stations through the website HDRadio.com or via the HD Radio Guide app on mobile devices.

Senior Vice President Joe D'Angelo identified two driving forces behind the creation of a monitoring network.

"First, we wanted to get a better technical insight of the HD Radio landscape for ourselves. We have scaled up to 2,300 licensed stations with over 3,000 programs and data services. There are also about 25 million HD Radio car radios. This project has a huge potential to provide useful information for iBiquity, as well as give feedback to stations," he said.

"Second, we wanted to enhance the HD Radio experience for our listeners, and provide a tool for them to find the format they want to listen to. Listeners can find out about stations through the HD Radio Guide app or at HDRadio.com. Both services use a database of station information, including call signs, frequencies and formats. The monitoring network is a way to keep that information current."

PARAMETERS

By way of example, D'Angelo said the monitoring sites briefly scan each station's data channel. If the program type doesn't match what is on the guide, the guide is updated. Right now there is a human step in between to validate the changes, but the process is expected to be automated soon.

Jeff Detweiler, executive director, broadcast engineering for iBiquity Digital, said the low-level technical capabilities of the system are comprehensive.

"We can monitor about 140 parameters for each station's HD Radio signal. We normally check 20 on a regular basis. If we note a problem, or one is reported by listeners, we can do a more detailed analysis, and reach out to the station's engineer."

After about a month of observing the technical parameters of HD Radio stations, Detweiler said the overall picture is "very good." While on the phone with Radio World, he makes a quick check of the dashboard for New York and observes that of the 23 HD Radio stations, all but two are green; those two have minor problems with level alignment, he said.

"Moving forward, we expect to see continuous improvement in the technical performance of HD Radio, as there is ongoing feedback from the monitoring network to iBiquity and on to the stations," he said.

D'Angelo emphasized that the network "is not a substitute for a station's due diligence in monitoring and maintaining their HD Radio parameters. They should think of it as a second form of validation."

The monitoring system is transparent to HD Radio stations; there is nothing station engineers need to do, except respond to calls from iBiquity if there is a problem. But D'Angelo said stations can take a step to help: "We maintain a database of contacts at each of the stations. Obviously, people move around. If stations can update their contact list when there are personnel changes, that would be very useful." He said the easiest way is via email to quality@ibiquity.com.

Although the rollout of Phase One is ongoing, iBiquity is planning for what comes next. "We want to be monitoring HD Radio stations in the top 75 markets or beyond by the end of 2016," said D'Angelo. He adds that the next year will also include adding the top seven or eight markets in Canada, as well as Mexico.

Under discussion is a plan to share technical data gathered from the monitoring network with equipment manufacturers. "We may be able to spot a small problem before it goes critical," says D'Angelo. "Putting the manufacturers in the loop may lead to fewer unnecessary service calls and more expedited repairs."

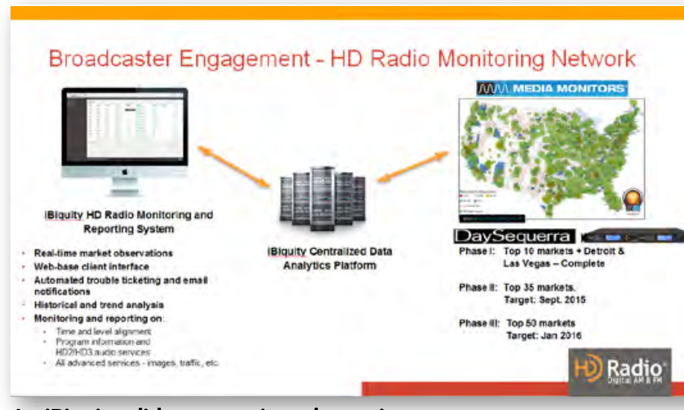
IN THE FIELD

All of the monitoring sites are equipped with DaySequerra MAM2 monitors. DaySequerra President David Day said the origin of the device is an interesting story.

"Initially, we were approached by one of the broadcast groups through iBiquity to develop an update for our Market Area Monitor that we fielded years ago with Arbitron. Shortly thereafter, iBiquity asked us to expand the project scope and develop a version that could monitor virtually every attribute of an HD Radio signal. The MAM2 was in development for over 2-1/2 years."

He said the MAM2 monitors are able to scan all analog AM/FM and HD Radio broadcasts in a market, and that the MAM2 software is customized for each customer.

"Every HD Radio signal has some parameters that are public, and some that are proprietary or unique to a group owner. Using an iBiquity-issued broadcast token, MAM2 users are able to view both the public and proprietary parameters of their own stations, but only the public parameters on other stations in the market," said Day. The monitors built for iBiquity Digital are able to monitor all parameters on all stations including EAS messages. Each MAM2 takes up half of one rack width.



An iBiquity slide summarizes the project.

Once the monitoring devices have been manufactured, they must be installed and maintained at the monitoring sites; that's where Media Monitors comes in to the picture.

Media Monitors is a subsidiary of broadcast software company RCS. President/CEO Philippe Generali said iBiquity Digital's decision to partner with his company was due in part to the infrastructure that Media Monitors has in place.

"We have monitoring sites in about 160 markets, so it's fairly easy to add the iBiquity monitors in our equipment racks." The sites are chosen for IT access, backup AC power, backup air conditioning, and of course excellent reception of all broadcast signals in the market. Most are in central downtown locations.

Generali said the rollout of the iBiquity monitoring sites is on schedule. "We expect to have the top 25 markets complete by the end of the summer, and the entire project done by the end of the year." ■

The DaySequerra MAM2 monitors analog AM/FM signals as well as HD Radio and EAS. Users can view the public parameters of all HD Radio signals in addition to the public and private parameters of their own stations via an iBiquity-issued broadcast token.

HD Multiplex Scheme Brings Promise, Obstacles

Demo at the spring show grabs attention; its long-term implications are to be seen

by **Scott Fybush**

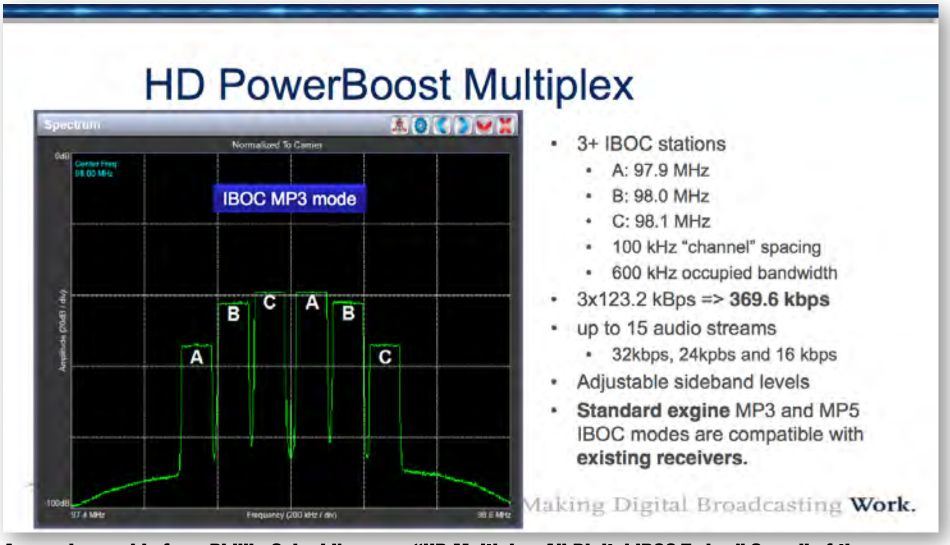
For broadcasters willing to dream big about a potentially disruptive change to the entire layout of the FM dial, Nautel's announcement of an experimental "HD Multiplex" technology at the NAB Show in April comes with the possibility of lower transmission cost and space for many more audio streams in any given market. The road from experiment to adopted technology could be a rocky one, though, especially on crowded U.S. radio dials.

"It is still very, very early on," says Nautel research engineer Philipp Schmid of the HD Multiplex system, which was envisioned just a few months before making its debut in Las Vegas.

At its core, the multiplex system starts with the digital carriers that currently sit on either side of an FM station's analog signal. While iBiquity's HD Radio system has long included at least the concept of an all-digital mode in which additional lower-level digital carriers would fill the 200 kHz hole where a station's analog signal now lives, "that hasn't really been implemented anywhere," Schmid says. "Now you can transmit HD without analog and it works, but it leaves that big gap in the middle."

Nautel is proposing to fill that gap by straddling it with additional digital carriers just like those used in the present hybrid digital/analog system. As it demonstrated in a test on the floor of the NAB Show, the Nautel multiplex system could stack three alternating sets of digital carriers across 600 kHz of spectrum in a way that most HD Radio receivers now on the market can receive. That could create room for as many as 15 streams of audio, which would appear on the radio as multiplex channels attached to three consecutive frequencies (say, 98.5, 98.6 and 98.7 MHz).

"The whole concept is very flexible," Schmid says.



A sample graphic from Phillip Schmid's paper "HD Multiplex: All Digital IBOC Today." See all of the graphics in his presentation here.

Unlike the European DAB systems or others that need specific carriers, Nautel's system can at least theoretically be expanded or contracted, functioning within as little as 400 kHz or, conceivably, adding still more alternating sets of HD multiplexes that could take up 800 kHz or even more, with correspondingly larger numbers of channels available.

"NEW GROUND"

"They're kind of breaking new ground here working with all-digital FM," says David Layer, senior director

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for advanced engineering at NAB. Layer says Nautel's proposed system is "unconventional" but intriguing, especially in the way it promises significant power savings.

"Normally a broadcaster would use three transmitters to provide three stations," he says, "but they've rigged software to do all three." Because HD Radio's digital carriers already operate at much lower power levels than the analog signal they sandwich, a multiplex of purely digital carriers would also operate at lower power with correspondingly lower power bills.

Inventing the technology is one thing, but getting it approved by regulators and finding a market for it may be a bigger challenge.

"The first thing you have to recognize is that all-digital FM is not currently recognized by the FCC," Layer says. "It would take a lot of work to get this to the point where it's something the FCC would even consider."

The multiplex system could stack three alternating sets of digital carriers across 600 kHz of spectrum in a way that most HD Radio receivers now on the market can receive.

Another informed observer is Milford Smith, vice president for radio engineering at Greater Media and chairman of the National Radio Systems Committee.

"I believe it would be a considerable challenge to fit this additional spectral occupancy into the existing tightly-packed FM spectrum. Full-power stations, many new LPFMs and many new translators have all made the FM band a very busy place," Smith said.

Nautel's Schmid says much of the interest in a multiplexed HD Radio system is coming from outside the U.S. "In Europe, HD Multiplex could become an in-band alternative to DAB, leaving Band III available for DVB." In Mexico, regulators are pushing to clear the AM band but have been thwarted in bigger markets by a lack of space on the FM dial. "So we have some broadcasters interested in trying all-digital IBOC there."

At least for now, most U.S. broadcasters aren't terribly interested in following those leads.

"I do not believe there would be a lot of real-world use of the concept in the near future, even if the potential allocation/interference issues could be solved," Smith says. "We still see very few FM broadcasters going beyond HD2 implementations now and fewer still able to appreciably monetize those multicast channels. I just don't know what one could do with all those additional channels that would make business sense circa 2015."

Schmid says one potential use in smaller markets might be allowing a single broadcaster (or several working together) to bring in niche formats that might not otherwise be feasible in their areas.

"Now that you have 15 audio streams, you could have 15 different genres with crowdsourced content. Each individual listener would have greater input into the playlist, and you could potentially have a big jukebox service."

Schmid also points to another announcement from the NAB Show, the HD Radio Ad Network that's already looking to place Radio Disney content on HD Radio subchannels in the top 60 markets.

But making the leap involved in turning off an FM analog signal is still a huge jump for most U.S. broadcasters.

"HD Radio penetration would have to be 90 percent or more before any broadcaster would likely even consider turning off the analog service," Smith says. "And even assuming that deployment could be possible and digital receivers were ubiquitous, I doubt if most FM broadcasters would be enamored with the idea of exponentially increasing the number of potentially competing signals."

Schmid says the proof will be in the testing, which is being planned both in the lab and, he hopes, under experimental licenses at stations willing to help demonstrate the system under real-world conditions.

"We do have stations stepping up and saying if you want to test, we've got an application for you," he said.

Whether this eventually becomes an industry standard or just an interesting technological footnote, NAB's Layer says he's pleased to see Nautel and other companies testing the limits of radio technology.

"I applaud Nautel for doing something this innovative," he says. "This is exactly the kind of activity you want to see with a technology like HD Radio. You want to see them doing things with the technology that even the developer didn't envision." ■

IBOC Broadcast Systems Architecture Technology Options and Assessment

An evolutionary history of HD Radio

by **Philipp Schmid**
Nautel Ltd.

Abstract — *The latest generation IBOC Broadcast Systems Architecture (BSA) as provided by iBiquity Digital Corp. transforms the present Importer, Exporter and Exgine hardware components into software-defined components able to run on any of three iBiquity-supported hardware platforms. This paper provides a history of how the IBOC Broadcast Systems Architecture has evolved and the different hardware platform choices available to IBOC equipment manufacturers today. An alternate peak-to-average power reduction algorithm (termed PAR2) helps with FM transmitter conversion requiring less transmitter power overhead as compared to legacy PAR1. The effectiveness of the available choices in peak-to-average power reduction on these platforms is compared with respect to potential transmitter power performance and impact on signal quality, such as the modulation error ratio.*

This paper was presented at the 2015 NAB Broadcast Engineering Conference. The conference proceedings are available for purchase here.

IBOC EQUIPMENT DESIGN PHILOSOPHY

In the United States, the National Radio Systems Committee (NRSC) officially oversees the In-Band On Channel (IBOC) standard termed NRSC-5-C [See reference 1]. This standard includes the definition of the IBOC AM and FM air interface, the data multiplex of audio transport and data services, and the transmission metrics that broadcasters and equipment manufacturers must adhere to. It is iBiquity Digital Corp. that holds the intellectual property rights to most of the NRSC-5-C Standard and makes this available in a fair, equitable, and non-discriminatory fashion to original equipment manufacturers (OEM) that have entered into a licensing agreement with them.

From the early days of IBOC broadcasting iBiquity has provided a reference design to OEMs to aid in the deployment of IBOC transmission equipment termed the HD Radio Broadcast Systems Architecture [2]. OEMs were never required to use the reference design as supplied by iBiquity. Through the above-mentioned licensing agreement, OEMs are able to implement parts of the system and innovate above and beyond the basic reference design while distributing key components as supplied by iBiquity to maintain consistency and interoperability. An iBiquity-defined certification test plan ensures that each OEM design complies in turn with NRSC-5-C [1].

EVOLUTION OF IBOC BROADCAST EQUIPMENT

To understand today's technology options in IBOC broadcast systems architecture (BSA), one must understand the evolution of IBOC broadcast equipment as a combination of iBiquity-supplied intellectual property along with various product differentiations supplied by individual manufacturers. The following is a chronological overview of this development with a focus on the exciter developments rather than the associated transmitter lines:

2001 to 2005

While a first generation of IBOC equipment existed, it was mainly an experimental platform not intended for commercial deployment. Only the second generation of IBOC equipment achieved commercial deployment and was the main platform used in the first wave of IBOC build out. This architecture consisted of a single x86-based IBOC modulator box that only considered the IBOC portion of the signal. The system supported both AM and FM. The FM version featured the first-generation peak-to-average power reduction method, sometimes also referred to as a crest factor reduction (CFR) method. This method is now termed **PAR1**.

2006

The Exgine modulator is what defined the third-generation BSA. In this architecture, the single modulator box was split into two components:

- The **Exgine** modulator allowed tight integration into the transmitter making the IBOC signal generation more robust. The Exgine was based on a Texas Instrument TMS320C6415 DSP processor. iBiquity supplied a firmware image with the appropriate interface definition, effectively turning the DSP into a modulator chip for the OEM. PAR1 was ported from x86 to this platform.
- The **Exporter** component performs the HD-1 audio encoding and aggregates the digital multiplex to be sent over IP to the Exgine modulator via the E2X data link. This allowed the Exporter to be separated from the Exgine.

Nautel realized early on that the E2X link had inherent vulnerabilities when applied to low-bitrate, unreliable wireless data links and developed the Reliable HD Transport protocol [1] to address these. In 2006 the third IBOC component, the Importer, achieved commercial adoption as it made possible two multicast channels and later three multicast channels. The **Importer** was a Windows XP application that interfaced to the exporter via the I2E link.

2007

In an effort to reduce the cost of IBOC broadcast equipment, the embedded Exporter NAB project was started. iBiquity ported the x86-based exporter implementation to a Texas Instrument TMC320C6713 DSP processor. However, this implementation still required a host processor. Nautel, in the end, found it more cost-effective to maintain the x86 Exporter core and remove the DSP.

2008

Nautel introduces the embedded exporter. The Exgine is applied to AM bringing the third-generation BSA to its new AM transmitter line. This year also saw the introduction of HD PowerBoost at the Broadcast Engineering Conference [2] as an example of an innovation that goes above and beyond the iBiquity reference design. Nautel presented HD PowerBoost with a demonstration based on Matlab vectors showing a potential 30 percent increase in TPO or achieving significant efficiency improvements.

2009

At the 2009 NAB Show Nautel demonstrated a proof-of-concept system able to process HD PowerBoost in real time on an 8 CPU x86 server. Nautel demonstrates IBOC SFN using IQ over IP. iBiquity also provides Exgine SFN synchronization hooks and performs on-air SFN tests.

2010

The IBOC power increase is approved, allowing IBOC carriers of up to –14 dBc for all and –10 dBc injection for stations without interference concerns. By the 2010 NAB Show HD PowerBoost had been translated into an efficient FPGA design that was integrated in Nautel's IBOC exciter line. Nautel also demonstrated asymmetric sideband operation using this system, which was also field tested at WAMU later that year.

2011

As part of an NRSC working group, the IBOC quality metric was defined and incorporated in NRSC-5-C [3].

2012

iBiquity releases **PAR2** on both x86 Gen2 and C64 Gen3 Exgine. It becomes apparent that both supported platforms have insufficient CPU resources to fully exploit PAR2 only achieving four and three iterations of the PAR2 algorithm, respectively. Nautel defines a PAR1 equivalent HD PowerBoost set point providing industry leading IBOC quality.

2013

iBiquity begins an industry partnership to develop a new hardware platform capable of supporting PAR2 and address stated obsolescence issues. This effort is truly a porting exercise of the Exgine from the C64 implementation into Xilinx Zynq family based FPGA fabric.

2014

Nautel introduces a spectrum and efficiency optimizer for HD PowerBoost systems. This system adaptively sets transmitter parameters in order to guarantee spectral compliance using its own measured spectrum while

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- **1st** to deliver asymmetrical HD sidebands.
- **1st** to deliver MER HD Radio instrumentation.
- **1st** to address HD Radio feed requirements with HD Reliable Transport.
- **1st** to deliver highest hybrid IBOC efficiency with the new HD Spectrum/Efficiency Optimizer.

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maintaining the best possible efficiency. This feature was used extensively to find the results in this paper.

2015

Fourth generation broadcast systems architecture is announced. Preliminary releases have been provided as early as 2014.

FOURTH-GENERATION BROADCAST SYSTEMS ARCHITECTURE

The new platform is loosely termed the fourth generation broadcast systems architecture, but strictly speaking does not represent a new BSA since no new system components are introduced [4]. Rather the fourth generation BSA is an effort to support core IBOC components on a number of hardware and software platforms, as shown in Table 1, including options to fully support the PAR2 algorithm. This approach provides tremendous flexibility in IBOC equipment product options where the core IBOC components can be combined or distributed across any number of hardware implementations.

For the purposes of the tests presented in this paper, PAR2 is demonstrated using x86 software implementations of the Exgine, Exporter and Importer components. A Nautel GV20 transmitter is used to demonstrate the effectiveness of PAR1, PAR2 and HD PowerBoost. However, the results found here should be equally applicable to other modern IBOC-capable transmitters.

	Hardware Platform	Software Platform
Importer core	x86 ARM	Java Linux Windows
Exporter core	x86 ARM TI C67 DSP	Linux (library) Windows (library) TI C67 (image)
Exgine core	x86 ARM+Zynq TI C64 DSP	Linux (library) TI C64 (image and library) Zynq FPGA

Table 1: IBOC Component Platform Options

HD POWERBOOST REVISITED

This section will only provide a brief description of HD PowerBoost. The interested reader is encouraged to refer to previous work on this topic [2] [5] describing basic IBOC operation, which is omitted from this paper.

The basic premise of HD PowerBoost is that the de-facto standard peak-to-average power reduction algorithm, now termed PAR1, requires modification for low level combined hybrid operation to take into account both the FM and IBOC signal components. From Fig. 2 it is clear that peaks only form when the two complex time-domain signals are in phase. When the two signals add partially in phase, only a smaller correction is required. When the signals add out of phase, often no correction is required at all. This observation is quite apparent to anyone having performed vector addition.

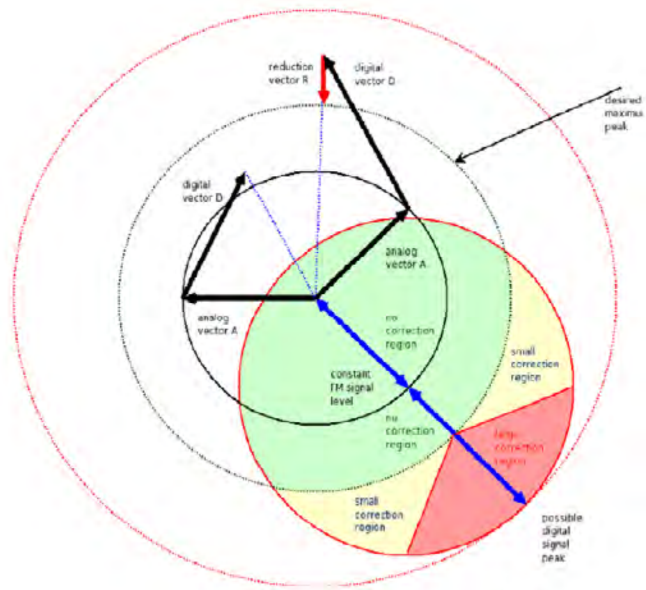

Fig. 2: FM and IBOC Vector Addition [5]

Less obvious is how PAR1 needs to be modified such that both signals are considered. PAR1 is an iterative process that first clips the IBOC signal, then demodulates the signal into the frequency domain in order to clean up excessive noise introduced into the constellation. Fig. 1 (pg. 21) shows how PAR1 (center) and in the same way HD PowerBoost is shaping the QPSK constellation. There exists a tradeoff between how much the constellation is corrected and how effectively peaks are reduced. Fig. 1 also shows the resulting HD PowerBoost constellations from the high efficiency mode that allows more noise in the constellation providing superior efficiency and power performance. The high quality mode provides an industry leading MER at a slightly better than PAR1 power and efficiency point at 23 dB MER.

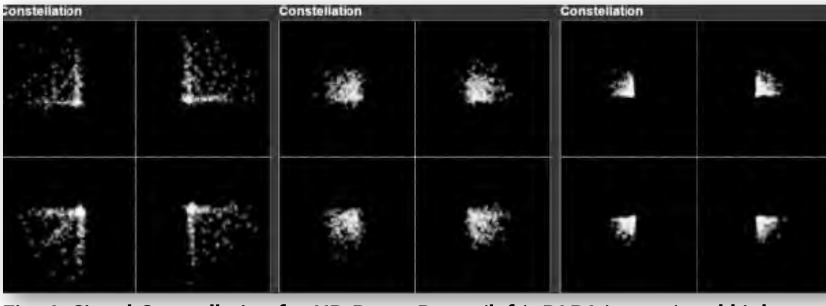

Fig. 1: Signal Constellation for HD PowerBoost (left), PAR1 (center) and high-quality HD PowerBoost (right)

The basic operation of all three peak-to-average power reduction methods is comprised of:

- Clipping the signal in the time domain
- Demodulating a symbol via an FFT to be able to view each carrier in the frequency domain.
- Correcting any constellation noise introduced in clipping
- Modulating a symbol via an IFFT
- Repeat

Since clipping and constellation correction are opposing processes, an iterative approach eventually converges on an optimal signal given the configured process parameters. The different peak-to-average power reduction methods mostly vary in how they use the above stated process. PAR1 only considers the IBOC signal, while HD PowerBoost considers both the FM and IBOC in the clipping process. It is these differences that lead to varying results. Table 2 presents the performance results in service mode MP3 for HD PowerBoost as contrasted to PAR1 and corresponds with the constellations shown in Fig. 1.

Compared to PAR1, HD PowerBoost provides up to 25 percent increase in transmitter output power along with an 11 percent improvement in efficiency while meeting the IBOC quality specification of 14 dB. A superior 23 dB MER at comparable PAR1 power levels is also achieved.

	High Efficiency Mode	PAR1 Mode	High Quality Mode
Quality (MER)	14.5 dB	17.8 dB	23.0 dB
Power increase	25-33%	-	4-6%
DC-RF efficiency	67.2%	56.0%	58.7%
PAPR	3.3 dB	4.4 dB	3.8 dB
Req. peak power (for 1 kW FM)	2.4 KW	3.1 kW	2.7 kW

Table 2: HD PowerBoost Performance (MP3 –10 dBc)

HYBRID PAR2 EVALUATION

PAR2 is iBiquity's peak-to-average power reduction alternative to HD PowerBoost. Just like HD PowerBoost, PAR2 recognizes that peak-to-average power reduction has to be performed while considering both the analog FM and digital IBOC signal components in a combined amplification system. In order to carry over features of PAR2 to IBOC-only systems, PAR2 provides a mode that does not require the presence of the analog FM system operating in a similar fashion to the original PAR1 algorithm.

PAR2 was initially introduced by iBiquity in software release 4.4.7 in 2012. However, it was clear early on that due to the increased computational complexity of the new algorithm, the existing third-generation C64 based Exgine was insufficient. It could only handle three iterations of the algorithm, where eight iterations were desired [6]. It is this fact that contributed to starting the development of a new hardware platform.

Since PAR2 is a major driver for hardware platform selection, the following sections evaluate the effectiveness of PAR2 in comparison to HD PowerBoost.

Service Mode MP3

Service mode MP3 is becoming the de-facto standard for specifying IBOC transmitter TPO as more stations are planning for multicast and advanced data services. MP3 combined with 100 percent 1 kHz modulated FM presents a worst-case scenario and is used to specify transmitter performance.

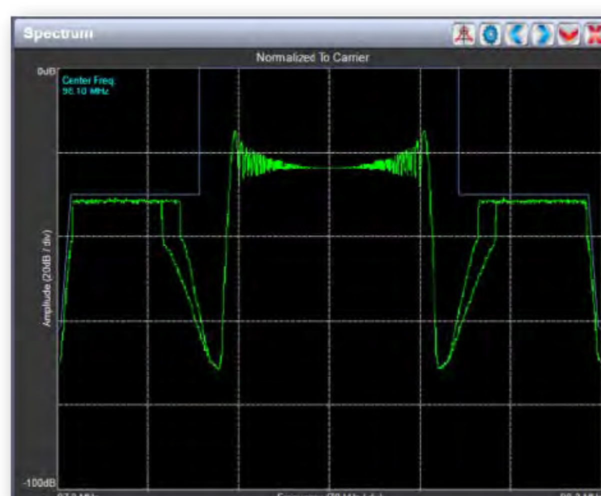

Fig. 4: MP3 carrier addition requires 0.8 dB more injection

In order to specify this operating point correctly, one must understand the MP3 signal specification. As shown in Fig. 4, MP3 adds two frequency partitions of 19 carriers each toward the FM signal on both sidebands; a total of 76 added carriers. It is important to note that the new carriers are added at the same power levels as all the other MP1 carriers, resulting in 20 percent more power on the IBOC signal. This changes the IBOC injection from –13 dBc per sideband to –12.2 dBc. The PAR2 algorithm must specifically be set to this –12.2 dBc injection ratio.

While a 0.8 dB increase in carriers may not seem like much, incorrectly configuring the injection ratio can lead a transmitter TPO specification to read 5–8 percent higher than what it should be. All tests below are conducted in MP3 mode with a –12.2 dB injection per sideband (–10 dBc MP1 level). It is important to note that MP3 mode must be correctly configured with –12.2 dBc per sideband or –9.2 dBc total injection to avoid TPO specification errors in the order of 5–8 percent.

Number of PAR2 Iterations

The chief parameter driving platform decisions is the number of PAR2 iterations the given hardware platform can support. In the original C64 Exgine design the DSP processor can support up to three iterations [6] of the hybrid PAR2 algorithm with the 2012 released code base. The Zynq platform released in 2014 is capable of supporting up to eight iterations [6]. The two platforms are contrasted in Fig. 3, where the CCDF shows the probability of exceeding a power level given a 1 kW FM carrier. Typically, CCDF plots are shown in dB. For clarity in the context of hybrid FM, absolute power levels are shown assuming a 1 kW FM carrier.

With three iterations, the transmitter must provide up to 3.5 kW peak power capability. Increasing iterations from three to eight effectively reduces maximum signal peaks by about 7 percent requiring 3.3 kW of peak power capability.

The more important figure of merit to look at is the 10^{-4} probability point, since infrequent peaks can be clipped in the amplifier with limited spectral impact depending on the amplifier. Note that one should use the absolute peak to determine absolute maximum voltage limits as the transmitter does not guarantee clipping peaks to any specific level. Assuming the transmitter can clip above 10^{-4}, one can estimate the transmitter power output (TPO) to increase by about 9 percent when moving from the Exgine. The C64 offers an insufficient implementation of PAR2 while the Zynq platform provides significant improvements. All PAR2 tests in this paper are performed with eight iterations, which is recommended for good PAR2 operation.

Configurable Mask Clearance

The PAR2 algorithm injects peak cancelling noise underneath the IBOC mask including underneath the FM carrier as shown in Fig. 5. It uses an internal mask definition to constrain the noise to within this mask boundary. The internal mask is composed of the standard NRSC-5-C mask [3] and a portion that extends under the FM carrier at –74.4 dBc. The clearance to the mask can be software adjusted between 3 and 24 dB below the mask.

PAR2 uses the extended carrier space for noise injection as it offers the highest noise level and thus

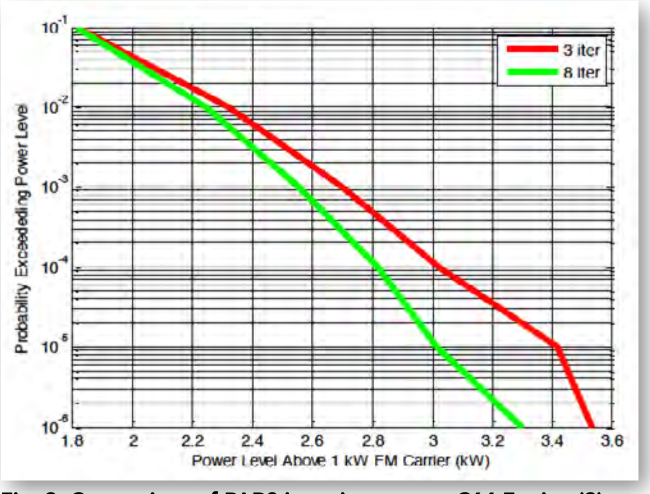

Fig. 3: Comparison of PAR2 iterations across C64 Exgine (3) and Zynq Platform (8)

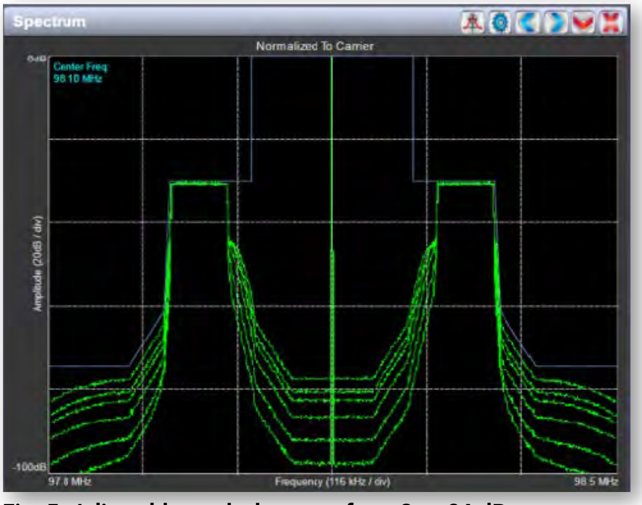

Fig. 5: Adjustable mask clearance form 3 to 24 dB

provides the biggest benefit. As the extended carrier partitions are used in higher service modes, such as MP3 and MP11, PAR2 loses this advantage.

Fig. 7 demonstrates that the PAR2 algorithm leans heavily on the noise injection for maximum peak control. Effectively turning the noise off at a 24 dB mask adjust yields signal peaks up to 25 percent greater than with a mask adjust of 3 dB. The 10^{-4} point is affected by 9 percent showing that PAR2 gets about half of its power benefit from this effect. It is clear that at least some degree of noise injection is intended to be used with PAR2.

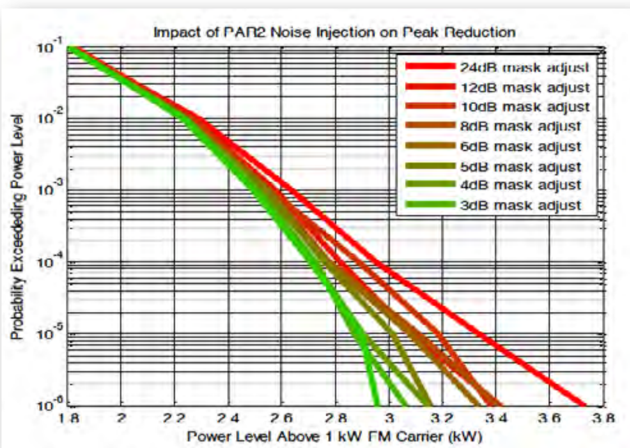

Fig. 7: CCDF of PAR2 with 1 kHz tone FM

The introduction of NRSC-5-C in 2011 also included relaxing the mask shoulders at ±200 kHz as a steep mask was shown to be very difficult to guarantee in real-world applications. Therefore, NRSC-5-C sloped this section out to ±207.5 kHz. PAR2 even uses this section of the mask for cancellation noise; it remains to be seen if this brings back this mask compliance issue.

The issue of greater concern is the noise beyond 200 kHz that has the potential to reduce the margin needed for IBOC spectral re-growth. Assuming the injected noise is placed at 3 dB below the mask, then any spectral re-growth at a comparable power level would result in a spectrum right on the mask. This is a situation where greater noise injection improves PAR2 operation, but in turn leaves less margin for spectral regrowth. So where does the optimal mask adjust value lie? To find out the answer, an experiment was set up where the maximum achievable TPO was measured while varying the mask clearance and keeping all other transmitter parameters, such as power amplifier supply voltage constant.

Table 3 shows the results from the experiment and indicates that an 8 dB mask adjust yields the highest TPO.

Mask adjust (dB)	5	6	8	12	24
FM power (kW)	10.0	11.3	12.1	12.0	11.5
RMS power (kW)	11.2	12.7	13.6	13.4	12.9

Table 3: Transmitter power performance versus mask adjust in MP3 mode at –10 dBc injection

A mask adjust of 5 or 6 dB shows a rather quick decline in TPO while greater mask adjust values show a gradual decline. This makes sense, as we would expect about a 5–6 percent decrease in TPO from the CCDF in Fig. 7.

Fig. 6 illustrates the balance of modulator injected noise and the added transmitter spectral re-growth at a mask adjust value of 8 dB. Since we are looking for 1–2 dB mask clearance, this only leaves the 6 dB above the noise level for spectral re-growth. To accomplish the results shown in this figure requires a highly linearized transmitter and may not be easily repeated on all IBOC capable transmitters. Some transmitters may require a greater mask clearance in order to provide the required margin for spectral regrowth.

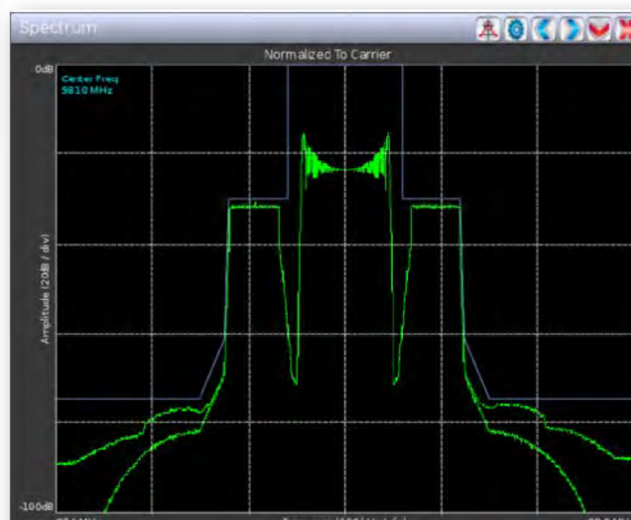

Fig. 6: Modulator versus Transmitter Spectrum at 12.1 kW FM (13.6 kW RMS) at 8 dB mask Clearance

PAR2 needs to inject noise underneath the spectral emissions mask in order to control peaks. An 8 dB mask clearance has been found to work best on real-world transmitters.

Impact of FM Modulation on Peaks

Using hybrid peak-to-average power reduction, such as PAR2 and also HD PowerBoost, the FM modulation now has an impact on the signal's CCDF power distribution. This certainly was never the case for FM signals (constant envelope) and is also not the case for PAR1, since the process is entirely de-correlated from the FM modulation. Unlike the mask clearance in Fig. 7 that shows an increase in maximum peak but similar performance in the lower range, Fig. 8 shows an entire shift of the signal envelope as modulation is increased. 1 kHz FM tone is a commonly used standard test signal intended to provide consistent results. Note that this specific effect is entirely modulator-dependent and has nothing to do with amplifier spectral regrowth. A 1 kHz modulated tone at 100 percent mod levels exhibits a 19 percent higher maximum peak compared to an unmodulated FM carrier. At the 10^{-4} level, the impact is reduced to 11 percent which represents a significant reduction of transmitter TPO specifications, typically taken with 1 kHz modulated FM. The delta between typical modulation including SCAs to 1 kHz is not as drastic but still represents an estimated 6 percent impact on TPO rating.

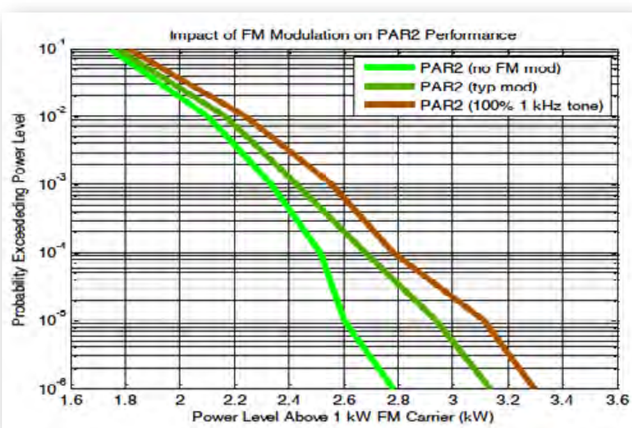

Fig. 8: Impact of FM modulation on PAR2 CCDF (MP3)

The most likely explanation for this effect is that many peaks in the hybrid waveform are harmonically related with unmodulated FM carrier; reducing one peak has a beneficial impact on the surrounding peaks. With increasing FM modulation, peaks are no longer as closely related making the algorithm work harder and hence less effective. FM modulation impacts PAR2 power performance by 6–11 percent with 1 kHz 100 percent tone modulation being the worst case. A transmitter should be able to meet spectral emissions for any type of FM modulation given it passes the worst-case tone modulation.

Constellation Slider

PAR2 can be configured by the manufacturer. One of the new additions is the ability to control the impact

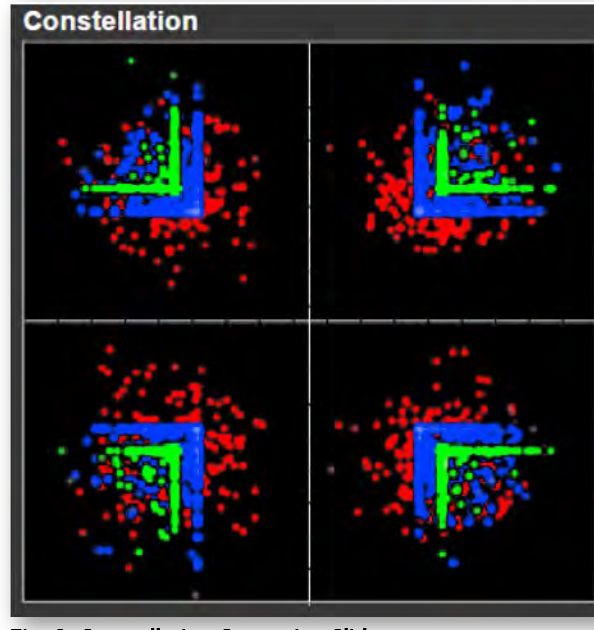

Fig. 9: Constellation Correction Slider

of PAR2 on the IBOC signal quality. Constellation noise can be pushed back a percentage of the way back to the original constellation point. Fig. 9 demonstrates a superposition of three constellation set points with low quality at 10 percent (red), typical quality at 75 percent (blue) and high quality at 91 percent (green). Across these set points power output is affected by 19–28 percent as shown in Fig. 10. Note that the low-quality set point produces an MER that violates IBOC quality specifications [7] and does not present a reasonable operating point.

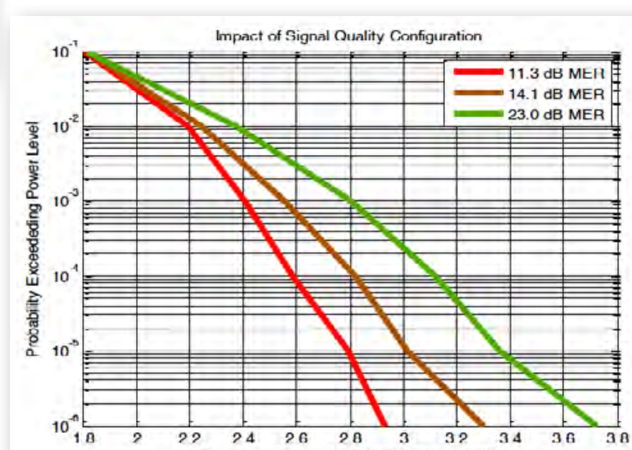

Fig. 10: Effect of IBOC constellation correction of power performance

Table 4 provides a numerical overview of these results. It is questionable if the PAR2 high-quality mode finds practical application due to the 28 percent increase in required transmitter overhead. The cost may be too high compared to simply turning up the IBOC power and injection ratio, if allowed.

	low quality	typical quality	high quality
MER	11.3 dB	14.1 dB	23.0 dB
Peak power (10^{-4})	2.6 kW	2.8 kW	3.1 kW
Peak power (10^{-6})	2.9 kW	3.3 kW	3.7 kW

Table 4: Impact of IBOC Quality MER on power capability

Please note that the IBOC Quality metric was defined such that a data carrier MER of 14 dB does not impact the IBOC coverage by more than 0.5 dB [7]. In other words, when comparing the performance of an ideal constellation to the performance of a 14 dB MER constellation, 0.5 dB additional power is required to achieve parity. We can typically increase the IBOC carrier power by more than 0.5 dB using crest factor reduction; HD PowerBoost allows for an increase of about 2–3 dB in IBOC injection. PAR2 high-quality mode requires 15 percent more power compared to HD PowerBoost high-quality mode and peaks are up to 37 percent higher.

Asymmetric Sidebands

Perhaps the most important feature of PAR2 is the ability to scale each IBOC sideband independently. This is accomplished via an equalization process that is built right into the operation of the PAR2 algorithm. This equalization process can be used not only to scale sidebands, but also allows for frequency equalizations of the IBOC signal for other effects after the power amplifier, such as channel combiners. Fig. 11 illustrates a typical asymmetric signal configuration with one sideband at –12.2 dBc and the other at –22.2 dBc in MP3 mode. Of course, the constellation levels follow this configuration.

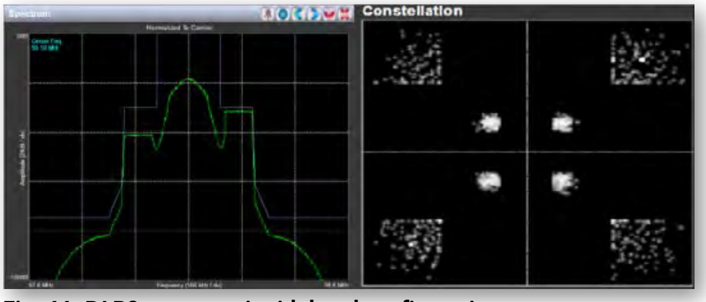

Fig. 11: PAR2 asymmetric sideband configuration

Impact of Service Mode

As already mentioned, MP3 is becoming the de-facto standard for transmitter TPO specification. Any transmitter capable of achieving a certain power level in MP3 mode should have no trouble achieving the same power level in MP1. While we focus on MP3 mode for this paper, we should have a brief look at what power de-rating one could expect by going from MP1 to MP3 mode. Fig. 12 shows the signal power envelope CCDF. Note that this representation is referenced to 1 kW FM power, which inherently takes into account the 2 percent increase in average power going to MP3 mode.

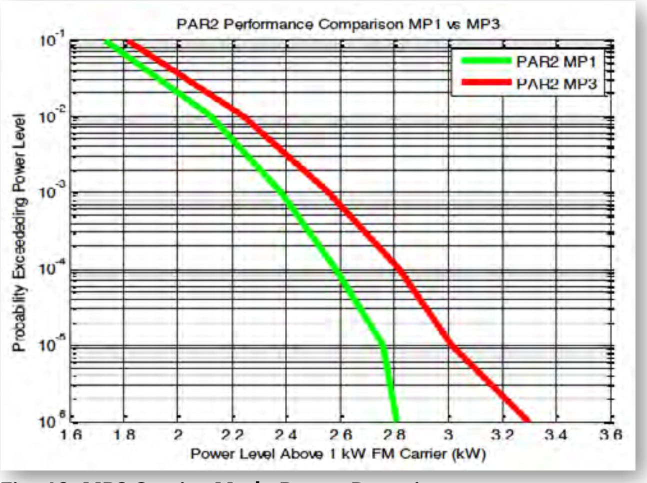

Fig. 12: MP3 Service Mode Power De-rating

PAR2 is at a handicap in terms of peak performance in MP3 mode, since the extended carrier portions of MP3 are no longer available for noise injection. In addition, PAR2 has to handle the increased power in the MP3 extended partitions. It is interesting to note that if the injection ratio is not correctly configured to –12.2 dBc, the CCDF for MP3 and MP1 are nearly identical. This suggests that it is not the added number of carriers, but rather the added digital power with respect to the analog FM carrier that causes the increased peaks. MP1 to MP3 service mode change in PAR2 requires at least 9 percent additional power with peaks increasing by 17 percent.

PAR2 Inner Carrier Protection

An interesting new feature of PAR2 is the added IBOC carrier protection from host interference. Since PAR2 handles both the FM and IBOC signals at the same time, it is possible for PAR2 to take into account the constellation error introduced by the FM.

This addresses the long-standing issue of destructive interference between 93 kHz SCA modulation and MP3 carriers that in some installations rendered the MP3 carriers non-receivable and could have audible effects on the SCA modulation. This feature will help to protect the IBOC, but will not help the performance of the SCA.

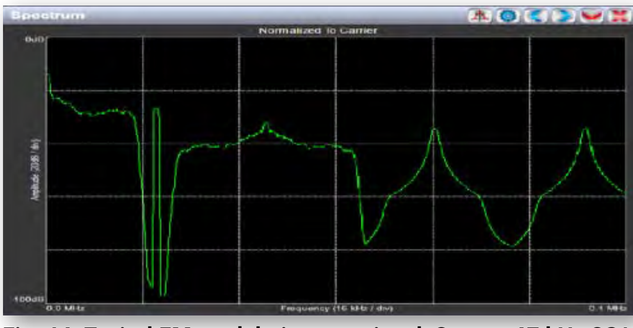

Fig. 14: Typical FM modulation test signal. Stereo, 67 kHz SCA and 93 kHz SCA.

When tested it was found that having two SCA carriers at 5 percent injection each caused measurable degradation in the IBOC signal at –20 dBc injection. Fig. 14 shows the MPX spectrum of the test signal used with densely processed FM audio and one SCA at 67 kHz and one SCA at 93 kHz each modulated with bandlimited random noise. Turning just one of these carriers off improved the IBOC signal quality significantly. Moving one of the SCAs to an HD side channel is a possible solution. Fig. 13 demonstrates the impact the FM modulation has on the IBOC signal quality when using PAR1 mode. At an IBOC injection of –20 dBc, the data MER drops to around 8 dB, well below 12–14 dB specified by the IBOC quality metric [7]. While the impact of the constellation is clearly visible, the MP3 carriers are still receivable, but are quite vulnerable. Considering that the HD channel placed on the MP3 partitions has no analog fallback, this configuration could lead to many audio dropouts. In order to demonstrate that PAR2 is working as expected the test signal in Fig. 14 was over modulated such as to produce 150 percent FM modulation with a –20 dBc injection ratio. At that point the PAR1 signal would lock on to HD-1, but could no longer acquire a channel on HD-4. Switching to PAR2 restored HD-4 under the same 150 percent over-modulated test conditions with very occasional drop-outs. Returning the test signal to 100–110 percent modulation produced solid HD-4 reception showing that the carrier protection does in fact work.

Fig. 13 also shows that by the time the IBOC carriers

Fig. 13: IBOC Quality impact of SCA modulation at -20 dBc and -14 dBc injection ratio (PAR1 mode shown)

are increased to –14 dBc, the IBOC signal quality has improved to be within specified limits. It is, therefore, concluded that while PAR2 does correct the inner carriers, the application for this technology is very narrow. Stations broadcasting multiple SCAs with –20 to –16 dBc injected IBOC could benefit from this feature. Alternatively, similar results could be obtained via proper audio processing that takes the entire MPX into account. This topic could benefit from additional bit error tests and an analysis on the impact of the IBOC on the SCA modulation.

PAR2 does effectively correct FM modulation peaks due to multiple SCAs and allows for robust extended MP3 carriers for injection ratios of –16 dBc to 20 dBc. Higher injection ratios do not require this feature due to the IBOC power increase.

PAR1 VERSUS PAR2 Reference Carriers

PAR2 handles reference carriers differently than PAR1. As shown in Fig. 16, PAR1 corrects constellation noise such as to fix the reference carrier's BPSK angle to 45 degree and 225 degree. However, significant amplitude variation is left in the carrier. This signal is well within the specified limits of the transmission specification [8] that states that reference carriers on average be better than 14 dB with no individual carrier being lower than 11 dB.

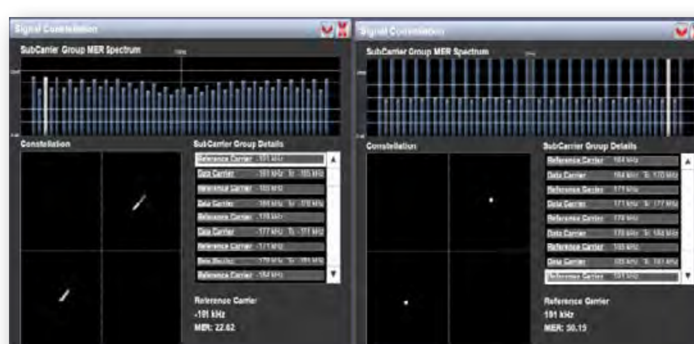

Fig. 16: Reference carriers in PAR1 (left) and PAR2 (right)

PAR2 corrects the reference carriers back to the ideal point with an MER of 50 dB or better even on a running transmitter as shown in Fig. 16. No added noise on a running transmitter demonstrates that it is not the transmission equipment introducing constellation noise.

PAR2 VERSUS HD POWERBOOST

In order to intelligently select the appropriate hardware platform for IBOC development one must first select the appropriate crest factor reduction method (PAR1, PAR2, or HD PowerBoost). Broadcast equipment manufacturers are often concerned with transmitter operation under 1 kHz FM tone modulation as it is the standard proof-of-performance test for transmitters. Broadcasters, on the other hand, are more interested in typical operating conditions. As we have seen earlier, the two cases lead to different results. Fig. 15 shows the CCDF power distribution of –10 dBc injected MP3 for PAR1, PAR2 and HD PowerBoost. PAR2 and HD PowerBoost are shown with typical modulation, as well as with a 1 kHz test tone.

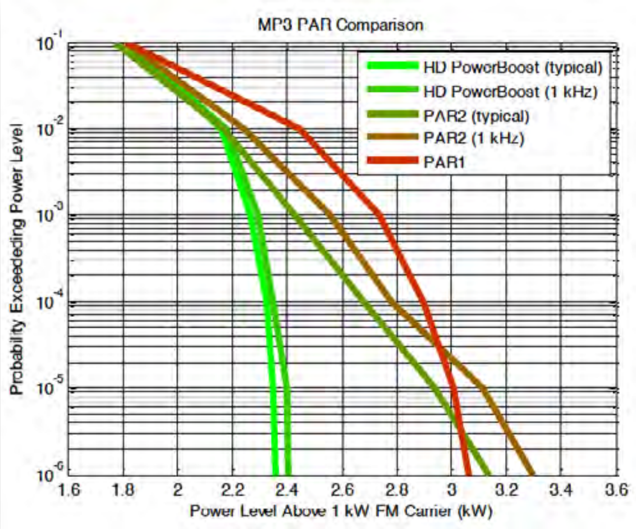

Fig. 15: CCDF for PAR1, PAR2 and HD PowerBoost

The key criteria to be looked at are:

- **Increased transmitter power** based on 1 kHz test tone modulation. Note that transmitter TPO specifications are subject to a number of de-rating factors not solely dependent on spectral compliance.
- **Maximum peak reduction** is of interest as the maximum peaks that a transmitter could pass dictate the absolute maximum voltage ratings of downstream broadcast equipment. This is also taken with 1 kHz tone modulation as it represents a worst case scenario. Likely an amplifier will attenuate these maximum peaks, but this is not a given.
- **Increased power** with typical modulation is only of academic interest as transmitters would typically be limited by their TPO rating established based on 1 kHz tone. It does, however, provide an indication as to how much headroom is available with typical modulation operating at the specified power level.
- **DC-RF efficiency** can be obtained by trading the amplifier headroom for increased efficiency. By finding an optimal balance between spectral regrowth and amplifier linearity leads to best possible efficiency. For this metric the PAR1 achievable power level is used in all cases rather than driving the transmitter to its limit. Note that AC-RF efficiency further applies transmitter specific power supply losses ignored here for comparative purposes.
- **Best achievable signal quality** at a reasonable power level is also shown. The PAR1 power level was used to measure the best possible data carrier MER.

As can be seen in Table 5, HD PowerBoost outperforms PAR2 in all of the categories listed. All tests were performed on the same 20 kW transmitter in order to provide a fair comparison and all results are stated as percent increase in order to avoid establishing proprietary transmitter specifications.

	PAR1	PAR2	HD Power Boost
Power increase (MP3 test tone)	0%	2%	25%
Power increase (MP3 typical mod)	0%	18%	33%
DC-RF efficiency (MP3 typical mod)	56.0%	61.9% (+5.9%)	67.2% (+11.2%)
PAPR 10^{-4}	4.1 dB	3.5 dB-4.0 dB	3.2 dB
PAPR 10^{-6}	4.4 dB	3.9 dB-4.7 dB	3.3 dB
Req. peak power (for 1 kW FM TPO)	3.1 kW	3.3 kW	2.4 kW
Data MER (max power)	17.8 dB	14.1 dB	14.5 dB
Data MER (PAR1 power level)	17.8 dB	14.3 dB	23.0 dB

Table 5: Comparison of PAR1, PAR2 and HD PowerBoost (MP3 -10 dBc injection)

A 2 percent power increase in PAR2 for tone modulation does not provide any significant gains while HD PowerBoost can claim 25 percent power increases and even 33 percent with typical modulation. PAR2 does, however, provide a respectable 18 percent power increase for typical modulation, but the transmitter could not pass 1 kHz modulated tone at that increased power level without failing the spectral emissions mask. PAR2 performance shows a strong dependence on the FM modulation, with 1 kHz test presenting a worst case. Furthermore, PAR2 no longer has the extended MP3 carriers available to inject peak cancelling noise, placing it at a handicap in MP3 mode. These factors contribute to intermittent, yet large power peaks in excess of established PAR1 levels. PAR2 cannot rely on the assumption that the amplifier can clip these peaks as these peaks can have significant impact on spectral re-growth.

Using PAR2 practically limits the available hardware platforms. Using the FPGA implementation of HD PowerBoost provides much greater platform flexibility since the Exgine can be configured in its simplest form by disabling the PAR algorithm. By not requiring PAR2, the C64, Zynq and x86 platforms are equally viable for the fourth-generation broadcast systems architecture. All current service modes and IBOC features other than PAR2 are available on all platforms.

CONCLUSION

HD PowerBoost provides 15–23 percent more transmitter power output and 5.3 percent better efficiency than PAR2. HD PowerBoost can provide a high quality IBOC mode of 23 dB MER at the same power level as PAR2 with 14 dB MER. PAR2 provides a modest improvement in transmitter output power with some gains in transmitter efficiency compared to PAR1. PAR2 provides only a limited benefit to the transmitter manufacturers as compared to PAR1 due to its high dependence on FM modulation.

Peak-to-average power reduction is only one part of optimizing transmitter performance; pre-correction and amplifier design are also important. The transmitter design must take into account all parts equally.

The fourth-generation broadcast systems architecture provides manufacturers greater flexibility in terms of the available hardware platforms and how to deploy the core IBOC system components on one or multiple systems. PAR2 is the driving reason to adopt the Zynq platform. Nautel offers a fourth-generation architecture path that does not require hardware platform changes while achieving superior peak power management with HD PowerBoost. ■

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